

The Use of Recycled Fibers in Fashion and Home Products

Karen K. Leonas

Abstract As the textile, apparel, fashion, and retail industries move to become more sustainable, an area of interest is the use of recycled fiber, yarn, fabric, and product content in the development and production of new products. The decision to use recycled materials in products must occur during design and product development and continue throughout the manufacturing processes. There are several recognized stages in recycling collection, processing, and then use in a new product. Recycled materials used in textile and apparel products can be obtained throughout the textile and apparel supply chain and post-consumer collection methods. The use of recycled raw materials aligns with the larger movements of global industries toward a circular economy (vs. linear) and working to achieve a closed-loop production cycle. This chapter reviews the textile and apparel industry, factors that have influenced the generation and use of waste and recycling processes currently used today. Selected brands that have programs and products that contain recycled content are identified here.

Keywords Circular economy • Closed loop • Recycled fibers • Recycled content • Waste • Recycling • Post-consumer

1 Introduction

As the textile, apparel, fashion, and retail industries move to become more sustainable, an area of interest is the use of recycled fiber, yarn, fabric, and product content in the development and production of new products. The decision to use recycled materials in products must occur during design and product development and continue throughout manufacturing processes. There are two stages in recycling—collection and processing. Recycled materials used in textile and apparel

K.K. Leonas (✉)

Department of Textile and Apparel, Technology and Management, College of Textiles,
North Carolina State University, Raleigh, NC 27695, USA
e-mail: kleonas@ncsu.edu

products can be obtained throughout the textile and apparel supply chain and post-consumer collection methods. The use of recycled raw materials aligns with the larger movements of global industries toward a circular economy (vs. linear) and closed-loop production. This chapter reviews the textile and apparel industry, factors that have influenced the generation and use of waste, recycling processes currently used today, and selected brands are identified in this chapter.

2 The Textile and Apparel Industry

Since the Industrial Revolution when the production of textiles became mechanized through development and commercialization of related technology including the spinning frame, power loom, and cotton gin, there had been increasing abilities to produce larger quantities of yarns and fabrics. Yarn and fabric production moved from the home and small enterprises to large, industrialized factories. In the mid- to late 1800s, the sewing process also became mechanized with the invention and patenting of the sewing machine. From 1842 to 1885, the USA issued over 7300 patents for sewing machines and accessories (Burns et al. 2011). Additional technological advancements such as motorized cutting knives and pressing equipment introduced in the late 1800s contributed to the growth of the industry and supported the development of the factory system. Although menswear was the first market segment to move to ready-to-wear apparel, other market segments including children's and women's apparels soon followed. Apparel styles for women also changed with the adoption of separates and shirtwaists, which was conducive for the ready-to-wear market.

In addition to technological developments in textile and apparel manufacturing, during the first half of the twentieth century, the development of regenerated and synthetic polymers suitable for use as textile fibers increased raw material availability. Production of manufactured fibers increased rapidly and by the 1980s the consumption of these fibers outpaced the consumption of natural fibers. Because of these many advancements, the production and availability of textiles and apparels increased dramatically. Developed countries around the world moved from producer to consumer societies supporting the growth of a linear economy.

Direct environmental impacts of the apparel and textile industry addressed in this chapter include the use of raw materials to produce textiles and the pollution and solid waste generated through the manufacturing process and the disposal of used textile and apparel products. In 2013, the global consumption of fibers and yarns increased to 90.1 million tons from a record of 82 million tons in 2011. To produce fibers in 2011, it required 145 million tons of coal and a couple trillion gallons of water (McGregor 2015a; Aizenshtein 2009). The US EPA estimates that textile waste occupies nearly 5 % of all landfill space and the average US citizen throws away 70 lb of clothing annually. It is also estimated that the textile recycling industry recycled approximately 3.8 billion pounds of post-consumer textile waste

that accounts for approximately 15 % of the total (National Cotton Council of America 2016).

The USA is not unlike other parts of the world as these short-lived products are in either landfills or incinerators sooner than more durable ones. In 2012, in the USA alone, the incineration of synthetic fibers resulted in 1.1 MMT (million metric tons) of CO₂e (carbon dioxide equivalents) emissions, while textiles in landfills contributed a net 8.5 MMT CO₂e that year (Patagonia 2016a). Organizations throughout the world, including major apparel brands, have acknowledged the environmental impacts of the textile and apparel industries as demonstrated by the following statements:

You cannot have infinite, unfettered growth and fast-fashion methods of consumption and production if you want to protect resources Gwen Cunningham, Circular Textile Program, (McGregor 2015a)

The nylon and polyester polymers we use in our technical shells—which we also use in some of our other products—are neither infinite nor sustainable (Patagonia 2016a)

and

The fashion industry is too dependent on natural resources and we must change how fashion is made. ...clothes are a necessity, However, the fashion industry requires large amounts of natural resources, lots of which can be reduced, recycled, substituted or eliminated Cecelia Brannsten, H&M (McGregor 2015a)

In January 2016, of 331 exhibitors at the Textile World, USA, there were 29 companies offering products with eco-friendly materials or using eco-friendly processes (McGregor 2016c). It is expected that increasing number of companies will begin to incorporate market sustainable products and practices at future exhibitions.

Textiles and apparel is a term that encompasses a plethora of items from the apparel worn for protection to self-expression, items in the home including linens and upholstery, geo-textiles, building materials, and automotive components to name a few. Not only does everyone use textiles in their everyday life, but in 2011 the fashion and textile manufacturing industry also employed more than a billion people globally (Hayes 2011). The movement in the textile and apparel industry from a linear to circular economy and to a closed-loop manufacturing process is seen in all product categories from activewear, basics (socks, t-shirts), fashion items to the highest performance athletic wear. Nike states *‘We envision a transition from linear to circular business models and a world that demands closed-loop products - designed with better materials, made with fewer resources and assembled to allow easy reuse in new products’* (Nike 2016c). This is aligned with similar transformational changes taking place in other global industries and seems to be changing consumer’s behaviors and attitudes. The goal to divert waste from the landfill is to disrupt the current production processes and waste management behaviors, both at an industry and at a personal level, that result in the reduction of waste.

3 Textile Recycling Aligned with the Circular Economy

There is movement in many industries, including the textile and apparel industry, toward the development of a circular economy and away from the traditional linear economy. Historically, the textile and apparel industry has been an excellent example of the latter. The linear economic model is represented by concepts of 'take, make, and dispose,' 'make, use, dispose,' or 'more is better.' This economy relies on large quantities of low cost, easily accessible materials. Moving to a circular economy reduces the impacts of a linear economy by creating a different system. A circular economy is known to be restorative and the concepts of 'reduce, reuse and recycle,' 'make/remake,' 'use/reuse,' and 'repurpose' represent this system. Goals of a circular economy are to use products, components, and materials to their highest value at all times. Resources are recovered and restored in the technical cycle, typically requiring human intervention. The recovered materials are then reused many times and repurposed to create a product of value (Ellen MacArthur Foundation 2012).

4 Open- and Closed-Loop Recycling

The two primary stages involved in recycling are collection and reprocessing. To create a closed-loop system, the additional stage of creating a new, recyclable product must be added. With regard to textiles and apparel industry, the collection process takes place at various points through the supply chain, and there are programs where the public can be involved in the process. Waste is also collected from sources outside the textile and apparel industry for reprocessing and use in apparel and textile end products. Reprocessing of the collected materials is critical in determining whether it will contribute to an open- or closed-loop system. In an open-loop system, the material is not recycled indefinitely and is eventually excluded from the utilization loop and diverted to the landfill. There are a number of reasons for excluding material from the loop. Two common reasons for this exclusion are: (1) degradation of the raw material that results in reduced quality and (2) incorporation of the raw material into a product that is not recyclable. In general, open-loop recycling postpones waste from being generated but does not ultimately keep product from the waste stream. An alternate and more sustainable strategy is the closed-loop recycling. The recycling of the material is indefinite and without degradation. This conversion of the used product back to raw materials allows for making the same product over and over again. Biodegradable products are also a part of the closed-loop recycling system. This is also known as cradle-to-cradle (Payne 2015). Payne (2015) provides a thorough overview of open- and closed-loop recycling for textile and apparel products including schematics of open- and closed-loop recycling systems (Figs. 1 and 2).

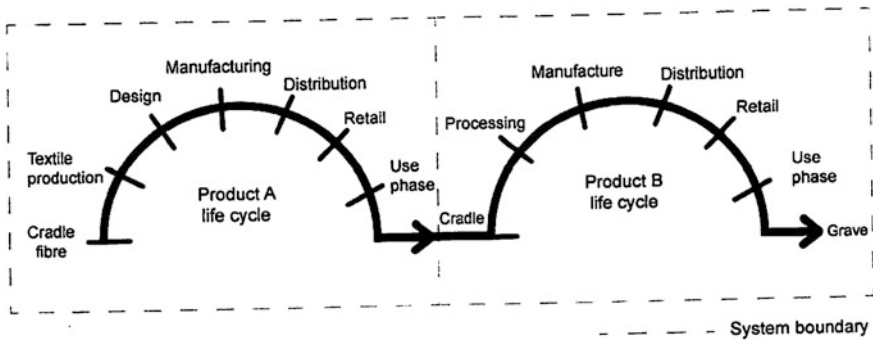
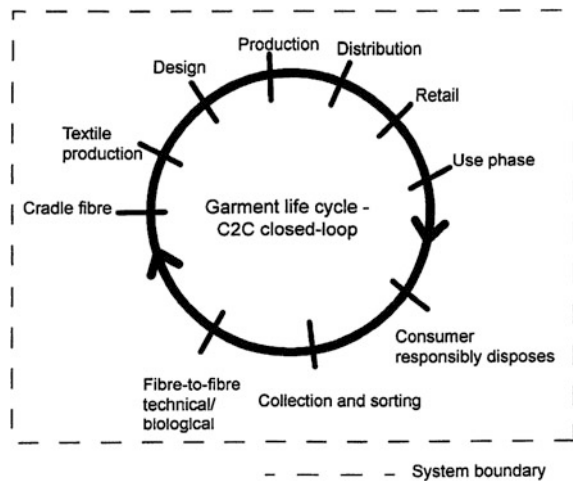


Fig. 1 Open loop recycling from Payne (2015, p. 107)

Fig. 2 Cradle-to-cradle closed-loop recycling from Payne (2015, p. 113)



A number of textile and apparel companies are working to achieve closed-loop recycling including Patagonia as seen on the company's Web site '*best option at this point is to buy recycled-content fabrics and to continually find new ways to recycle our products at the end of their life and keep them out of traditional disposal methods*' (Patagonia 2016a). As a brand, Patagonia is aware of challenges with the use of recycled fibers. As many of their products fall into the high-performance category, they are concerned with the loss of durability in the resulting fabric. High-quality fabrics that exceed the expected performance have been developed from the recycled polyester. However, they have found that recycled nylon is less durable, more difficult to obtain the necessary quantity, and has increased weight when compared to virgin nylon (Patagonia 2016a).

5 Recycling and Reuse

Recycling and reuse of materials is not new to the textile and apparel industry. Payne distinguishes between recycling and reuse as follows: Recycling ‘*refers to the breakdown of product into its raw materials in order for the raw material to be reclaimed and used in new products. In contrast, reuse refers to an existing product being used again within the same production chain. Textile recycling may involve reclaiming pre- consumer waste or post-consumer waste*’ (Payne 2015, p. 105). For centuries, end products were repurposed after they have reached the end of their use in one product.

There are a variety of methods in which reuse occurs. The used product can be disassembled and then reassembled into a new, and possibly different, product. Examples of repurposing are frequently seen in pop culture including a scene from *Gone with the Wind*, where Mamie removed the green velvet drapes and repurposes them into a gown for Scarlett O’Hara (Mitchell 1936). Historically, it was common that when apparel was no longer useful, once outgrown or no longer in style, it was remade to fit someone else or redesigned to create a more stylish garment. The recycling of wool is hundreds of years old. After apparel (i.e., wool sweaters) had been worn threadbare, it was collected and shredded into individual fibers and then converted into blankets. Today it is quite common for apparel items to be donated to charities for resale or discarded in the trash bin after they have fulfilled their initial use. In some cases, items that are no longer useful as their original product are used for other purposes such as rags or stuffing. Hawley provides an extensive review of the many ways in which discarded apparel is reused. There is a detailed schematic (Fig. 3) of the multiple options for post-consumer textile products included in her work (Hawley 2015).

Recycling is the breakdown of a product into its raw materials. For centuries, textile products (apparel and fabrics) were broken down to the yarn stage and the yarn was used to produce different knitted or woven fabrics. In some cases, the yarns are further broken down to the fiber stage and then the fibers were respun into yarns to be used in new textile products. This was quite common prior to the mid-twentieth century. In 1939, the US Federal Trade Commission introduced the Wool Products Labeling Act which requires accurate labeling of wool products that distinguishes between fibers that have never been reclaimed from woven or felted wool products, identified as ‘wool’ and ‘recycled wool’ in which the fiber used has been previously been spun, woven, knitted, or felted into a wool product (Federal Trade Commission 2016).

With the introduction of manufactured fibers in the late nineteenth century and synthetic fibers in the twentieth century, the practice of breaking down post-consumer products and reusing the fabric, yarns, and/or fibers was reduced for several reasons. With increased raw materials available, products were discarded rather than reused or recycled. Next, as natural and man-made fibers were blended and products with mixed fibers became more popular, it was difficult to separate the fibers by generic class. This separation is critical in the recycling process due to the

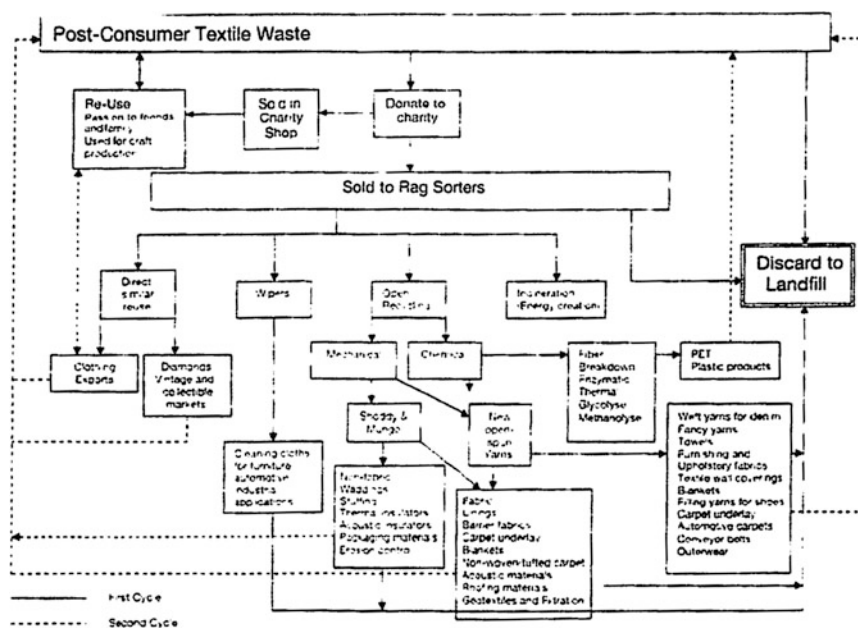


Fig. 3 Schematic showing the multiple options for post-consumer textile products from Hawley (2015, p. 212)

varied processing and performance parameters required by each individual fiber type. A challenge facing the industry related to the recycling process is the separation of the fibers by chemical class. There are a number of processes where non-contaminated waste (pure generic fiber content) can be collected throughout the supply chain. In addition, technology is being developed to achieve the separation of fibers. Today, mixed fiber and/or contaminated waste are commonly used as a fuel through incineration. However, technological development shows promise for increased success in collection, separation, and use of recycled mixed fiber materials.

Textile wastes can be classified into several ways. Commonly they are classified as to the point in which the supply chain they are collected. These include three categories: (1) pre-consumer waste, (2) post-industrial textile waste, and (3) post-consumer textile waste. There are also four recycling approaches identified in the literature. The first refers to the collection process; the second, third, and fourth focus on the processing of the waste. These approaches are: (1) primary—recycling industrial scrap; (2) secondary—processing a post-consumer product into raw materials; (3) tertiary—converting plastic wastes into basic chemical monomers called fuels; and (4) quaternary—incinerating waste as a way of reclaiming the embedded energy (Vadicherla and Saravanan 2014).

Wastes generated by the original manufacturer that never reaches the consumers are best classified as pre-consumer waste. Post-industrial textile wastes are

generated during the manufacturing process. On average, about 15 % of fabric used in garment production is cut, discarded, and wasted in the process, which contributes to post-industrial waste (Beitch 2015).

Post-consumer textile wastes are the wastes that come from the consumer. Collection at this point in the supply chain requires buy-in of the public and is recovered from the consumer supply chain (Vadicherla and Saravanan 2014).

Although over the past quarter century, recycling has increasingly become an intrinsic part of our everyday language, the textiles and apparel industry has been slow to adopt this practice. In the USA alone, 14.3 million tons of textile waste were created last year. While 2.3 million tons of it was recycled, the goal is to increase these numbers. The textile and apparel industry is global and uses a resource-intensive supply chain that causes massive waste and creates environmental harm. The industry is one of the world's largest producers of toxic environmental waste, affecting air, water, and soil resources. This poses major challenges for brands and their efforts to produce eco-friendly products (Evrnu 2015a, b).

Preferences for recycling of textile wastes in the industry appear to the predominantly thermoplastic polymer-based fibers due to the ease and feasibility of reprocessing them. In addition, these materials have the ability to take on different forms and shapes after recycling. Natural fibers such as cotton, wool, and silk are also finding their ways into recycling streams. The majority of textile wastes reported in the literature included polyester, polyethylene, nylon, p-aramid, carbon, silk, polybutylene terephthalate, bamboo, cotton, and kenaf (Vadicherla and Saravanan 2014).

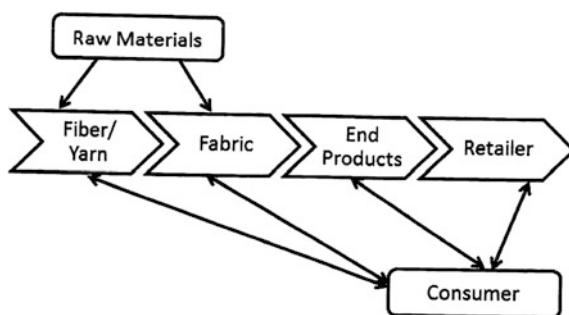
Using recycled thermoplastic fibers reduces the dependence on petroleum as a source of raw materials. It curbs discards, thereby prolonging landfill life and reducing toxic emissions from incinerators. It helps to promote new recycling streams for polyester clothing that is no longer wearable.

6 The Textile and Apparel Supply Chain

It is important to review the textile and apparel supply chain to better understand the recycling approaches and categories described in the previous section. Recycling involves two primary steps, collection and processing. To achieve a closed-loop system, the processed waste must then be used in new recyclable products. The collection of waste can occur at various points throughout the textile and apparel supply chain. The textile, apparel, and fashion industry is complex and includes a variety of product categories covering diverse market sectors. Generally, it is accepted that production of fashion and textiles utilizes one of the longest and most complex industrial chains in the manufacturing industry (Hayes 2011).

Due to the diversity of raw materials and end products, there are numerous and varying supply chains used. A simplified supply chain for fashion, textile, apparel, and retail items will include raw materials (fibers and yarns), fabric production, end product manufacturing, the retailer, and the consumer (Kincade and Gibson 2010).

Fig. 4 Textile product supply chain



See Fig. 4. Supply chains are based on the specific product and expand to include all findings, finishes, etc., used in the final product.

Pre-consumer wastes are generated throughout the first stages of the supply chain. In the raw materials sector (fiber and yarn production), ginning wastes, opening wastes, carding wastes, comber noils, combed waste yarns, roving wastes, ring-spinning waste fibers, ring-spun waste yarns, open-end spinning waste fibers, and open-end spinning yarn wastes are commonly collected for recycling. From sector two (fabric production), knitting waste yarns, woven fabric scraps, trimmed selvages, poor quality fabrics, and warper tie in scrap yarns are examples of wastes collected and suitable for recycling. Examples of post-industrial waste can be found at several points within the supply chain. When producing thread, it is common to collect waste thread throughout the production process. American and Efir thread generates approximately 20,000 lb of waste thread each month that is diverted from the landfill through their recycling programs (Summers 2016). In sector three, end product manufacturing, which includes cut-and-sew operations, there is significant fabric waste resulting from leftover fabric between individual pattern pieces and areas along the selvage (Payne 2015). Scrap fabrics from the wet processing sector of the industry also yields suitable waste for recycling (Vadicherla and Saravanan 2014).

Post-consumer waste is received from the public, which includes items that have no more use for the owner. This commonly includes donated and discarded apparel and some plastic items such as plastic bottles made from polyethylene terephthalate. Nylon can also be recycled and large source of post-consumer nylon waste is fishing nets left in the ocean.

As noted previously, the second major step in recycling is the processing. This is dependent on the chemical and physical characteristics of the collected items and the demand for the recycled product. The chemical properties are determined by the fiber.

There are numerous of fibers used in apparel, and home textiles are selected based on a variety of considerations including comfort, flexibility, appearance, cost, and hand with attention to other properties as determined by the function necessary in the product. The selection of the appropriate fiber begins during product development and throughout the design process. Fibers are the building block of the textiles with their performance properties determined by their chemical and physical properties. Fibers are classified as natural or manufactured depending on how they

are produced. Natural fibers commonly used in apparel and home textile products include cotton, flax, hemp, wool, and silk. Manufactured fibers are further categorized as those regenerated from natural materials (regenerated) such as cellulosic and protein, or from a petrochemical base (synthetic). Regenerated fibers used in textiles include rayon, bamboo, and Lyocell, and general use of synthetic fibers include polyester, nylon, spandex, and acrylic.

Polyester is now the single largest fiber group in the world. In 2004, world demand for polyester was 24.7 million tons, slightly ahead of the demand for raw cotton (Hayes 2011). Cotton makes up 35.3 % of fiber used in apparel products (National Cotton Council of America 2016). Large percentages of cotton and polyester used in textiles and apparel products contribute to the interest in the development of successful recycling programs. Benefits of polyester recycling methods include reducing the high ecological and social cost of oil reducing petrochemical pollution and reduction production emissions, including environmentally damaging chemical such as cobalt, manganese salts, sodium bromide, antimony oxide, and titanium dioxide (Hayes 2011).

Studies have shown that recycled polyester fibers, yarns, and fabrics made of different textiles and polymeric bottle wastes possess physical properties similar to that of virgin polyester.

7 Recycling in the Textile and Apparel Industry

In the textile and apparel industry, there are numerous examples of recycling collection and processing programs. There has been great effort and interest in recycling of polyester and cotton due to their wide use. The most successful programs focus on polyester and cotton. However, other fibers can be recycled, and nylon and wool have successful recycling programs. In addition, some firms are beginning to recycle aramids such as Kevlar® (National Spinning 2016). In the processing, there are two categories commonly used in textiles, mechanical and chemical.

8 Mechanical Recycling

Mechanical recycling processes can result in the production of fabric, yarns, or fibers to be used in new products. The discarded textile is opened up, apparel is disassembled, and fabrics are cut into smaller pieces. It is then passed through a rotating drum to continue the breakdown and fibers are obtained. This process is known as garneting. The resulting fiber characteristics of length, fineness, strength, polymer, and color determine the quality and what the most appropriate new end product would be. Typically, waste collected from the manufacturing supply chain will produce higher-quality recycled fibers that those collected from post-consumer waste. The pre-consumer and post-industrial processed waste can be respun into

yarns which woven or knitted into fabrics, and then used in apparel, sheeting, and upholstery. Medium-grade fibers can be used to make fabrics but are used in end products such as wipes and fillings. Lower-quality fibers will be used as reinforcement in other structures (i.e., concrete), nonwoven fabrics, carpet underlays, shoe inlays, automotive sound and thermal insulation, home insulation, stuffing for toys, and other end products.

Plastics, including plastic bottles and thermoplastic fibers, are commonly recycled using mechanical methods. In these cases, the plastic waste is chopped into small flakes that are melted and then extruded into a form to be used in a new product. This melt can be extruded into filaments, yarns, or other formed products. There is a little noticeable difference between virgin polyester and recycled polyester fibers. This is a common method for reprocessing the plastic water bottles and fishing nets. However, not all recycled thermoplastic fibers have properties similar to virgin fibers.

9 Chemical Recycling

Chemical recycling is the other method commonly used to process the collected waste in the textile industry. Synthetic fibers including polyesters, polyamides, and polyolefins can be chemically recycled. This falls under the tertiary class of recycling which requires the breaking down of the synthetic fibers for repolymerization. This process can be used when PET plastic water bottles are recycled. Whether it is the collection of used polyester apparel, fabric scraps, yarns waste, or other plastics, the recycled items are broken into small pieces from which chips are produced. The chips are decomposed to form dimethyl terephthalate, which is then repolymerized and spun into new polyester fibers, filaments, and yarns.

Blends are in particular challenging to recycle due to the disparate physical and chemical properties of the fibers in the waste. Cotton and polyester blends are one of the most commonly used apparel and home textile items. Chemical recycling has proven successful when used with blended materials as it uses a selective degradation method. In products of cotton and polyester, the fibers can be chemically separated and then reformed into new fibers. Currently, there is a process being developed using *n*-methylmorpholine-*N*-Oxide, which dissolves cellulose. The dissolved cellulose and polyester are separated by filtration and the captured polyester is respun into a fiber, filament, or yarn. The dissolved cellulose can be used in the production of regenerated cellulosic fibers including Lyocell (McGregor 2015b; Zamani 2011).

Nylon and spandex is a blend commonly found in high-performance sportswear and activewear. Generally, the percentage of nylon is much greater than that of spandex and nylon can be recycled and reused. It is known that spandex can be removed from blended fabrics by dissolving it in solvents such as *N,N*-dimethylformamide. However, this solvent is expensive and there are environmental concerns with its use. There has been success by first treating the blended

fabric with heat to degrade the spandex, and then exposing the fabric to a washing process using ethanol, which effectively removes the spandex residue leaving only the nylon (Yin et al. 2013).

Today, for products of single fiber content fabrics, mechanical recycling is more prominent. The chemical recycling procedures require more energy consumption and there is high capital investment so this option is only practical for large-scale manufacturers. As the technology improves, the demand for recycled content increases, and as the cost of virgin raw materials increases, there is likely to be a shift from mechanical to chemical recycling of these materials (Agrawal et al. 2015).

10 Textile and Apparel Recycling Programs in the Industry

Throughout the textile and apparel industry, there are numerous programs that focus on collecting and processing of textile waste. Several companies have established used apparel and or footwear drop boxes where the product goes through a recycling process and the materials can be reused. There are few closed-loop programs but an increasing number of companies are have set closed-loop production as a goal. In addition, there are programs related to brands promoting the use of recycled content. As companies begin to consider their role with regard to environmental impact of their products, there are many considerations. The information here focuses primarily on collection, processing, and reuse of recycled content in products throughout the supply chain including products sold directly to the consumer. Although not all programs are included, a variety of supply chain sectors, product categories, and retailers are highlighted. The decision to use recycled content must begin with the product development and design team and then be implemented through the sourcing of certified recycled fibers, yarns, and/or fabrics. Challenges when using recycled content include an increased cost due to the additional procession costs, limited color selection, consumer acceptance, less uniform fibers associated with mechanical recycled natural fibers, which lead to production difficulties, and an uncertain supply chain.

As the industry of the industry to a more closed-loop manufacturing model efforts to collect and process waste to be used in new products is increasing. In this chapter, recycling in the textile, apparel, and fashion industry will be explored focusing on examples of brands that are utilizing recycled content in their products.

11 Raw Materials—Fibers/Yarns

The use of recycled fibers to produce yarns that are then used in final products can be found from home textiles, to fashion items, to sportswear, and many other product categories. Cotton and polyester are probably the most common fibers

recycled, but other fibers including wool, nylon, and even aramids are being recycled in yarn production. There are many yarn manufacturers incorporating recycled content into their products. Much of the research and development revolving around this takes place in this sector (raw material) of the industry supply chain. This section will highlight several yarn manufactures and their recycling programs.

12 Unifi¹

Repreve[®] is a brand of recycled fiber that made from recycled polyester including post-consumer plastic bottles and post-industrial waste from manufacturing wastes. Using post-consumer waste offsets the need to use new resources (i.e., petroleum) and therefore, there is a reduction in the production of greenhouse gasses. Produced by Unifi, Repreve[®] is used in numerous brands including Quicksilver, Haggard Clothing, Patagonia, Roxy, Katmandu, Russell, Starter, Adidas, to name a few (Repreve 2016). Through this process, over 630 million plastic bottles have diverted from the landfill and used in fibers. There are several programs within the Repreve[®] brand including the Repreve[®] Textile Takeback Program and Repreve 100. In 2015, The Repreve Textile Takeback program, with the help of companies they partner with like The North Face, surpassed three million pounds of takeback fabric and have expanded the program into other categories including apparel, automotive, hospitality, healthcare, and contract furnishings (Beitch 2015). Jay Hertwig, Vice President of global brand sales and marketing for Unifi made the following statement: *'At Unifi, we continue to expand the process for making Repreve, engineering new ways to recycle materials throughout the supply chain. We are proud to provide our customers with sustainable solutions for recycling their own waste into new products, whether it's bottles or fabric scraps.'*

13 Tenjin

Ecocircle[®] is a fiber produced from recycled polyester. The process is a fiber-to-fiber polyester recycling system that was developed by Teijin Fibers. It is a closed-loop recycling system for polyester products and a chemical recycling processing is used. The fabrics produced from Ecocircle[®] are innovative and developed for use in the men's and women's active wear markets. In 2002 when the closed-loop recycling system began, only three companies were involved. By 2016, 150 companies are participating (Tenjin 2016).

¹“Unifi extends recycled fibre range, moves production to China and introduces verification programme”, 2009, *Advances in Textile Technology*.

14 Aquafil

Nylon 6 can also be recycled and the Econyl[®] Regeneration System was introduced in 2011 and provides opportunities for a new supply chain, which is infinite, innovative, and sustainable. In this system, the Nylon 6 polymers are produced using both post-consumer waste and preconsumer waste. Aquafil began working on the process in 1998 and they continue to expand the process by increasing the percentage of post-consumer waste collection sites for the program. Much of the post-consumer waste comes from fishing nets discarded in the ocean and the pile of used carpet (carpet fluff). They continue to increase the waste collection network and collect materials for recycling throughout the world. Currently, they have collection sites in the USA, Egypt, Pakistan, Thailand, Norway, and Turkey. Their collection strategy includes having partnerships with institutions, customers, and various consortia including Carpet America Recovery Effort. They have partnerships with brands including Levi's, Milliken, and Speedo who use the yarn in their products (Aquafil Global 2016; Econyl[®] 2016; McGregor 2015c).

15 Martex Fiber

Martex Fiber collects textile waste and supplies the textile and related industry with recycled cotton textiles. They use a 360° recycling process and provide goods for use in a variety of industries including automotive, bedding, home furnishings, construction, nonwovens, and geo-textiles (Martex Reclaimed Fiber 2016)

Jimtex yarns, a division of Martex Fiber, specializes in the production of spun yarns using reclaimed cotton fibers that can be found in home textiles, apparel, or hosiery. Their ECO2Cotton[®] is ecological and economical and produced from post-industrial waste obtained from cut-and-sew operations in apparel manufacturing. The process first requires that the post-industrial waste is sorted by color and then is defiberized. The reclaimed cotton fibers are blended with acrylic or polyester for strength. Jimtex provides yarns with 70–75 % cotton content, in a variety of colors, yarn sizes, and plys (JimTex Yarns 2014).

16 Evrnu

Evrnu uses post-consumer cotton garment waste to create a high-quality, bio-based fiber (Evrnu 2015a). After collection of the cotton garment waste, the dyes and other contaminants are removed. The cotton is then pulped and broken down into the fiber molecules. The molecules are then recombined and extruded as a new fiber. It is possible to engineer certain characteristics of the new fiber including the

diameter and cross-sectional shape. The properties include a filament that is finer than silk and stronger than cotton (Enrvu [2015b](#)).

17 EcoAlf

EcoAlf is an apparel brand that was founded in 2009 with the goal of creating fashion that is eco-friendly and sustainable. In the fall of 2015, they launched a project to use plastic waste from the ocean by collecting trash from the seabed and then reprocessing it into yarns used in fabrics. They have recycled fishing nets, plastic bottles, tires, and other wastes into jackets, shoes, and bags. To collect the waste, they have collaborated with fishing vessels in the Mediterranean Sea to ‘catch’ the plastic waste (Advanced Textiles Source [2013](#)).

In addition to waste found in the oceans, they collect other post-consumer waste, such as coffee and cotton, and post-industrial wool. EcoAlf competes in the mid- to high-end fashion market with three lines of clothing and accessories. In addition to their own retail stores, their products are sold over 300 other sites including Nordstrom, Barney’s, Urban Outfitters, Saks Fifth Avenue, Harrods, Goop, and Bloomingdales.

18 Timberland

In 2012, it was reported Camtex Fabrics, the maker of Cambrelle® shoe linings introduced fabrics with recycled content. This was at the request of Timberland for a product in their Earthkeeper shoes, boots, and clothing. The goal at that time was to develop a material that had at least 50 % recycled content. The product was polyester and the recycled content was from recycled bottles (Camtex Fabrics Ltd. [2015](#)). It was reported in April 2015 that Timberland increased the use of renewable, organic, and recycled (ROR) materials in its footwear incorporating ROR in 79 % of its offering in 2014, a 9 % increase from 2013. More than 1.25 million pounds of recycled PET was used in the branded shoes and 6.9 million featured outsoles containing up to 42 % recycled rubber. The timberland apparel lines contained 36.7 % ROR in 2013 but that dropped to 18.8 % of all materials in 2014. The primary challenge was due to cost (McGregor [2015d](#)).

19 Nike

Nike, like The North Face, views sustainability hand in hand with innovation. For a number of years, Nike has been looking for ways to reduce their environmental impact. Beginning in the early 1990s, the Reuse-A-Shoe program was introduced.

In this program, post-consumer wastes (in the form of old athletic shoes) are processed into Nike Grind and then reused in new products (Nike 2016b). In February 2010, Nike announced its fabric suppliers would source discarded plastic (PET) bottles from Japanese and Taiwanese landfill sites to produce new yarn for use in national soccer team jerseys. The jerseys for Brazil, the Netherlands, Portugal, Serbia, and Slovenia were made completely from recycled polyester. It was estimated that this project alone diverted 13 million plastic bottles from the landfill (Hayes 2011).

In most recent sustainability report that Nike released, it was reported that they continue to reduce their environmental footprint throughout the product lifecycle; one way of doing this is to close the production loop. About 60 % of the environmental impact in a pair of its shoes is embedded in the materials used. Approximately 71 % of Nike's footwear and apparel products contain recycled content and can be found in everything from trims to the flyknit shoes (McGregor 2016b). In FY15, 54 million pounds of post-industrial waste, factory scrap, were reprocessed and then used in new Nike footwear and apparel products. Nike identifies their Flyknit shoes and Nike Grind programs as their two most sustainable innovations (Nike 2016a).

20 Speedo

Speedo, a PVH Corp licensee, launched Powerflex Eco[®] in August 2015. This was a partnership with Aquafil, and Italian yarn maker. The partnership involves the collection of fabric scraps from cut-and-sew manufacturers which was then processed into the fiber Econyl[®]. Econyl[®] is a synthetic textile made using a variety of wastes including the post-industrial scraps and post-consumer waste such as abandoned fishing nets and old carpets. Powerflex Eco[®] is a combination of Econyl[®] (78 %) and extra-life nylon fabric (22 %) with chlorine-resistant pieces that retain their shape up to 10 times longer than traditional swimwear. The collection has a price range of 40–79 UDS which is like that of other similar speedo products (McGregor 2015c).

21 Adidas

In 2014, the German sportswear manufacturer announced a partnership with Parley for the Oceans, an organization that is working to eliminate plastic waste in the ocean. Initial products that Adidas created from this post-consumer waste included 3D-printed running sneakers and apparel using recycled content. Adidas developed a shoe with the upper made from yarns and filaments recycled from ocean waste (Shepherd 2016; Velasquez 2014a).

In 2015, Adidas announced a program known as Sports Infinity where the material is a 3D material that can be recycled over and over. Sports Infinity is a partnership that fosters working relationships among industry and academic experts. It is led by Adidas, funded by the European Commission, and partners include BASF, KISKA, the Center of Technical Textiles at the University of Leeds, Friedrich-Alexander Universitat Erlangen-Nürnberg in Germany and others. The Sports Infinity program will promote development of innovative processes and products that will move the industry closer to closed-loop recycling programs (Lamicella 2015).

22 Hanes

In 2010, Hanes introduced a new line, EcoSmart®. This line includes apparel items with recycled cotton and/or polyester fiber content. Products include fleece apparel, socks, polo's and t-shirts and items are available for men, women, and girls (Sustainable Brands 2010; Hanes for Good 2016). The Hanes EcoSmart® and Champion Future Friendly® apparel reuses polyester from recycled plastic bottles. Hanes owns approximately 80 % of their own production plants and from these they collect post-industrial wastes from the cut-and-sew operations. In a partnership with Martex Fiber, Jintex Yarns division, they send the collected post-industrial waste to the yarn production plant in Lincolnton Georgia and then recycled in the EcoSmart® products. The Black EcoSmart socks are made with 55 % recycled cotton fiber, which is all of the cotton used in these socks (Hanes for Good 2016).

23 H&M

H&M, the Sweedish-based fast-fashion apparel retailer, introduced two eco-collections in 2014, Conscious Collection and Conscious Exclusive. The Conscious lines are designed with more sustainable materials including organic cotton, Tencel®, hemp, and recycled components. One purpose of these lines was to show how eco-friendly garments can also be stylish and fashionable. In 2016, 2 years after the launch of the Conscious Lines, organic, recycled and Better Cotton represented 31 % of total cotton use. H&M claims to be one the biggest users of recycled polyester in the world (McGregor 2016a).

In 2013, H&M launched its in-store Garment Collecting Initiative and by 2015 they had collected 19,000 tons of discarded clothing. In 2014, they released the first products from a closed-loop system. These items were made with 20 % of recycled materials. Also in 2014, 10 new denim styles were released that contained recycled cotton fiber from the clothing collected. This supported their goal to move from linear production model to a circular one by closing the loop for textiles (McGregor 2016a).

H&M was selected to design and provide a wide range of uniforms for their home country's athletes for the 2016 Summer Olympics and Para Olympics. Items

included outfits for the opening ceremonies, closing ceremonies, and athletic competitions in between and included recycle content. Pernilla Wohlfahrt, the design and creative director at H&M stated: *'We are truly honored to also do the competition outfits for some selected sports. The result is a technical, high-fashion Olympic collection with a lot of the garments made in sustainable materials such as recycled polyester'* (Porter 2016).

24 The North Face

The North Face, a brand that is a part of VF Corporation, is a leading supplier of technically innovative outdoor gear. The North Face development team knows there is a deep connection between sustainability and innovation. A goal in improving the sustainability of their products is to use recycled materials whenever possible. In June 2011, about 15 % of total material volume was from recycled content, accounting for about \$150 million of product sold (Moore 2011).

In 2015, The North Face announced it would incorporate Unifi, Inc.'s Repreve® into its Denali line of fleece jackets. Three eco-friendly materials were integrated into the Denali jackets: (1) Repreve® recycled yarn, Repreve® WaterWise yarn with color technology, and Repreve® Textile Takeback yarn reprocessed from leftover fabric and recycled plastic bottles.

By using Repreve® fleece products, over 30 million plastic bottles are diverted from landfills and used to create Denali jackets each year. Repreve's WaterWise yarn with color technology also reduces the amount of water and chemicals needed to dye the fabric. The Denali jackets are available in black and heather gray reducing the amount of water, chemicals, and energy required in the fabric dyeing and finishing process.

Unifi and The North Face have developed another level of collaboration by collection of the post-industrial waste created during the production of the Denali Jackets. This waste is sent to Unifi's Repreve® recycling center to be processed into the Repreve® Takeback yarn. The yarn is then knitted into new Denali Jackets and so they have achieved a closed-loop system.

For every 10 Denali jackets produced, a sufficient amount of fabric scrap is collected to produce an additional four jackets.

25 Patagonia

Patagonia has several established recycling programs and actively uses recycled fiber in their products. The recycling programs are in place used for polyester, wool, and cotton. Patagonia began making recycled polyester from plastic soda bottles in 1993 and was the first outdoor clothing manufacturer to transform trash into fleece. They started using fiber-to-fiber recycling system to keep used clothing products out of the

waste stream and trash incinerators. Today, they not only used soda and water bottles, but they also collect post-industrial manufacturing waste and post-consumer worn-out garments for reprocessing and use in new apparel. They also have increased the number of products that have recycled polyester content including Capilene® baselayers, shell jackets, board shorts, and fleece. Using recycled polyester lessens the dependence on petroleum as a source of raw materials (Patagonia 2016c).

Patagonia also uses recycled wool in its wool products. To control quality, a meticulous sorting process is necessary. The materials are sorted by color prior to shredding. By selecting and blending colors of dyed wool fabrics and garments, the dyeing process would be eliminated further reducing energy, water, and chemicals (Patagonia 2016d).

Patagonia has a partnership with the TAL Group, a large garment manufacturer, where the post-industrial cotton scraps from their China and Malaysia factories are collected and then reprocessed. This cutting-room scrap gathered to fiberize it, spun into yarns that are woven or knitted into fabric, which is then used in the production of new products. The scraps from 16 virgin cotton shirts can be turned into one cotton shirt produced from reclaimed fibers.

In reality, the reclaimed fiber is combined with virgin organic cotton and used in the Men's Reclaimed Cotton Hoody and Women's Reclaimed Cotton Crew (Patagonia 2016b).

Patagonia is moving toward more and more product with recycled content. On their Web site, under the heading 'What do we Think,' it states that the '*best option at this point is to buy recycled-content fabrics and to continually find new ways to recycle our products at the end of their life and keep them out of traditional disposal methods*' (Patagonia 2016a).

26 Cone Denim

A partnership between Cone Denim and Unifi in 2014 resulted in the development and launch of a soft stretch denim, Cone Touch™. The denim is designed to provide better comfort and stretch for jeans. ConeTouch™ incorporates Unifi's Repreve® post-consumer recycled polyester content fibers and yarns. Each pair of jeans made with ConeTouch™ contains an average of eight recycled bottles (Velasquez 2014b). The Cone Touch™ products add to Cone's Sustainable™ line of eco-friendly products.

27 Levi Straus & Co

Levi Strauss & Company has several programs that incorporate recycled fibers into their products. In Levi's (2012) introduced a new collection of denim identified as Waste Less™. Each product contains a minimum of 20 % post-consumer waste.

The waste included PET plastic bottles and black food trays. They collaborated with municipal recycling programs throughout the USA to collect the waste. The Waste Less jeans are available for both men and women and each pair will have, on average, eight to 12 plastic bottles. The post-consumer waste is first sorted by color, crushed into flakes, melted, and extruded as a fiber (Green Retail Decisions 2012; Levi's 2012).

In Spring 2015, Levi Strauss & Co. and Evrnu, SPC announced that they have created a jean made from regenerated post-consumer cotton waste. The process uses a new, patent-pending recycling technology to turn discarded consumer waste into a renewable fiber. The jean is made from approximately fiber-discarded t-shirts and virgin cotton. The warp yarns are virgin cotton and the new fiber produced by Evrnu is in the filling direction. Currently, there are several prototypes of the garment and it is hoped that the new technology can be put in place on a large scale to meet the industry demand (Peters 2016).

28 Conclusion

The textile and apparel industry is moving toward a circular economy and closed-loop manufacturing. To achieve this, one feasible method is the use of recycled materials in textile and apparel products. The future of recycling relies heavily on the development of new advanced technologies and approaches for material processing (without quality loss), collection, sorting, processing, and utilization in a new product that is also recyclable. Creating a demand for new products with recycled content is critical. It is important to include the recycled content in the design and product development stages of fashion and home products but there is also a need to encourage flows that promote recycling and reuse.

Sarah Ditty, Deputy Editor of Source Intelligence, believes there are four reasons that companies are using recycled materials: (1) driven by media scrutiny; (2) consumer demands; (3) cost; and (4) resource scarcity. *'Big companies know they have to be inventive and innovative to survive, but their supply chains are so complex it takes a lot of time and money to implement new systems,' she says. 'It's slow moving and a long journey, but we're on the right tracks'* (Rivera 2013).

There are many challenges and opportunities facing the industry with regard to environmental sustainability. Partnerships and collaboration will be critical to successfully addressing these developing efficient, cost-effective, and closed-loop recycling programs. Levi Strauss believes *'competition and collaboration must go hand in hand to push progress in the industry'* (Sustainable Apparel Collation 2016).

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