Chapter 2
Risks and Management of Textile Waste

Ipek Yalcin-Enis, Merve Kucukali-Ozturk, and Hande Sezgin

Contents

Abstract World textile production has been consistently increasing in recent years. Global population growth and rising living standards have caused an increase in textile demands as a natural consequence of basic needs and have also resulted in overconsumption as a consequence of fast fashion trends. A World Bank study has predicted a 70% global increase in municipal solid waste by 2025, which means that the expected waste volume will rise from today's 1.3 billion tonnes to 2.2 billion tonnes per year. Solid waste dumping is a crucial risk, especially for developing

I. Yalcin-Enis · M. Kucukali-Ozturk · H. Sezgin (✉)
Textile Technologies and Design Faculty, Department of Textile Engineering,
Istanbul Technical University, Istanbul, Turkey
e-mail: ipekyalcin@itu.edu.tr; kucukalim@itu.edu.tr; sezginh@itu.edu.tr

K M Gothandam et al. (eds.), *Nanoscience and Biotechnology for Environmental Applications*, Environmental Chemistry for a Sustainable World 22,
https://doi.org/10.1007/978-3-319-97922-9_2

countries. Insufficient collection and thoughtless disposal of solid waste causes land and air pollution and creates risks to human health and the environment. Thus, the management of textile waste has gained importance, and developing nations should spend a major part of their municipal revenues on waste management.

In this chapter we review the risks of textile waste and waste management strategies from various aspects. The general outline of this review includes three main topics: (i) the types of textile waste, (ii) the top five strategies for waste management, and (iii) utilization of textile waste in novel product designs. Textile waste can be divided into three groups: production waste, preconsumer waste, and postconsumer waste. Although 35% of the initial input is lost before the product reaches the consumer, the main risk pertains to postproduction waste when a 2-year lifetime for clothing is taken into consideration as a consequence of fast fashion trends. Moreover, the management of textile waste is a formidable problem. The overall guiding principles for waste management, from the most to the least environmentally favored, are reduction, reuse, recycling, energy recovery, and disposal of waste. Unfortunately, huge amounts of textile waste are landfilled just because of thoughtless types of acquisition. However, 45% of postconsumer textile waste can be worn as secondhand clothing, 30% of it can be cut up and used as industrial rags, 20% of it can be biodegraded after landfilling, and only the remaining 5% of it will be unusable. Since waste generation is not adequately controlled, utilization of this waste is gaining importance; thus, both designers and engineers are studying ways of making new products from this waste. These promising solutions are discussed in the latter part of this review.

2.1 Introduction

According to forecasts, the world's population will reach 8.2 billion in 2025, with a current annual growth rate of 1%. Nearly half of this population is now living in urban areas. In developing countries, the rate of urbanization is higher, with growing industrialization, which can result in increases in energy consumption and waste generation (Ouda et al. 2016). A World Bank study has predicted a 70% global increase in municipal solid waste by 2025, which means that the estimated waste volume will rise from today's 1.3 billion tonnes per year to 2.2 billion tonnes per year by 2025. Moreover, the amount of waste in developing countries is predicted to more than double (Girl 2015). Fossil fuels are still mostly used in energy supply although they pollute the environment and their use causes climate change. Therefore, renewable energy sources have become crucial in recent times (Ouda et al. 2016). Since solid waste is increasing day by day, solid waste management has become a worldwide environmental matter. In general, awareness of organization and planning in waste management has not yet reached a satisfactory level since the available information about current regulations is deficient and there are also financial limitations in many developing countries (Tıinmaz and Demir 2006).

The received wisdom is that textiles are a necessity in human beings' lives. However, with overconsumption of textile products, scarcity of raw materials and future environmental damage come into prominence (Torstensson 2011). The textile industry comprises many production steps such as fiber harvesting, cleaning, spinning, fabric formation, dyeing, and processing with different treatments. Every step brings about environmental hazards (Torstensson 2011). The textile industry creates large volumes of fibrous waste. Therefore, the utilization of this waste for development of fiber-reinforced composites is also gaining importance and people have become more focused on it in recent times (Umar et al. 2017). Unlike primary textiles, recycled textiles are mostly used in low-grade applications such as insulation and seat-filling materials in automobiles, building materials, and upholstery materials because of their low quality indexes (Lu and Hamouda 2014). Although textile production is moving away from the USA and Europe, the utilization of textile waste still maintains its importance in those parts of the world. Since they now have less industrial textile waste (production waste), the USA and Europe are mostly focused on utilization of postconsumer waste (Altun 2016).

The life cycle of textile materials is getting shorter day by day because of continuous changes in fashion markets, in association with low prices (Lu and Hamouda 2014). The fashion industry has a huge influence on the global and human resources needed for both production and consumption of products. Moreover, the increasing interest in fast fashion trends has caused reductions in the production times, prices, and life-spans of fashion items. Thus, an overconsumption problem arises (Lawless and Medvedev 2016). Waste recycling is a very important issue to save natural resources and help minimize climate change (Umar et al. 2017). Since textiles are almost 100% recyclable, everything in the textile and apparel industries should be utilized (Hawley 2006). With increasing environmental awareness, the need to optimize solid waste management is becoming significant. Therefore, the textile and apparel industries are making efforts to decrease postconsumer textile waste disposal (Domina and Koch 1997).

2.2 Textile Waste

Things that people do not need anymore and want to get rid of can be defined as waste (Nielsen and Schmidt 2014). Different types of waste can be classified as solids, liquids, or gases, according to their physical state. Different types of solid waste can be classified according to their original use (packaging waste, textile waste, food waste, etc.), materials (glass, paper, etc.), physical properties (combustible, compostable, recyclable, etc.), origin (domestic, commercial, agricultural, industrial, etc.), and safety level (hazardous or nonhazardous). Household waste and commercial waste together can be classified as municipal solid waste (McDougall et al. 2008). The world's annual waste generation amounts to 7–10 billion tonnes in total, approximately 2 billion tonnes of which is municipal solid waste (International

Solid Waste Association 2015). Hence, it is a fact that unnecessary consumption is a part of everyday life, resulting in huge volumes of solid waste (Costa et al. 2017).

Although textiles are fundamentally used to protect the body from cold, heat, and light, and to preserve modesty, they have become a reflection of personality, wealth, or interest in fashion. Nowadays, because of technological improvements, textiles are used in a wide range of applications rather than only for fabrication of garments (Gulich 2006). From the sourcing of raw materials to textile production, garment manufacturing, and distribution to retail stores, the textile industries generate huge amounts of waste, which occupy a large place in the municipal solid waste category (Karaosman et al. 2017).

Global population growth and increasing demand for new products have led to irrepressible textile production and consumption (Zamani 2014; Barot and Sinha 2015). One of the most important reasons for textile waste generation is the idea, created by the fashion industry, that people need new products each season (Zamani 2014). Large amounts of production and postconsumer fiber waste have been amassed with the growth of the world's population and rising living standards (Lu and Hamouda 2014). It is predicted that global fiber consumption will reach 110 million tonnes in the year 2020 (Voncina 2016).

The idea of recycling textile materials arose during the Industrial Revolution in the UK in the 1700s and 1800s (Gardetti and Torres 2013). The importance of reusing or recycling textile waste becomes more prominent when it is considered that for the production of one T-shirt and one pair of cotton jeans, 2720 liters and 10,850 liters of water, respectively, are needed (Ringler and Zhu 2015). However, it has been seen that recycling of textile products falls behind recycling of other materials. While 15–20% of textile materials are recycled, 80% of steel, 65% of paper, and 30% of plastics are recycled (Voncina 2016). Textile waste can mainly be categorized into three groups: production waste, preconsumer waste, and postconsumer waste (Fig. 2.1).

2.2.1 Production Waste

Production waste is composed of fibers, yarns, fabric scraps, and apparel cuttings generated by fiber producers, textile mills, and fabric and apparel manufacturers (Domina and Koch 1997). The types of waste can vary depending on the manufacturing steps used where the waste is generated (Wang 2010). Especially in the manufacturing sector, fabric cutoffs and fabric roll ends constitute a large amount of waste (Gardetti and Torres 2013). Additionally, fabric defects that occur during manufacturing generate production waste, which results in tremendous costs to organizations. It is a fact that the total cost of defects is often a significant percentage of the total manufacturing cost in most organizations. Moreover, reworking, replacement production, and inspection incur wasteful handling time and effort (Silva 2012). The carpet sector also generates a lot of waste (mostly composed of a single fiber type) but has devoted significant effort to carpet waste collection and

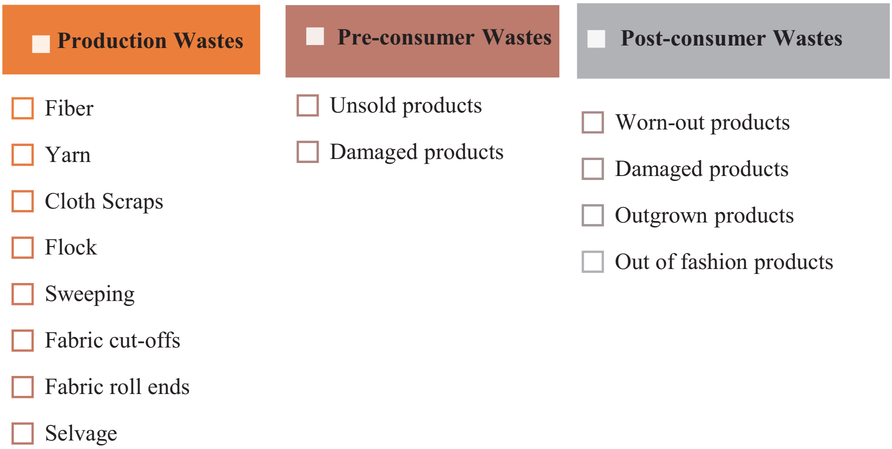

Fig. 2.1 Different types of waste. Solid textile waste can be divided into three categories: production waste, preconsumer waste, and postconsumer waste. Production waste comprises waste from several textile manufacturing steps, preconsumer waste can be unsold/damaged products in stores, and postconsumer waste consists of products that the owners no longer want to use

recycling (Wang 2010). There are three ways to dispose of production waste: (i) it can enter the solid waste stream and end up in landfills or waste incinerators; (ii) it can be converted into energy to power the manufacturing process; or (iii) it can be sold to a textile waste recycler, who may process it into fibers that can be made into new recycled fabrics, apparel, or nonapparel items (Domina and Koch 1997).

2.2.2 Preconsumer Waste

Preconsumer waste consists of products that are manufactured with design mistakes, fabric faults, or the wrong colors being produced for sale and consumption (Ekström 2014). In other words, preconsumer waste consists of unsold and damaged products in the retail sector (Gardetti and Torres 2013). Preconsumer waste is not completely valueless for the retailer because it can be sold to an outlet, jobber, or consolidator. Preconsumer waste can be mainly disposed of in four ways: (i) it can be sent directly to the companies' own outlets; (ii) it can be sold to other outlets, jobbers, or consolidators, who in turn resell the merchandise to other outlet stores; (iii) it can be sent directly to nonprofit organizations if retailers neither have their own clearance centers nor sell this waste to jobbers; or (iv) it can be sent directly to landfill by retailers. However, this last option is the least used one, since most preconsumer waste still has some resale value (Domina and Koch 1997). Companies have different suggested solutions for these products. For instance, H&M sells these products in its own outlets, while Marks & Spencer directs these products to charities (Gardetti and Torres 2013). Approximately 65% of the initial input is delivered to consumers as new clothing, while 35% of the initial input becomes waste during the production and preconsumer stages (Karaosman et al. 2017).

2.2.3 *Postconsumer Waste*

Postconsumer waste consists of any types of garments or household articles made from fabricated textiles that the owner no longer needs and decides to discard. Consumers may discard these articles when they are worn out, damaged, outgrown, or out of fashion. The volume of postconsumer waste is very large and is comparable with the rate of fiber consumption (Wang 2010). Although a part of this postconsumer waste is given to charities or passed on to friends and family members, most of it is deposited into the trash and ends up in municipal landfills (Hawley 2006). The amount of postconsumer waste is very large in comparison with other waste types (Wang 2010). It has been estimated that the volumes of postconsumer textile waste that go to landfills are 10.5 million tonnes per year in the USA, 350,000 tonnes per year in the UK, and 287,000 tonnes per year in Turkey (Karaosman et al. 2017). Since an item of clothing has approximately a 2-year lifetime, postconsumer waste should be collected for acquisition purposes (Karaosman et al. 2017).

2.2.3.1 Fast Fashion Trends

The apparel industry is currently dominated by fast fashion, resulting in overconsumption, where consumers buy more than they need (Pookulangara and Shephard 2013). Therefore, beyond consumer need, the desire for fashionable goods contributes to consumption in greater volumes (Hawley 2006).

Fast fashion can be defined as providing the newest fashionable products that respond quickly to consumers' demands. In contrast to the standard 6-month time to market in the apparel industry, fast fashion involves only a few weeks of time in the product development process from the design to the finished product. Of the pioneer fast fashion retailers, Topshop has reduced its time to market to 6–9 weeks while H&M's time to market is only 3 weeks. Besides a reduced time to market, the fast fashion industry offers a large number of different styles of clothing. For instance, Zara produces 12,000 styles selected from 40,000 styles created by 200 in-house designers annually. Since the fast fashion industry offers products at low prices, the volumes of postconsumer textile waste that consumers throw away after wearing them several times are increasing day by day (Lee 2017). Moreover, consumers are more likely to throw away inexpensive clothes than expensive ones, as the latter would give them feelings of guilt (Strähle and Hauk 2017).

In compliance with the fact that fashion relies on new materials to replace old ones, there is a strong relationship between the fashion system and waste (Binotto and Payne 2017). In other words, it can be said that the end of fashion is the beginning of waste (Torstensson 2011). When a textile product is thrown away as post-consumer waste in a landfill, all of the materials and energy used during its manufacturing—as well as the carbon emissions from transport of the product along the supply chain and the labor input throughout these stages—are wasted (Binotto and Payne 2017; Strähle and Matthaei 2017).

2.2.3.2 Slow Fashion Trends

In recent years, the existence of fast fashion has encouraged the growth of the slow fashion movement. Rather than focusing on time, the slow fashion movement is based on a philosophy of awareness of designers', buyers', retailers', and consumers' respective needs and the impacts of fashion on workers, consumers, and ecosystems (Pookulangara and Shephard 2013). In contrast to fast fashion, slow fashion focuses on reducing the number of trends and seasons, and this maximizes the production quality to improve the value of garments (Ozdamar Ertekin and Atik 2015). To sustain the slow fashion movement, three approaches have been defined: (i) emphasis on local design and production, which encourages local producers and creates cultural diversity; (ii) creation of a transparent production system by elimination of generic designer or brand names and improved relations between producers and consumers; and (iii) improvement in the understanding of textile articles from raw materials to end products, by raised awareness of the hidden realities of material sourcing, production stages, working conditions, distances traveled for distribution, and so on (Clark 2008). H&M's sustainability report emphasizes transparency by stating that H&M was the first fashion retailer to make its supplier list public (in 2013) and continues to collect more in-depth product information to share with customers and other stakeholders (H&M Group 2016).

2.3 Textile Waste Management

The management of municipal solid waste has reached a critical phase, owing to the lack of suitable facilities to treat and dispose of huge amounts of the waste generated in metropolitan cities (Sharholy et al. 2008). Most countries are trying to decrease the amount of disposal in landfills and increase the amount of recycling. For instance, the European Union (EU) has tasked member countries with reusing or recycling 50% of their municipal waste by 2020 (Fortuna and Diyamandoglu 2017). In the waste hierarchy (see Fig. 2.2), prevention constitutes the first stage; reuse, recycling, production of energy from waste, and landfilling come after it.

The purpose of the circular economy is to extend the life of materials and promote recycling to maximize material service per resource input while reducing environmental impacts and resource usage (Tisserant et al. 2017). Furthermore, the

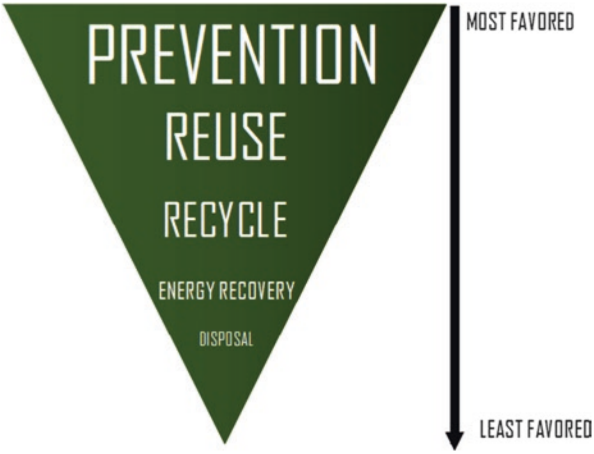

Fig. 2.2 The textile waste management hierarchy ranks the various management strategies from the most to the least environmentally preferred. The hierarchy emphasizes prevention, reuse, and recycling as key to sustainable materials management. At the top of the five stages of the hierarchy is waste prevention, which is the best option

circular economy promotes collection of products and their recovery in the same product chain (Fortuna and Diyamandoglu 2017). The 3R (reduce, reuse, and recycle) approach to waste management has been established internationally as one of the fundamental concepts of the circular economy for a sustainable society (Yano and Sakai 2016; Tisserant et al. 2017). Among leading fashion retailers, H&M, Levi Strauss & Co., and Marks & Spencer are brands that pay attention to the circular economy (H&M Group 2016; Levi Strauss & Co. 2015; Marks & Spencer 2016).

2.3.1 Disposal (Landfilling)

Disposal of solid waste is the least favored waste management method, in which the last destination of waste is a landfill site. Countries try to manage waste with other options. However, there is still a huge amount of waste that ends its life in a landfill even though it could be recycled (Bhuiya 2017). In the USA, only 15% of postconsumer textile waste was recycled or donated in 2009, while the rest of it (85%) was landfilled. Thus, of the USA's total textile production weight of 25.46 billion pounds in 2009, 21 billion pounds was subsequently landfilled. Since the USA's projected textile production weight in 2019 is 35.4 billion pounds, efficient use of landfill capacity has become an important issue (Lee 2017). On the other hand, if appropriate acquisition techniques are used, 45% of postconsumer textile waste can be worn as secondhand clothing, 30% of it can be cut up and used as industrial rags, 20% of it can be biodegraded after landfilling, and only the remaining 5% of it will be unusable (Lee 2017). In landfills, synthetic textile waste does not decompose, while woolen garments do decompose but produce methane and carbon dioxide gases, contributing to global warming (Strähle and Hauk 2017). With the disposal of waste in landfills, it must be noted that methane emissions are more harmful than carbon dioxide emissions (Sotayo et al. 2015).

2.3.2 Energy Recovery (Energy from Waste)

Energy from waste, or waste to energy, is a process of generating energy in the form of heat and/or electricity from the treatment of waste. This process mostly produces energy by burning or from inflammable fuel elements such as methane, methanol, ethanol, or synthetic fuels (Klass 2000).

Energy can be recovered from waste by different techniques—mainly incineration, gasification, and anaerobic digestion (Murphy and McKeogh 2004).

Incineration is the combustion of waste to recover energy, in which the residual waste is burned at a high temperature and energy is recovered as electricity or heat. In some countries, textile waste is incinerated. The heat and power that are recovered from this process can be used instead of other sources of energy (Zamani 2014). Incineration decreases the amount of the waste by about 90%, depending on the degree of recovery and the composition of the materials. Incineration cannot end the need for landfilling, but it can reduce the amount of waste that is landfilled. Throughout the incineration process, flue gases (CO_2, H_2O, O_2, N_2) are generated, which are the main sources of fuel energy (Bosmans et al. 2013). In the past, incineration of waste posed a risk to the environment by creating toxic compounds during the process (Tammemagi 1999). Nowadays, however, this environmental risk can be eliminated if the incineration method is combined with energy recovery, control of the emissions, and use of a suitable method for disposal of the final waste (Bosmans et al. 2013).

Gasification is partial oxidation of organic substances at high temperatures (500–1800 °C) to produce a synthetic gas (Bosmans et al. 2013). The main advantage of gasification compared with incineration is higher electrical generation efficiency. This can be provided by use of combined cycle gas turbines in this method. On the other hand, these turbines decrease the temperature of the residual heat and thus reduce the thermal energy production. Gasification is preferably used for electricity production (Morris and Waldheim 1998).

Anaerobic digestion converts organic waste into a methane-rich biogas with use of microorganisms. The obtained biogas is burned to generate electricity and heat, or it is turned into biomethane (Nishio and Nakashimada 2007). The aim of anaerobic digestion is to convert organic waste into biogas—a renewable fuel further used for the production of green electricity or heat, or as a vehicle fuel. The digested substrate in anaerobic digestion can be used as a fertilizer in agriculture (Holm-Nielsen et al. 2009). Anaerobic digestion of animal fertilizer provides some environmental and agricultural advantages such as increased fertilizer quality of the manure, a considerable reduction in odors, inactivation of pathogens, and biogas production (Holm-Nielsen et al. 2009).

The cellulosic part of a waste textile such as cotton or viscose constitutes about 40% of the total waste textile. Waste cellulosic textiles can be used in biomass production, while waste cotton textiles are preferred for both biogas and methane production. Ethanol is also one of the products that can be produced from cotton-based waste textiles by use of enzymatic hydrolysis, followed by fermentation (Jeihanipour et al. 2010).

2.3.3 Recycling

The term “textile recycling” has come to the fore since the mid-1940s, when US charities and the textile industry started repurposing clothes, shoes, and accessories (Nodoushani et al. 2016). In daily life, all types of utilization of textiles are mostly included in the category of recycling. However, according to the quality of the final product, this category can be also subcategorized into “downcycling” and “upcycling.” In the recycling process, the quality of the recycled final product is equal to that of the base or original product. Downcycling is a recovery process in which a waste material is reprocessed into raw material with a lower value than the original material. Downcycling can avoid dissipation of useful materials, decrease the usage of new raw materials and air, and decrease water pollution. Upcycling is a recovery process in which a waste material is reprocessed into a raw material with a higher value than the original material (Vats 2015). In other words, upcycling can be defined as transforming waste material into a new product of the same quality as—or of better quality than—the old one. The idea of upcycling products was introduced by William McDonough and Michael Braungart. They put forward the idea that there should be a process, unlike recycling, in which the final product has a value at least equal to that of the original product (Gardetti and Torres 2013). Turning an old curtain into a new garment or an old pair of jeans into a new bag can be examples of upcycling (Ekström 2014).

In the process of recycling postconsumer textile waste, recyclers are confronted with many toilsome operations such as sorting, separation, and processing (Strähle and Philipsen 2017). Ninety-seven percent of textile waste can be recycled (Briga-Sá et al. 2013). However, the recovery rate for textiles is only 15% (Wang 2006). Textile recycling can be classified into mechanical recycling, chemical recycling, thermal recycling, and a mix of these technologies. Mechanical recycling is the most preferred technique and can be used for recycling of a wide range of textile waste composition (Zonatti et al. 2016). Mechanical recycling is based on a technique that reduces textile materials to smaller pieces (Oliveux et al. 2015). Traditional mechanical recycling turns waste garments into yarns and fibers (by pulling the fabric apart), and then they are either processed into recycled yarn for textile applications or processed for other applications such as nonwoven products, carpet underlay, sound insulators, thermal insulators, phase change materials, geotextile materials, filtration material, and many others (Haule et al. 2016). In the most commonly used mechanical method, the fabric is shredded into small pieces (Zamani 2014). Textile waste items in the form of fabric should be separated by their composition and color prior to shredding in order to prepare the recycled fibers for use in yarns or nonwoven applications (Zonatti et al. 2016). These recycled fibers are mostly used as filling materials for mattresses or upholstery, and as insulation material. In another mechanical recycling method, after the textile waste is shredded into small pieces, it is turned into low-quality fiber for use in insulation materials, napkins, carpet underlays, and disposable diapers. Another mechanical method transforms high-quality textile products into different types of products, and this process is a type of upcycling.

Although the mechanical method can be applied to all kinds of fibers, the chemical recycling method is applied to synthetic fibers and their blends. In the chemical process, fibers are separated chemically, degraded, and then repolymerized into new fibers (Zamani 2014). One of the world's most popular sports brands, Nike, carries out 100% recycling of postconsumer and defective athletic shoes. The three main materials in the shoes—consisting of the upper fabric, midsole foam, and outsole rubber—are separated by a chemical process and ground up to be used in new products in the field of sports surfaces, such as grind rubber, grind foam, and grind fluff (Strähle and Philipsen 2017).

Other fiber recycling approaches are melt processing, polymer depolymerization, and waste-to-energy conversion (Wang 2010). Large numbers of products are generated from reprocessed fibers that are respun into new yarns or fabricated into woven, knitted, or nonwoven fabrics such as upholstery materials, composites, garment linings, household items, furniture upholstery, insulation materials, automobile sound absorption materials, automobile carpeting, and toys (Bhatia et al. 2014). For instance, polyester fiber-to-fiber recycling can enhance the sustainability of the textile industry, since polyester fibers are of the first rank in world fiber production (Lu and Hamouda 2014).

Thermal processes include different types of pyrolysis, and fibers can be recovered by these techniques. However, it is not only valuable fiber products that are recovered; gases such as carbon dioxide, hydrogen, and methane are produced by volatilization of the resin, and the resin can become carbonized on the fibers. These processes occur at temperatures between 450 °C and 700 °C, depending on the type of resin. For example, polyester resins need lower temperatures, whereas higher temperatures are required for epoxides or thermoplastics (Oliveux et al. 2015).

Pyrolysis is a process in which textile fibers are heated and the molecules of the polymers begin to divide into smaller molecules. Fuels are also pyrolysis products. The types and amounts of the produced fuels vary depending on the textile type because of the variety of textiles and the polymers that are used. Moreover, the amounts of smoke and fumes that are produced and how strongly the textile burns play important roles in the fabric treatment. Pyrolysis results in a 74 wt.% (weight percent) loss of the total textile weight, of which 31.5 wt.% is a light liquid fraction, 42.5 wt.% is a heavy liquid fraction, 12.5 wt.% is solid residue, and 13.5 wt.% is noncondensable gases (Miranda et al. 2007). With use of thermal recycling by way of pyrolysis and activation, textile waste is reprocessed for the production of a higher-value activated carbon product. Acrylic textile fabric waste is one of the polymers that is widely used in the textile field for this process (Nahil and Williams 2010).

2.3.4 Reuse

Directive 2008/98/EC of the European Parliament and of the Council (2008) describes reuse as follows: "Reuse means any operation by which products or components that are not waste are used again for the same purpose for which they were conceived." Product reuse and environmentalism are interrelated. The reuse of products plays an important role in waste management by conserving resources, reducing negative environmental influences, and diminishing the burden on waste management systems (Fortuna and Diyamandoglu 2017). Even when the prestages of collection, sorting, and reselling of secondhand garments for reuse are taken into account, reuse of textile products (instead of production of the same products from unused material) can reduce energy consumption by 90–95% (Zamani 2014). Moreover, by reuse of 1 kg of a textile product instead of production of a new one, 6000 L of water, 3.6 kg of carbon dioxide, 0.3 kg of chemical fertilizer, and 0.2 kg of insecticides can be saved (Vats and Rissanen 2016). Therefore, reuse of a product promotes sustainable consumption in contrast to the idea of the throwaway society (Fortuna and Diyamandoglu 2017).

By lengthening product life, reuse delays the time when the product enters the municipal solid waste stream, prolongs the life of waste management facilities, and helps to avoid the cost of recycling. Therefore, consumers need to be encouraged to broaden their environmental awareness by reusing products (Domina and Koch 1999). H&M has started a global garment collection program in cooperation with I:CO. If the collected garments are of wearable quality, they are sold as secondhand clothes, otherwise they are processed for reuse as cleaning cloths (Strähle and Philipsen 2017).

2.3.4.1 Secondhand Clothing

Secondhand items are products taken into a new stage of usage without a change in the product design or perhaps only with some (optional) refurbishment. The useful life of a product and the product life cycle have different meanings. The useful life of a product is defined as the period between acquisition of a new product and the time when its performance is no longer considered satisfactory. The definition of the product life cycle, from the consumer's point of view, is the period of use between the purchase and the discarding or replacement of the product. In general, the life cycle of a product is shorter than its useful life because consumers regularly replace used items with new products. Because these textiles have completed their life cycle but can still serve a purpose, a market for secondhand products is created (Strähle and Matthaei 2017). In the 1960s and 1970s, the secondhand market was controlled by charity shops, but in the 1980s, profit-oriented secondhand shops appeared (Voncina 2016). There are many factors (such as inexpensiveness, uniqueness, and environmental issues) that direct people to use secondhand clothes instead of new ones. As is known to all, “green” products, which support environmental sustainability, are mostly highly priced products and many people cannot afford to buy them. However, by purchasing secondhand clothes, people can reduce the number of new products, and this can be more beneficial to the environment (Xu et al. 2014).

2.3.4.2 The Vintage Clothing Trend

Although vintage clothing is mostly confused with secondhand clothing, there are differences in their definitions. Vintage clothing can be identified by the age of the clothing (generally manufactured between the 1920s and 1980s). Textiles produced before 1920 are defined as antique, whereas clothes made since the 1980s are classified as modern pieces (Strähle and Matthaei 2017). In one study, Cervellon et al. (2012) studied the motivations of female consumers to buy secondhand or vintage fashion clothes. Their results indicated that strong differences in customer profiles and motives exist. The findings of the study showed that buying vintage items creates nostalgia, while consumers feel unique by using these items. Moreover, a higher level of education results in willingness to purchase more vintage pieces. On the other hand, Williams and Paddock (2003) have claimed that economic motives are the main factors in shopping for secondhand clothes.

2.3.5 Prevention (Reduction)

Waste prevention can be defined as acquisition of awareness about the adverse effects of generated waste on the environment and on people, and the importance of waste reduction and reuse of products (Nielsen and Schmidt 2014). Directive 2008/98/EC of the European Parliament and of the Council (2008) describes prevention (reduction) as follows: “Prevention means measures taken before a substance, material or product has become waste, that reduces: (a) the quantity of waste, including through the reuse of products or the extension of the life span of products; (b) the adverse impacts of the generated waste on the environment and human health; or (c) the content of harmful substances in materials and products.”

2.4 Utilization of Textile Waste

Rather than being an option, sustainability is a necessity today (Dissanayake et al. 2017). Since the market has to keep on going, reducing production is not a realistic solution to control waste, but reinvention of methodologies to reduce waste and conserve natural resources can be. Therefore, designers and engineers are taking on the responsibility for making new products from industrial waste (Costa et al. 2017). In the following sections, some academic research and novel designers' works are described to point out new perspectives and solutions for textile waste.

2.4.1 Engineering Solutions

When the literature is examined, it is seen that textile waste is mostly used in the production of insulation materials for building structures. In one study, Patnaik et al. (2015) designed and produced nonwoven sound and thermal insulation mats from waste wool, recycled polyester (RPET) fibers, and a mixture of them. Waste wool fiber is a commonly preferred raw material source for thermal and sound insulation applications because its use and disposal stages consume less energy than those of other natural materials. The results of this study showed that mats made from mixed RPET and wool waste provided the best insulation and acoustic properties among all samples tested. Binici and Aksogan (2015) used cotton waste and fly ash together with cement and water in building material production and tested the insulation properties. The results indicated that the thermal conductivity coefficients of the composite structures were about 29% lower than those of conventional concrete structures. Building weight is an important factor in earthquakes, and earthquake damage can be reduced with a lower specific weight of concrete. In this study, it was observed that while conventional concrete blocks had a specific weight of 1200 kg/m^3, composite blocks had a basic weight of about 800 kg/m^3. Briga-Sá et al. (2013) designed thermal insulation materials for roof construction and internal walls by using polyester apparel cutting waste of different sizes and compared their thermal conductivity with that of conventional insulation materials. The fabric waste was consolidated by sewing. The results showed that the thermal conductivity of the samples was between 0.052 and 0.060 W/mK. The authors noted that materials with a thermal conductivity coefficient less than 0.1 W/mK can be regarded as thermal insulators. Jordeva et al. (2015) manufactured sound insulation materials for roof construction and internal walls from polyester apparel cutting waste. They reported that the resulting insulation material had similar sound absorption properties (54.7–74.7% at a frequency range of 250–2000 Hz) to those of commercially used materials.

Carpet waste is also a big problem for the environment because it degrades very slowly in landfills. Fibers recovered from carpet waste are reprocessed into textile products such as nonwoven products. Recycled fibers from used carpets can be used as concrete reinforcing material to improve the shrinkage and toughness properties of the material (Wang 2010). In one study, Pakravan and Memarian (2016) used needle felt carpet waste in lightweight polymer concrete as aggregate to study the effect of the carpet waste on the physical and mechanical properties of the concrete. They shredded the carpet waste into small pieces and added it to the concrete material. Their results indicated that addition of 2.5% carpet waste to the polymer concrete decreased the density of the concrete by 23%. It was also seen that the strain capacity and toughness of the concrete were increased by addition of carpet waste. Moreover, the energy absorption capacity of the concrete was increased by 53–129%, depending on the waste content. However, it was observed that the flexural and compressive strength of the polymer concrete decreased as the amount of added carpet waste increased. Mohammadhosseini and Yatim (2017) used carpet fiber waste and palm oil fuel ash to enhance the physical, mechanical, and microstructural properties of concrete. The results showed that although the compressive strength of concrete samples was not improved by the addition of fiber waste, higher tensile, impact, and flexural strengths were achieved with its addition.

Textile fiber waste has also been used as reinforcement in composites or laminates to achieve desired mechanical properties in different application areas. It has the ability to improve the strength and rigidity of composites. Ramamoorthy et al. (2014) reused discarded cotton–polyester blend bed linen fabrics as reinforcement material in composite production with different processing parameters (compression temperature, time, and pressure). They used three different matrices: polyester from the fabric itself, soybean oil–based thermoset resin, and thermoplastic bicomponent fiber. The results showed that the best mechanical properties were achieved with the soybean oil–based composites reinforced with recycled cotton–polyester. Yalcin et al. (2013) used needle-punched polyester nonwoven selvage waste (cut pieces, fibers, and in particle form) as a reinforcement material for the production of composite structures. They preferred low-density polyethylene and polypropylene as matrix materials. They also reprocessed the particle form–reinforced composites to see the effects of reprocessing on the mechanical and thermal properties of the composite structures. The results suggested that the particle form–reinforced composites had better mechanical properties, while the composites made with the cut pieces and fiber had better thermal properties and lower densities. The authors stated that these composite structures could be used in applications where high-density chipboard or compacted panels are used. Umar et al. (2017) used cotton noil waste and knitting waste yarn to produce woven fabrics and then used those fabrics as reinforcement materials in the manufacturing of composite structures. Their mechanical test results (tensile, bending, and impact) revealed that while the tensile and bending strength of waste yarn–reinforced samples were lower than those of glass fiber–reinforced samples, the impact energy of the waste yarn–reinforced samples was greater. They noted that waste yarn–reinforced composites could be used in areas where mechanical stresses are low.

Araújo et al. (2017) reinforced a polypropylene matrix with untreated cotton waste and cotton waste treated with acetylation or silanization to obtain a composite material with high mechanical and improved thermal properties for the automotive industry. Scanning electron microscopy images demonstrated that the fibers were broken by chemical treatment and the thermal stability of the fibers decreased with acetylation treatment. However, it was shown that through reinforcement of the polypropylene matrix with treated and untreated cotton waste, higher storage modulus, Young's modulus, and tensile strength values were achieved in comparison with those of neat polypropylene. In another study, Liu et al. (2017) manufactured foamed concretes from flue gas desulfurization gypsum and textile fiber waste to increase the energy efficiency of buildings. They used different amounts of textile fiber waste (1, 2, 3, 4, and 5 wt.%), and the results showed that samples reinforced with 3 wt.% textile fiber content had the best performance in terms of both compressive strength and density values.

Sezgin et al. (2012) manufactured cotton and E-glass waste–reinforced hybrid composite plates with different amounts of E-glass and cotton fiber by a compression molding technique. The mechanical performance of the hybrid composites was evaluated by Shore-D hardness, tensile strength, and impact testing. On the basis of the mechanical test results, the authors concluded that the hybrid composites could be used as a buffer material in the automotive industry. Yalcin et al. (2012) manufactured textile waste–reinforced composites for developing tea tray designs (Fig. 2.3). They used 100% cotton knitted and woven fabric waste as a reinforcement material, while polypropylene was used as a matrix material. The performance of the tea trays was investigated by a three-point bending test, staining test, water absorption test, and surface temperature test. The results showed that the textile waste–reinforced tea tray possessed the necessary properties to be used as a tea tray in daily life.

Vats and Rissanen (2016) aimed to upcycle textile waste from hospitals (e.g., blanket covers and bed sheets) for use in new products. These polyester–cotton and cotton waste textiles were characterized for their mass per unit area, breaking force, and polyester content. It was indicated that the minimum breaking force needed for upcycling of different types of products should be between 150 and 400 N, and the results showed that the breaking force for the hospital textile waste exceeded the minimum requirement. However, it was noted that the bed sheets and blanket covers showed greater loss of mechanical properties at the corners.

Another application for textile waste is conversion into useful chemicals. In one study, Sheikh et al. (2015) converted terry towel waste into carboxymethyl cellulose, used it as a thickener in textile printing, and compared it with standard carboxymethyl cellulose by measuring the color value, bending length, and fastness to washing, crocking, and light. The results indicated that the pseudoplastic and shear

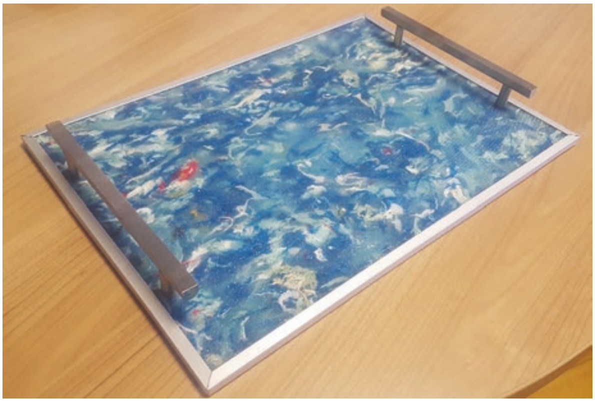

Fig. 2.3 Textile waste–reinforced composite tea tray created by Yalcin et al. (2012). This tray, composed of 100% cotton knitted and woven fabric production waste and a polypropylene matrix, is produced by a compression molding technique. (Reproduced from Yalcin et al. (2012), with permission)

thinning behavior, fastness properties, and color strength of the printed samples were similar to those of the currently used carboxymethyl cellulose.

In another study, Koç et al. (2016) obtained methyl cellulose from cotton towel waste. They characterized the structure of the methyl cellulose by analytical and spectroscopic methods and then analyzed the effect of the methyl cellulose on the hydration time of cement paste. They reported that the hydration start time was postponed by increasing the amount of methyl cellulose in the cement paste, which could provide higher-quality cement paste. In their study, Barot and Sinha (2015) chemically recycled postconsumer polyester clothing into bis(2-hydroxyethyl) terephthalate monomers, which could be further utilized industrially for various applications. Nahil and Williams (2010) thermally recycled acrylic textile waste by way of pyrolysis and activation to produce a higher-value activated carbon product. The results of Fourier transform infrared spectroscopy analysis showed that aromatic ring formation with nitrogen in the char structure occurred at high temperatures. Thus, after the recycling process, acrylic textile waste could be physically activated to produce microporous activated carbon with a large surface area.

Jeihanipour et al. (2010) used an eco-friendly solvent for cellulose N-methyl morpholine-N-oxide for separation and pretreatment of the cellulose. This solvent was mixed with blended textile fibers at 120 °C and at atmospheric pressure to dissolve the cellulose and separate it from the undissolved noncellulosic fibers. The cellulose was then either hydrolyzed by cellulose enzymes, followed by fermentation, to produce ethanol or digested directly to produce biogas. This process produced remarkable increases in the enzymatic hydrolysis rate and the biogas production rate. Moreover, during 3 days of digestion there was a 30% yield of methane from the N-methyl morpholine-N-oxide–treated cotton and viscose fibers, while untreated fibers produced only 0.02% and 1.91% of their theoretical yield over the same time period. In other research, Haule et al. (2016) studied the dissolution of purified cotton waste garments in N-methyl morpholine-N-oxide solution and then they spun them into new fibers. The molecular and mechanical properties of these fibers were analyzed and compared with those of standard lyocell fibers. In terms of molecular properties, the fibers spun from cotton waste garments had higher molecular weight and specific gravity than the standard lyocell fibers, with greater tensile properties and improved wet strength recovery. Gholamzad et al. (2014) applied an alkaline pretreatment to textile waste in order to enhance ethanol production from the cellulose part of a polyester–cotton textile and recovery of the polyester. The pretreatment was applied by using different alkaline solutions. The results of this study showed that all of the pretreatments provided an increase in the enzymatic hydrolysis yield to over 88%, while it was only 46.3% for the untreated textile. The maximum yield of ethanol production, which was 70%, was achieved after pretreatment with sodium hydroxide–urea at −20 °C. Moreover, alkaline pretreatment followed by hydrolysis provided recovery of 98% of the polyester without any significant change in properties.

Fig. 2.4 Biocomposite furniture set designed by Bernardita Marambio, a Chilean designer. The chairs and table are made with Demodé®, a new material that utilizes what would otherwise be wasted textiles from factories in Santiago, Chile, for use by consumers. The particle board is made with 100% biodegradable starch-based bioresin, which gives structural strength and is eco-friendly. (Costa et al. 2017) (Courtesy of Bernardita Marambio)

2.4.2 Design Perspectives

In addition to academic studies focusing on utilization of textile waste, designers are also working on this subject. Kushwaha and Swami (2016) have developed 30 different upcycled products (cushion covers, table mats, holders and folders, handbags, wallets, yokes, collars, earrings, and necklaces) from leather scraps to increase the value of leather waste. Bernardita Marambio, a Chilean designer, has used cotton textile waste together with a 100% biodegradable adhesive made with starch to design novel value-added furniture, including chairs and a table (Fig. 2.4). The designer's aim was to draw attention to the large amount of textile waste in landfills (Costa et al. 2017).

In one study, Kim (2014) designed 29 different high value–added upcycled luxury handbags for the Dubai fashion market by using preconsumer leather and fabric waste. The upcycled items were produced to sell at Harvey Nichols and Bloomingdale's in Dubai.

As is known, babies grow so fast that they can wear their clothes for only a very short time. Cara Sheppard, a Canadian crafter, launched an initiative in 2015, designing keepsake animal toys for families from their babies' old clothes (Fig. 2.5). Through this initiative, she not only recycles babies' textile waste but also preserves an adorable memory for their families (Keepsakes 2015).

Fig. 2.5 Keepsake Memory owl and turtle—upcycled from old fabric such as sleepwear, hospital blankets, or baby clothes—created by Cara Sheppard, a Canadian crafter. By creating these toys, she not only recycles babies' textile waste but also preserves an adorable memory for their families. (Keepsakes 2015) (Courtesy of Cara Sheppard)

Fig. 2.6 Plant sculptures created from upcycled textile waste by Wendy Moyer, a textile sculptor. She transforms textile waste into lush soft plant sculptures by using hand sewing and heat together to create the final shape, and she describes her technique as "fire sculpting" (Moyer) (Courtesy of Wendy Moyer)

Wendy Moyer, an American textile sculptor living in the artists' community of San Miguel de Allende in Central Mexico, upcycles fabrics from their original purposes to create impressive new objects (Fig. 2.6). She utilizes natural and synthetic fabric waste, transforming them into lush soft plant sculptures. She uses both hand sewing and heat together to create the final shape, and she describes her technique as "fire sculpting" (Moyer).

Fig. 2.7 Upcycled-Saree Collection Furniture created by Avni Sejpal, a Mumbai-based designer, who upcycles old sarees that have holes, stains, or tears into poufs, ottomans, stools, and benches. With this collection, she became the winner of the A'Design Award & Competition in the category of projects and green design in 2015. (A'Design Award & Competition 2015) (Courtesy of Avni Sejpal)

Avni Sejpal, a Mumbai-based designer, has created a collection called Upcycled-Saree Collection Furniture. She upcycles old sarees (bright and vivid draped garments worn by Indian women) that have holes, stains, or tears into poufs, ottomans, stools, and benches (Fig. 2.7). All of the products are handcrafted, and the wooden stools are manufactured with mango or acacia wood. With this collection, she became the winner of A'Design Award & Competition in the category of projects and green design in 2015. (A'Design Award & Competition).

2.5 Conclusion

For the global textile industry, one of the biggest challenges is the scarcity of resources, while the demand is ever increasing. With the overconsumption of resources and the preponderance of fast fashion trends in the textile industry, the generated textile waste volumes increase correspondingly day by day. In addition to production and preconsumer waste, postconsumer waste constitutes a huge proportion of the textile waste category generated by consumers captured by fast fashion movements. Although landfilling is the least favored option in the textile management hierarchy, vast amounts of textile waste are disposed of in landfills every day. However, it should be taken into consideration that during waste disposal, all of the materials, the consumed energy, the carbon emissions during the transport of the goods along the supply chain, and the labor input are also wasted. Furthermore, money is wasted. Therefore, besides energy recovery from textile waste, recycling and reuse of this waste should be encouraged in order to decrease the environmental impacts and energy consumption, for a more livable world. On the other hand, the first priority for management should be the prevention option, which should be assisted by creating environmental awareness to minimize the amount of solid waste going to landfills.

In this chapter we have highlighted the importance of waste management and shown the pros and cons of different waste management options. After describing the textile waste types, we have analyzed every step of the waste management hierarchy at length. We have also described engineering solutions for textile waste by referring to technical information on alternative usage and designers' work, including novel and value-added products/items created using different upcycling techniques, in which the designers take responsibility for creating public awareness of this issue. Through this review, the ever-growing risk of textile waste that is disposed of in landfills has been brought to light by discussion of management options in every aspect and ways of utilization from different perspectives. Moreover, it is hoped that the enriched content of this work may help to create awareness not only among those who produce, distribute, and sell these items, but also among consumers, by encouraging them to consider the history of textile items before buying, while using, and after consuming them.

References

A'Design Award & Competition. Upcycled-Saree Collection Furniture (2015) https://competition.adesignaward.com/design.php?ID=36254. Accessed 27 Apr 2017

Altun S (2016) Tekstil Üretim ve Kullanım Atıklarının Geri Kazanımı, Çevresel ve Ekonomik Etkileri; Uşak Ticaret ve Sanayi Odası Raporu. Uşak Chamber of Commerce and Industry, Uşak

Araújo RS, Rezende CC, Marques MFV et al (2017) Polypropylene-based composites reinforced with textile wastes. J Appl Polym Sci 134:45060/1–45060/10. https://doi.org/10.1002/app.45060

Barot AA, Sinha VK (2015) Chemical scavenging of post-consumed clothes. Waste Manag 46:86–93. https://doi.org/10.1016/j.wasman.2015.09.012

Bhatia D, Sharma A, Malhotra U (2014) Recycled fibers: an overview. Int J Fiber Text Res 4:77–82

Bhuiya MH (2017) Upcycling the garment solid waste in Bangladesh. Thesis, Tallinn University of Technology

Binici H, Aksogan O (2015) Engineering properties of insulation material made with cotton waste and fly ash. J Mater Cycles Waste Manag 17:157–162. https://doi.org/10.1007/s10163-013-0218-6

Binotto C, Payne A (2017) The poetics of waste: contemporary fashion practice in the context of wastefulness. Fash Pract 9:5–29. https://doi.org/10.1080/17569370.2016.1226604

Bosmans A, Vanderreydt I, Geysen D, Helsen L (2013) The crucial role of waste-to-energy technologies in enhanced landfill mining: a technology review. J Clean Prod 55:10–23. https://doi.org/10.1016/j.jclepro.2012.05.032

Briga-Sá A, Nascimento D, Teixeira N et al (2013) Textile waste as an alternative thermal insulation building material solution. Constr Build Mater 38:155–160. https://doi.org/10.1016/j.conbuildmat.2012.08.037

Cervellon M-C, Carey L, Harms T (2012) Something old, something used: determinants of women's purchase of vintage fashion vs second-hand fashion. Int J Retail Distrib Manag 40:956–974. https://doi.org/10.1108/09590551211274946

Clark H (2008) SLOW + FASHION—an oxymoron—or a promise for the future …? Fash Theory 12:427–446. https://doi.org/10.2752/175174108X346922

Costa C, Monteiro M, Rangel B, Alves FJL (2017) Industrial and natural waste transformed into raw material. Proc Inst Mech Eng Part L J Mater Des Appl 23:247–256. https://doi.org/10.1177/1464420716677087

Dissanayake DGK, Perera S, Wanniarachchi T (2017) Sustainable and ethical manufacturing: a case study from handloom industry. Text Cloth Sustain 3:2. https://doi.org/10.1186/s40689-016-0024-3

Domina T, Koch K (1997) The textile waste lifecycle. Cloth Text Res J 15:96–102. https://doi.org/10.1177/0887302X9701500204

Domina T, Koch K (1999) Consumer reuse and recycling of post-consumer textile waste. J Fash Mark Manag Int J 3:346–359. https://doi.org/10.1108/eb022571

Ekström KM (2014) Waste management and sustainable consumption: reflections on consumer waste. Routledge, Abingdon. https://doi.org/10.1007/s40622-015-0087

European Parliament, Council of the European Union (2008) Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain directives. Eur-Lex. https://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX:32008L0098

Fortuna LM, Diyamandoglu V (2017) Disposal and acquisition trends in second-hand products. J Clean Prod 142(4):2454–2462. https://doi.org/10.1016/j.jclepro.2016.11.030

Gardetti MA, Torres AL (2013) Sustainability in fashion and textiles: values, design, production and consumption. Greenleaf, Sheffield. doi: https://doi.org/10.1108/meq.2013.08324daa.012

Gholamzad E, Karimi K, Masoomi M (2014) Effective conversion of waste polyester–cotton textile to ethanol and recovery of polyester by alkaline pretreatment. Chem Eng J 253:40–45. https://doi.org/10.1016/j.cej.2014.04.109

Girl G (2015) The World Bank's waste report. Our Waste Matters. https://ourwastematters.com/2015/02/07/the-world-banks-waste-report/. Accessed 26 Apr 2017

Gulich B (2006) Designing textile products that are easy to recycle. In: Wang Y (ed) Recycling in textiles. Woodhead, Cambridge, pp 25–37

H&M Group (2016) The H&M Group Sustainability Report 2016. http://sustainability.hm.com/

Haule LV, Carr CM, Rigout M (2016) Preparation and physical properties of regenerated cellulose fibres from cotton waste garments. J Clean Prod 112(5):4445–4451. https://doi.org/10.1016/j.jclepro.2015.08.086

Hawley JM (2006) Textile recycling: a system perspective. In: Wang Y (ed) Recycling in textiles. Woodhead, Cambridge, pp 7–24

Holm-Nielsen JB, Al Seadi T, Oleskowicz-Popiel P (2009) The future of anaerobic digestion and biogas utilization. Bioresour Technol 100:5478–5484. https://doi.org/10.1016/j.biortech.2008.12.046

International Solid Waste Association (2015) ISWA report 2015. International Solid Waste Association, Vienna

Jeihanipour A, Karimi K, Niklasson C, Taherzadeh MJ (2010) A novel process for ethanol or biogas production from cellulose in blended-fibers waste textiles. Waste Manag 30:2504–2509. https://doi.org/10.1016/j.wasman.2010.06.026

Jordeva S, Tomovska E, Trajković D, et al. (2015) Sound insulation properties of structure designed from apparel cutting waste. In: 15th Autex World Textile Conference 2015

Karaosman H, Brun A, Morales-Alonso G (2017) Vogue or vague: sustainability performance appraisal in luxury fashion supply chains. In: Gardetti MA (ed) Sustainable management of luxury. Springer, Singapore, pp 301–330

Nestling Kids Keepsakes (2015) About us. https://www.nestlingkids.com/pages/about-us. Accessed 27 Apr 2017
Kim HJ (2014) A study of high value-added upcycled handbag designs for the Dubai luxury fashion market. J Korean Soc Fash Des 14:173–188
Klass DL (2000) Fuels from biomass. In: Kirk RE, Othmer (eds) DF (eds) Encyclopedia of chemical technology. Wiley, New York
Koç A, Ziba CA, Akarsu S et al (2016) Tekstil Atıklarından Selüloz Eldesi, Metil Selüloz Sentezi, Karakterizasyonu ve Çimento Pastasında Kullanımı. KSU J Eng Sci 19:115–123
Kushwaha S, Swami C (2016) Upcycling of leather waste to create upcycled products and accessories. Int J Home Sci 2:187–192
Lawless E, Medvedev K (2016) Assessment of sustainable design practices in the fashion industry: experiences of eight small sustainable design companies in the northeastern and southeastern United States. Int J Fash Des Technol Educ 9:41–50. https://doi.org/10.1080/17543266.2015.1116616
Lee KE (2017) Environmental sustainability in the textile industry. In: Muthu SS (ed) Sustainability in the textile industry. Springer, Singapore, pp 17–55. doi: https://doi.org/10.1007/978-981-10-2639-3_3
Levi Strauss & Co. (2015) How we're embracing the circular economy. http://levistrauss.com/unzipped-blog/2015/07/embracing-the-circular-economy/. Accessed 26 Apr 2017
Liu Y, Zhang Y, Guo Y et al (2017) Porous materials composed of flue gas desulfurization gypsum and textile fiber wastes. Waste Biomass Valoriz 8:203–207. https://doi.org/10.1007/s12649-016-9617-y
Lu JJ, Hamouda H (2014) Current status of fiber waste recycling and its future. Adv Mater Res 878:122–131. https://doi.org/10.4028/www.scientific.net/AMR.878.122
Marks & Spencer Group (2016) Plan A report 2016. Marks & Spencer Group, London
McDougall FR, White PR, Franke M, Hindle P (2008) Integrated solid waste management: a life cycle inventory. Wiley, Hoboken
Miranda R, Sosa_Blanco C, Bustos-Martínez D, Vasile C (2007) Pyrolysis of textile wastes: I. Kinetics and yields. J Anal Appl Pyrolysis 80:489–495. https://doi.org/10.1016/j.jaap.2007.03.008
Mohammadhosseini H, Yatim JM (2017) Evaluation of the effective mechanical properties of concrete composites using industrial waste carpet fiber. INAE Lett 2:1–12. https://doi.org/10.1007/s41403-017-0016-x
Morris M, Waldheim L (1998) Energy recovery from solid waste fuels using advanced gasification technology. Waste Manag 18:557–564. https://doi.org/10.1016/S0956-053X(98)00146-9
Moyer W. Wendy Moyer textile sculptor. http://textileartistmx.com/. Accessed 27 Apr 2017
Murphy JD, McKeogh E (2004) Technical, economic and environmental analysis of energy production from municipal solid waste. Renew Energy 29:1043–1057. https://doi.org/10.1016/j.renene.2003.12.002
Nahil MA, Williams PT (2010) Activated carbons from acrylic textile waste. J Anal Appl Pyrolysis 89:51–59. https://doi.org/10.1016/j.jaap.2010.05.005
Nielsen R, Schmidt A (2014) Changing consumer behaviour towards increased prevention of textile waste: background report. Nordic Council of Ministers, Copenhagen
Nishio N, Nakashimada Y (2007) Recent development of anaerobic digestion processes for energy recovery from wastes. J Biosci Bioeng 103:105–112. https://doi.org/10.1263/jbb.103.105
Nodoushani O, Stewart C, Kaur M (2016) Recycling and its effects on the environment. Compet Forum Indiana 14:65–69
Oliveux G, Dandy LO, Leeke GA (2015) Current status of recycling of fibre reinforced polymers: review of technologies, reuse and resulting properties. Prog Mater Sci 72:61–99. https://doi.org/10.1016/j.pmatsci.2015.01.004
Ouda OKM, Raza SA, Nizami AS et al (2016) Waste to energy potential: a case study of Saudi Arabia. Renew Sust Energ Rev 61:328–340. https://doi.org/10.1016/j.rser.2016.04.005

Ozdamar Ertekin Z, Atik D (2015) Sustainable markets: motivating factors, barriers, and remedies for mobilization of slow fashion. J Macromark 35:53–69. https://doi.org/10.1177/0276146714535932

Pakravan HR, Memarian F (2016) Needlefelt carpet waste as lightweight aggregate for polymer concrete composite. J Ind Text 46:833–851. https://doi.org/10.1177/1528083715598657

Patnaik A, Mvubu M, Muniyasamy S et al (2015) Thermal and sound insulation materials from waste wool and recycled polyester fibers and their biodegradation studies. Energ Buildings 92:161–169. https://doi.org/10.1016/j.enbuild.2015.01.056

Pookulangara S, Shephard A (2013) Slow fashion movement: understanding consumer perceptions—an exploratory study. J Retail Consum Serv 20:200–206. https://doi.org/10.1016/j.jretconser.2012.12.002

Ramamoorthy SK, Persson A, Skrifvars M (2014) Reusing textile waste as reinforcements in composites. J Appl Polym Sci 131:1–16. https://doi.org/10.1002/app.40687

Ringler C, Zhu T (2015) Water resources and food security. Agron J 107:1533–1538. https://doi.org/10.2134/agronj14.0256

Sezgin H, Yalcin I, Berkalp OB (2012) Re-evaluation of cotton and E-glass fibre fabric wastes in the manufacture of hybrid composites. J Int Sci Publ Mater Methods Technol 6:296–302

Sharholy M, Ahmad K, Mahmood G, Trivedi RC (2008) Municipal solid waste management in Indian cities—a review. Waste Manag 28:459–467. https://doi.org/10.1016/j.wasman.2007.02.008

Sheikh J, Bramhecha I, Teli MD (2015) Recycling of terry towel (cellulosic) waste into carboxymethyl cellulose (CMC) for textile printing. Fibers Polym 16:1113–1118. https://doi.org/10.1007/s12221-015-1113-7

Silva S (2012) Applicability of value stream mapping (VSM) in the apparel industry in Sri Lanka. Int J Lean Think 3:36–41

Sotayo A, Green S, Turvey G (2015) Carpet recycling: a review of recycled carpets for structural composites. Environ Technol Innov 3:97–107. https://doi.org/10.1016/j.eti.2015.02.004

Strähle J, Hauk K (2017) Impact on sustainability: production versus consumption. In: Strähle J (ed) Green fashion retail. Springer, Singapore, pp 49–76

Strähle J, Matthaei FS (2017) The value chain of a branded second hand store—possible activities to be integrated by a conventional fashion brand. In: Strähle J (ed) Green fashion retail. Springer, Singapore, pp 175–198

Strähle J, Philipsen F (2017) Closed-loop production: a literature review. In: Strähle J (ed) Green fashion retail. Springer, Singapore, pp 27–48

Tammemagi HY (1999) The waste crisis: landfills, incinerators, and the search for a sustainable future, 1st edn. Oxford University Press, New York

Tıinmaz E, Demir İ (2006) Research on solid waste management system: to improve existing situation in Çorlu town of Turkey. Waste Manag 26:307–314. https://doi.org/10.1016/j.wasman.2005.06.005

Tisserant A, Pauliuk S, Merciai S et al (2017) Solid waste and the circular economy: a global analysis of waste treatment and waste footprints. J Ind Ecol 21(3):628–640. https://doi.org/10.1111/jiec.12562

Torstensson R (2011) A new player in the accelerating textile industry—upcycled textile products. Thesis, University of Boras

Umar M, Shaker K, Ahmad S et al (2017) Investigating the mechanical behavior of composites made from textile industry waste. J Text Inst 108:835–839. https://doi.org/10.1080/00405000.2016.1193982

Vats S (2015) Upcycling of hospital textiles into fashionable garments. Thesis, Tampere University of Technology

Vats S, Rissanen M (2016) Parameters affecting the upcycling of waste cotton and PES/CO textiles. Recycling 1:166–177. https://doi.org/10.3390/recycling1010166

Voncina B (2016) Recycling of textile materials. 2B Funtex-MDT. http://www.2bfuntex.eu/sites/default/files/materials/Recycling%20of%20textile%20materials_Bojana%20Voncina.pdf

Wang Y (2006) Recycling in textiles. Woodhead, Cambridge

Wang Y (2010) Fiber and textile waste utilization. Waste Biomass Valoriz 1:135–143. https://doi.org/10.1007/s12649-009-9005-y

Williams CC, Paddock C (2003) The meanings of informal and second-hand retail channels: some evidence from Leicester. Int Rev Retail Distrib Consum Res 13:317–336. https://doi.org/10.1080/0959396032000101372

Xu Y, Chen Y, Burman R, Zhao H (2014) Second-hand clothing consumption: a cross-cultural comparison between American and Chinese young consumers. Int J Consum Stud 38:670–677. https://doi.org/10.1111/ijcs.12139

Yalcin I, Berkalp OB, Sezgin H, Gok Sadikoglu T (2012) Design of a tea tray from textile waste reinforced composite. In: 7th Central European Conference, Portorose

Yalcin I, Sadikoglu TG, Berkalp OB, Bakkal M (2013) Utilization of various non-woven waste forms as reinforcement in polymeric composites. Text Res J 83:1551–1562. https://doi.org/10.1177/0040517512474366

Yano J, Sakai S (2016) Waste prevention indicators and their implications from a life cycle perspective: a review. J Mater Cycles Waste Manag 18:38–56. https://doi.org/10.1007/s10163-015-0406-7

Zamani B (2014) Towards understanding sustainable textile waste management: environmental impacts and social indicators. Thesis, Chalmers University of Technology

Zonatti WF, Baruque-Ramos J, Duleba W (2016) Brazilian scope of management and recycling of textile wastes. In: Fangueiro R, Rana S (eds) Natural fibres: advances in science and technology towards industrial applications. Springer, Dordrecht, pp 429–439