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**Review Article**

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# Perspectives of Textile Waste Management in the U.S. – A Review

**Ishmam Zahin Chowdhury, Sumit Mandal*, Anna Bazhaw-Hyscher, Libby Rodriguez, Aliyah England, Moriah Moody, Maddie Taylor and Brin Hague**

*Department of Design, Housing and Merchandising, Oklahoma State University, USA*

***Corresponding author:** Dr. Sumit Mandal, Department of Design, Housing, and Merchandising, Oklahoma State University, USA.

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## Abstract

In the last 30 years, global consumption of textile articles has increased significantly. Population increase along with the booming of fast fashion trends are facilitating the growth of global textile consumption. The current pandemic situation is raising the consumption of protective clothing. Such scenarios are diminishing the lifecycle of textile products significantly. Consequently, the world has observed a considerable increase in textile waste generation in recent years and is predicted to increase even more in the coming years due to the current consumption trends. Despite being highly recyclable, much of such wastes go into open dumps or landfills. The U.S. has also seen an increase in textile waste generation, and most of the wastes is landfilled. Disposing of such a huge waste stream can be identified as mismanagement due to its impact on the environment, society, and corresponding footprints. To counter the impact of the rising textile wastages, it is necessary to address sustainable approaches via a structured textile waste management system. This review aims to observe the textile waste scenarios based on the U.S.'s perspectives. An overall aspect of textile waste generation has been presented briefly while considering the current circumstances in the U.S. Current trends of textile waste management in the U.S. have been discussed while mentioning other available options in waste management. Lastly, this review has proposed some probable study directions that would facilitate establishing efficient textile waste management across the U.S.

**Keywords:** Fast fashion; Municipal solid waste; Textile waste; Wastewater; Waste management; Recycle; Reuse; Production wastages; Pre-consumer textile wastages; Post-consumer textile wastages

**Abbreviation:** EPA- Environmental Protection Agency; ISO - International Organization for Standardization; COD- Chemical oxygen demand; CFR-Code of Federal Regulations; NPDES- National Pollutant Discharge Elimination System; POTW- Publicly Owned Yreatment Works; PFAS- Per- and Polyfluoroalkyl Substances; PPE- Personal Protective Equipment

## Introduction

Global consumption of textile products has been doubled in the last two decades due to the increased population and introduction of fast fashion [1-3]. In North America, the average trend of textile consumption in a year is 37 kg per person which is more significant than in Australia (27 Kg) and western Europe (22 Kg) [1,3]. With increased textile consumption, production, pre-consumer, and post-consumer textile waste is also growing. Each year Americans generate around 16 million tons of textile waste, which makes up around 6% of overall municipal waste [2]. The introduction of the circular textile economy (fabrication-utilization-recycling/reuse) is encouraging the recycling of such textile waste. Recent statistics show that 700,000 tons of the waste are exported overseas, whereas 2.5 million are recycled [2]. However, the prevailing traditional linear model of the textile economy (fabrication-utilization-disposal) still contributes to more than 3 million tons of incinerated apparel and 10 million tons of textile landfills [2,4]. Such a discrepancy in the disposed and recycled textile waste quantity is a genuine concern to be addressed to achieve a sustainable future.

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Due to the rising concern towards a sustainable future, the recycling of textile products has increased steadily over the last six decades [5]. However, the percentage of recycled clothing is less than 1%, whereas the amount sent to landfills has quintupled over the years [5]. The data summarizes that most unwanted clothing in the U.S. is still preferred to be left in the environment rather than recycled or reused.

The current trend in the predominant linear model of the textile economy is generating more waste due to the introduction of fast fashion, lack of government regulations, uninformed consumers, and throwaway culture. The lifecycle of the textile product is much less than at any other time in the previous era. Overconsumption of textile products is becoming more prominent due to the fast-fashion trends [6]. Fast fashion, the quick response to the everchanging consumer fashion demands by the fashion retailing house, generates new fashion trends within a very short period. As a result, the current fashion trends are becoming obsolete within a very short time. The previous long fashion cycles are becoming short cycles of transient fashion trends. Each trend creates its own sets of wastage throughout the fashion cycle: production wastes, pre-consumer wastes, and post-consumer wastes. Production wastes from the apparel manufacturing steps, unsold or damaged products at the pre-consumer stage, and worn-out, out-of-fashion products at the post-consumer stage are the sources of such textile wastes. The textile wastes are increasing in quantity with the throwaway tendency of the fast-fashion consumers. Increased population and lack of government regulations of waste apparel disposal are contributing to increasing the wastes even more. Steps to control the increasing textile wastages are essential to adopt early to have a smaller environmental footprint generated through the fashion industry. Reuse or recyclability provides a better sustainable approach to managing the increasing textile wastes.

According to the data provided by the U.S. Environmental Protection Agency (EPA), textile wastes contributed about 6% of the total municipal solid wastes in 2018 [5]. Around 14% of the textile wastes were recycled, where almost 71% went to landfills for disposal. Another 15% were utilized in energy recovery by incineration with other solid wastes. Only about 4% of recycled solid wastes are from textile sources, even though textile products have almost 100% recyclability [5,7]. The data shows that sustainable waste management of textile waste needs to be explored thoroughly. In the U.S., to counter the impacts of overconsumption of textiles and frequent changes in fashion trends, recycling or reusing textile wastes will save resources and minimize environmental change. This review aims to evaluate the current sustainable approaches adopted by the U.S. in textile waste management. The article explores the textile reuse/ recycle trends in the U.S. Understanding the present scenario of textile waste management in the U.S. will enable the development of more sustainable approaches to reduce the impact of increasing textile waste on the environment.

## Textile Waste Scenario in the U.S

With the enhancement of the living standards of the increased global population, apparel consumption also rises worldwide. In developed and developing countries, fashion industries now simulate the idea of new fashion trends for each season [8]. As a result, the fashion diffusion curve is becoming transient for each style, sustaining only one season. Like the mass adoption of each style, the obsoletion of each trend is becoming more rapid in frequency. As a result, the apparel production cycles are becoming shorter- increasing the production rates significantly to support the increased demands of transient fashion trends. The textile industry generates production waste throughout the manufacturing processes, affecting the environment. Moreover, the apparel product lifecycle generates textile waste in pre- and post-consumer stages. Unutilized and thrown-out textile products can be identified as pre- and post-consumer textile wastes.

Depending on the apparel's manufacturing process, the production wastes could be of many types [6,9]. The production-waste generation continues throughout the apparel production, including raw materials such as cotton, yarn. Water, chemicals used in the fiber, yarn, and fabric treatment contribute to the textile production waste. Cellulose fiber such as cotton, protein fiber such as wool, or synthetic fiber such as nylon requires different chemical and physical treatments. The wastes generated from these treatments could be identified as wastewater containing the discarded water with chemicals, pesticides, insecticides, or fertilizers [10]. Wastewater composition from fiber production includes pesticides, fertilizers, scouring agents (natural fibers), and petroleum oil, pigment, dyes (synthetic fiber) [10]. Yarn to fabric production generates chemical wastes from sizing chemicals, lubricants, bleaching agents, mercerizing agents, de-sizing chemicals, oxidative agents, dyes, pigments, and other chemicals for additional functional properties: fire retardancy, antibacterial properties, or water-resistance [10]. Solid wastes from the production process include spinning waste, fabric cutoffs, fabric roll ends, fabric defects, woven and knit cutting waste [6,11,12]. The utilization of production waste has its importance in the U.S. However, in recent years, textile and apparel production has shifted significantly from the U.S. Compared to 2009, textile manufacturing dropped from $18.79 billion to $9.5 billion in 2019 [13]. Approximately 98% of the apparel is imported [2]. So, in the U.S., the priority on production waste utilization has shifted to post-consumer waste management [14]. A change in textile production has been observed recently where special fabrics such as protective clothing, medical textile, nonwoven contributed to more than 34% of the U.S. textile export in 2021 [13]. Also, the U.S. is one of the leading exporters of cotton supporting 35% of the global cotton demands [15]. So, production waste management still needs to be monitored to counter the risk of such waste.

Pre-consumer wastes are unsold or damaged retail products yielded from design mistakes, fabric faults, wrong color production, or fail-to-sale products [12,16]. A general estimation is that 70% of the apparel production is sold, leaving 30% unsold stock [17]. In actual practices, this type of waste is mainly utilized by nonprofit organizations in donation, manufacturers in recycling the source materials, and retailers in other markets via consolidators or jobbers. So, these wastes are not actually unutilized or thrown out. Only a very small portion of pre-consumer waste is thrown out to landfills by retailers [18]. About 65% of the initial input of the global textile supply chain can flow through clothing manufacturers to the consumers as the final products, whereas 35% of the input turns into textile wastes in the production and pre-consumer stages [4].

Wastes from the post-consumer stage generate from the utilized textile materials, which lost their utility to the consumer and deiced to be thrown out. Consumers decide to throw out the textile articles when they are worn out, damaged, outgrown, or become outdated [6]. As in most cases, throwing out of the articles means accumulating new products or vice versa; the post-consumer waste amount can be comparable to the fiber consumption rate of textile production [9]. So, it can be inferred that the amount of post-consumer waste is similar to the production and pre-consumer waste amount [9]. Every year the amount of thrown-away textile is around 30 kg per person [19]. Though the reusability of such products is high, most of such wastes either go into municipal waste or are incinerated. In the U.S., thrown out post-consumer waste utilized in the landfills amounted to around 10.5 million tons per year, surpassing 350,000 tons in the U.K. and 287,000 tons in Turkey [4]. In 2019, post-consumer textile waste generated around 16.89 million tons of waste, covering approximately 6.3% of municipal solid waste [20]. Among these 16.89 million tons of waste, about 16.05 million tons (95%) were suitable for recycling [21]. However, only 2.57 million tons were subjected to be recycled, leaving most of the parts to be utilized in combustion and landfills [21]. In the socio-economic aspects of the U.S., the determinants of post-consumer waste amount generation are income range, education, accessibility to clothing stores, and residential segregation [22-24]. People living in higher accessibility of education and high-income areas generate more textile waste than people living in other regions [22,25]. High racially segregated regions and more accessible clothing stores also positively impact waste generation [22]. Such determinants highlight the apparel overconsumption tendency resulting from fast fashion.

'Fast Fashion' can be defined as the quick response of fashion retailers to the everchanging consumer demands [6]. In such a retail model, the products reach customers within a few weeks from the product development stage. In contrast to the traditional six months production timeline, popular clothing retailers are now adopting a 3-9-week production timeline [6]. As a result, fast fashion trends are currently generating about 52 micro-seasons dedicated to specific styles per year. In contrast, there were only four seasons in the traditional fashion cycle (pre-fall, fall, pre-spring, spring/ summer) [26]. For example, leading fast-fashion retailer 'Zara' generates around 12,000 styles per year [6]. Low-quality textile products are used to generate the sale inventory to support the high pace of bulk production while considering cost reduction and profit maximization [27]. Such poor material choice and low price encourage consumers to discard the previous textile article and acquire new trends [28, 29]. As a result, overconsumption and thrown-away culture generated from fast fashion is now contributing to a significant amount of post-consumer waste in the U.S. Pre-consumer and production wastes are also increasing globally due to the high production rate and fast fashion market share.

## Impacts of Textile Wastes

The environmental and societal issues surrounding textile wastes begin at the very beginning of the textile supply chain. Production and utilization of textile articles generate waste throughout the production, pre-consumption, and post-consumption stages. With the increase in apparel consumption, the wastes generated from this sector are affecting the global environment and resource management. As there are no structured waste disposal procedures to address the textile wastes, such wastage points out the inefficient global resource management, affecting the environmental and social footprint. Due to the increased apparel consumption, textile wastes are now affecting the environment and the socio-economic aspects of surrounding communities more drastically than before.

The apparel production process impacts the environment through water usage, carbon or greenhouse gas emission, and energy consumption. Followed by the oil and petroleum industry, the textile manufacturing industry is the 2nd most polluting sector around the globe, responsible for 20% of the total carbon emission around the world [2,21]. If the current growth of the textile sector persists, it will be responsible for 26% of the global carbon budget by the end of 2050. By 2050, the textile sector will be utilizing 300 million tons of nonrenewable raw material, where 22 million microplastics will be released to the ocean [29].

At the preliminary stages of textile production, a large amount of water, fertilizer, pesticides, and other chemicals are used for fiber sourcing. The chemical treatments vary throughout the manufacturing process depending on the fiber types (natural, regenerated, and synthetic). A greater portion (around 63%) of consumed textile fibers comes from petrochemical or synthetic polymer sources. Synthetic fibers production requires many chemicals, and the process absorbs more energy than natural fiber production, consequently raising the global $CO2$ emissions [30,31]. Cotton is the most widely used natural fiber. It takes around 5,300 gallons of water to produce just 2 pounds of cotton [2,32]. Global cotton production single-handedly utilizes 44% of the total water usage [32]. In addition to this, the high rise of apparel consumption leads to increased demand for textile fibers. More cotton farms are being established by sacrificing forests to yield high cotton production. Every year around 70 million trees are being cut down to support the increased demand for textile products [2]. Chemical fertilizers, pesticides, and irrigation techniques are being utilized to increase the cotton farms' yield. Therefore, soil infertility, desertification, and water pollution are observed in the surrounding areas [2,33]. A prominent example of such could be the Aral Sea in Central Asia. The Aral Sea has been completely drained and dried up largely due to cotton production and has caused many problems for surrounding communities [2]. Supporting the commercial production of protein fibers from animals (wool, angora, cashmere) requires large grazing fields, significantly impacting land erosion and carbon emissions [34].

The later stages of textile production contribute to environmental pollution even more. At the dyeing, washing, and drying phases of textiles production, a huge amount of wastewater generates, containing different dyes and chemicals [35]. The wash phases of synthetic textiles also generate microplastics that pollute water and food [36]. The energy consumption and corresponding carbon emissions of the fabric and apparel production process are also huge for the application of highly efficient industrial machines [37,38]. Washing of one jeans pair could release carbon quantity equivalent to driving 69 miles [3].

Pre- and post-consumer wastes thrown out as landfills or open-air dumps also severely impact the environment [39]. Accumulation of landfill sites destroys natural habitats for the animals [40]. Decomposition of post-consumer wastes releases greenhouse gases such as methane, CO2, and chemical leachates. In the case of open-air dumping, the probability of chemical leachates escaping into waterways is high, which significantly affects human and animal health [41-43]. Such scenarios are much more common in developing and underdeveloped countries as often they don't have advanced municipal waste management systems [44].

With the introduction of "Fast fashion," overconsumption and throwaway culture are now prevailing. To meet the high demands of the new fashion products, retailers often ignore the manufacturers' production capability. To meet the retailers' supply demands, manufacturers often disregard the workers' needs. Workers at the manufacturing end are often exposed to chemicals, fiber dust, and noise. Long working hours in those environments with repetitive working steps affect the mental and physical state of the workers [45]. Low payment rates, child labor, are also not uncommon in the global textile supply chain [3]. Though top retailers often conduct audits to ensure work and environmental safety at the manufacturing ends, the presence of the production subcontractors often remains outside of the audit purview [4]. For high production demand, manufacturers often have to employ subcontracting agencies, who often ignore basic workers' rights [4]. Aside from these, the dumping sites of the textile wastes are often placed near underdeveloped regions, marking the environmental injustice as throwaway culture predominantly persists among highly educated and well-to-do communities [22].

The wastes generated from different steps of the global textile supply chain and after consumerism affect the world environment. In the global textile supply chain, the U.S. is one of the primary suppliers of raw materials like cotton, synthetic fibers. Commercial apparel production is not primarily based in the U.S., and most of the consumed textile products are imported. However, the U.S. is one of the leading manufacturers of functional clothing like protective clothing, medical textiles, and smart textiles. The U.S. textile exports have seen a 14% growth from 2010 to 2019 in special fabrics and yarns [13]. Production processes of such special textile products need to be monitored to categorize the waste generated. Consumption of imported textile products has also been increased due to the introduction of 'Fast fashion.' 'Fast fashion' associated high production rate is sacrificing the material quality, resulting in poor aging of textile articles. As a result, the U.S. has seen a 100% increase in the amount of thrown-away clothing in the last 20 years [46]. Most of such wastes find their way to landfills. Addressing such an increasing quantity with 'Reuse' or 'Recycle' will reduce the post-consumer textile waste and the supply-demand. As a result, the textile industries' impact on the global environmental footprint can be controlled with higher efficiency. Such an approach marks the 'Circular textile economy,' contributing to control the resource management of the global textile supply chain. An integrative approach by fashion retailers, manufacturers, government, and consumers will surely minimize textile waste's environmental and societal impact [4]. A structured textile waste management system adopted by the U.S. will solve the municipal solid waste problem and contribute to forming the sustainable global textile supply chain.

## Textile Waste Management

The 'Environmental Management System' (EMS) has been introduced to promote sustainability in the textile supply chain [47,48]. ISO 14000 has been proposed to set up the rules and standards identifying the degree of the textile industry's impact on the environment [10]. To control the environmental impact of textile waste, 'Waste management' has been incorporated in the EMS. 'Waste Management' refers to the steps taken to minimize waste generation. 'Textile Waste Management' aims to reduce waste generation, control environmental impact, and minimize resource input by promoting 'Recycle' or 'Reuse' in the textile products' lifecycle (production, pre-consumer, and post-consumer) [10,49]. Textile wastes can be categorized into wastewater and solid waste based on their physical attributes. Wastewater is the effluent of the textile production processes, whereas solid wastes are the fiber, yarn, fabric, and apparel wastes thrown out in production, pre-consumer, and post-consumer stages [10]. So, 'Textile Waste Management' can be classified as wastewater management and solid waste management.

## Wastewater management

Wastewater contains washed-away chemicals of textile production processes, oil, grease, and other particulate matters. Wastewater management refers to treating the effluents to reduce the chemical concentration and remove harmful substances before disposal to control the environmental impact. Treatment of the effluents could be categorized into physical, chemical, and biological processes [10]. Physical treatments are adopted to remove floating, suspended particulates from the wastewater. Such treatments refer to the utilization of screened filters of different fineness to filter out the particles. Mechanical flocculation and membrane filtration can also be adopted in the physical treatments of wastewater. Mechanical flocculation utilizes mechanical stirring to generate the floc of small, suspended particles. Membrane filtration can also remove some dyes along with the particles but is not economical due to the clogging and displacement risk of the membranes. Aside from the mentioned treatments, treatment via electron beam radiation has been seen to reduce the COD value of the wastewater [10,50]. Chemical treatments aim to adjust the pH value of the wastewater, reduce the COD, and decolorize it. Discoloration of the textile wastewater is achieved by adding neutralizing agents of multivalent cations and coagulation/ flocculation agents to separate the suspended particles. Ozonation, Fenton reaction (hydrogen peroxide and ferrous ion treatment) neutralizes toxic chemicals where chemicals like Aluminum sulfate, Poly-aluminum chloride, and poly-ferrous sulfate are used as coagulation/ flocculation agents [10,51-54]. Biological treatment is another alternative to treat wastewater and could be used in combination after physical and chemical treatments. Biological treatments help remove finishing agents and dye substances from the wastewater. Enzymes or microorganism cells are used in biological treatments. In the case of fungal treatment (Pleurotus ostreatus, Gloeophyllum odoratum, and Fusarium oxysporum), monoculture shows better results than co-culture treatment in dye removal [55]. Application of enzymes such as Lacasse can also be found efficient to remove certain types of dyes [56,57]. Mild operating conditions, larger space, and longer time to process wastewater make biological treatment a less favorable option for wastewater treatment [58]. The utilization of biodegradable materials (mangrove bark as dyes, bee wax, enzyme, and aloe vera as finishing agents), less harmful chemical agents ($H_2O_2/O_3$ instead of chlorine bleaching agents) in the textile production process will reduce the detrimental impact of wastewater effluents. Such an approach marks the prevention of harmful waste generation [59-62]. Aside from previously mentioned treatments, textile wastewater could yield value-added products such as biogas and biohydrogen. Studies have found that biogas generation effectively reduces COD value in wastewater [63-65]. Gasification of textile wastewater could be utilized to yield synthetic gases, which could be applied to generate electricity [66,67].

## Solid waste management

With the increase in textile product consumption, solid waste from textile sources is also increased significantly in the last 20 years. With the conventional textile solid wastes handling systems, most of the wastes found their way into the municipal solid waste stream. Due to the lack of suitable facilities to manage the huge municipal waste stream, many such wastes are used as landfills or incinerated. Solid waste management aims to optimize waste generation or waste utilization via reuse, recycling, and energy recovery to counter the impact of the increasing textile consumption on solid waste generation. Textile Solid waste management could be categorized into the disposal, energy recovery, recycling, reuse, and prevention, arranged from least environment-friendly to best [6]. Conventional textile solid waste management refers to the disposal of textile wastes which mostly go to the landfills. Increased municipal solid wastes mark the lack of proper waste management facilities, expanded landfill sites to dispose of the increased share. In the landfills, synthetic solid wastes do not decompose, while the organic (wastes generated from natural or regenerated fiber products) wastes decompose but yield $CH_4$ and $CO_2$ [6]. Energy recovery refers to generating energy by incineration, gasification, or anaerobic digestion of textile wastes. Incineration takes up almost 90% of the textile wastes to generate flue gases ($CO_2$, $H_2O$, $O_2$, $N_2$), which can be utilized as fuel energy [68]. Though the incineration process generates harmful gases and leaves burnout wastes, emission control, energy recovery, and suitable facilities to discard the wastes can impart sustainability [68]. Gasification refers to the partial oxidation of organic compounds at higher temperatures (500 °C- 1800 °C) [68]. With the application of combined cycle gas turbines, such a process has higher efficiency in generating electric energy due to better thermal energy optimization [67]. Anaerobic digestion utilizes microorganisms to convert the organic wastes into biogas which could be utilized in green energy production. The residuals of such treatment could be used as fertilizer also [69,70]. Recycling means reprocessing the textile wastes into another useful material via combined operation of sorting, separation, and processing [71]. Textile solid wastes could be turned into raw materials of production processes or value-added end products, called downcycling and upcycling, respectively [6]. Recycling processes can be categorized into mechanical, chemical, thermal, and combined recycling processes [6]. Mechanical recycling shreds the textile waste items previously sorted based on color and quality [72]. Resultant shredded wastes can be converted to yarn or fibers, can be used as insulative materials, raw materials of nonwovens manufacturing, filling materials for mattress or upholstery, carpet underlays, or disposable diapers/napkins [6,72-74]. Chemical recycling is best suited for synthetic fiber wastes. Wastes from synthetic textiles can be converted into new yarn or fabricated into new woven, knitted, nonwoven, and composite products via chemical processes like polymer-depolymerization [75]. Other applications of such recycled synthetic fibers include household items, automobile carpeting, sound absorption materials, insulation materials, and toys [6,75]. Thermal recycling mainly refers to the pyrolysis of textile wastes. Textile wastes can be converted into synthetic fibers generating byproducts like CH4, H2, CO2 [6]. Based on the fiber resin, the pyrolysis temperature could vary between 450 °C and 700 °C. Synthetic fibers yielded by such a process can sometimes result in high-valued carbon activated fibers due to the resin carbonization [76]. Reuse means reutilization of the textile article for the same purpose it has been conceived [77]. Instead of throwing out, reusing a textile product will generate less waste throughout the whole textile supply chain. Reusing the article minimizes the products' environmental footprint. Reusing 1 kg of textile products saves 6000 L of water, 3.6 kg less CO2 production, 0.3 kg of chemical fertilizer, and 0.2 kg less pesticide utilization [78]. So, the reuse of a textile product contributes to less waste generation, minimizes energy utilization in that products' supply chain. Textile articles can be sold as secondhand clothing, cleaning cloths, or as vintage fashion articles after proper collection and sorting based on their conditions and antiquity [71]. Prevention refers to promoting awareness against waste generation. In the present 'Fast fashion' era, consumers, retailers, and manufacturers should be informed how textile wastes are affecting the environment and society. Building awareness will encourage the reuse of textile products, recycling the thrown-out articles, and facilitating the proper collection, sorting, and processing of textile wastes even at the consumer level [6,79].

## Textile waste management reality in the U.S

Regarding the textile mill effluent or wastewater management, the U.S. Environmental Protection Agency (EPA) complies with the limitation guidelines and standards listed in chapter 40 of the U.S. Code of Federal Regulations contained in part 410 (40 CFR part 410) [80,81]. Based on the regulations, EPA adopted the National Pollutant Discharge Elimination System (NPDES)- a permit program to regulate the guidelines and standards of '40 CFR part 410' [81,82]. Most textile mills utilize publicly owned treatment works (POTWs) to treat the wastewater. More than 14,000 POTW facilities are currently operating across the U.S. [83]. Such wastewater is generally discarded into the POTW without any prior pretreatments. As a result, POTWs have developed their local limit of essential pollution parameters to check whether the wastewater discharge adequately follows NDPES compliance [84]. EPA biennially publishes Effluent Guidelines Program Plan to review the guidelines and standards. In the recently released Preliminary Effluent Guidelines Program Plan 15 (September 2021), EPA has announced to conduct a study of per- and polyfluoroalkyl substances (PFAS) discharge from landfill and textile manufacturers [85]. According to EPA, most textile mills currently are not being monitored in terms of PFAS discharge [80].

The U.S. Environmental Protection Agency (EPA) published data regarding textile solid waste management in the U.S. [5]. Available data measures the municipal textile solid waste generation, amount of textile wastes used in landfills, energy recovery, and recycling purposes. It can be seen that after the booming of fast fashion in the 90s, textile waste generation has increased. Even though textile waste recycling has increased, landfill remains the prevalent method of textile waste management. On average, the U.S. generates approximately 16 million tons of textile waste per year, recycles only 15% of the wastes leaving almost 65% in the landfills [5]. EPA estimates that textile wastes cover approximately 5% of all the landfill space in the U.S [5]. Even though 95% of the textile wastes are recyclable, landfill is still the preferred option for textile solid waste management [21]. The challenges of textile recycling are largely relevant to the quality and characteristics of textile wastes. The utilization of solid textile wastes depends on the efficient sorting of the wastes [86]. Proper sorting and separation of the wastes based on the fiber/yarn types, colors, and apparel systems determine the recycling process or reusability. The absence of a structured textile waste collection system makes the sorting and separation process harder, given the increasing quantity of municipal solid waste. The lack of identified end-users of recycled textile raw materials impedes promoting commercial incentives for textile recycling [86]. The following waste generation data only considered the thrown-out textiles, leaving the reused textile products (Table 1).

**Table 1**: Textile solid waste management data (in millions of U.S. tons) [5].

| Management Pathway | Year | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1970 | 1980 | 1990 | 2000 | 2005 | 2010 | 2015 | 2017 | 2018 |
| Total municipal solid waste | 121.1 | 151.6 | 208.3 | 243.5 | 253.7 | 251.1 | 262.1 | 268.7 | 292.4 |
| Total textile solid waste | 2.04 | 2.53 | 5.81 | 9.48 | 11.51 | 13.22 | 16.06 | 16.89 | 17.03 |
| Recycled amount of textile wastages | 0.06 | 0.16 | 0.66 | 1.32 | 1.83 | 2.05 | 2.46 | 2.57 | 2.51 |
| Energy Recovery | 0.1 | 0.5 | 0.88 | 1.88 | 2.11 | 2.27 | 3.06 | 3.17 | 3.22 |
| Landfilled | 1.97 | 2.32 | 4.27 | 6.28 | 7.57 | 8.9 | 10.54 | 11.15 | 11.3 |

The textile resale market has seen growth in recent years in the U.S., much similar to the global market. In 2019 the global secondhand clothing market share was $28 billion [87]. Whereas, in 2018, it was $24 billion, and in 2017 it was $20 billion [87]. In 2020, the market share decreased to a value of $27 billion due to the pandemic compared to 2019. However, observing the current trends in 2021, it has been predicted that the value will rise to $77 billion in the next three years [87]. The monthly domestic secondhand retail sales are more than $1.25 billion on average, where the predominant buying trend is preowned clothing [87]. The U.S. is also one of the leading exporters of secondhand clothing. In 2019, the U.S. trade value of exported secondhand clothing was approximately $737.7 million, which is expected to rise due to the increasing global demand for reused textile products [87]. The reuse and resale of textile articles are currently increasing due to the build-up of sustainability awareness. The pandemic-affected economic condition is also encouraging the reuse tendency as less than 3% of the household budget now goes into buying clothes [87].

The change in the waste generation scenario in the current pandemic situation is also needed to be considered. The utilization of personal protective equipment has become the norm in the high propagation stages of covid-19. As a result, the production and utilization of face masks, gloves, protective suits, safety boots have substantially increased- most of which are of limited usage and thrown out after single or several usages. Such waste sources have a high potential to exacerbate the solid waste management system. Moreover, most of the PPEs (Personal Protective Equipment) are made of synthetic fibers such as polypropylene, polystyrene, polycarbonate, polyethylene, or polyester [88]. Mismanagement of the thrown-out PPEs results in such wastes being in landfills or seas [89]. During 2020-2021, total mismanaged plastic waste amounted to 8.4 million metric tons around the globe- 6% of which came from North America [90]. PPEs have contributed to 7.6% of the total mismanaged waste- amounted to approximately 0.64 million metric tons [90]. PPE production also includes specific chemical processes based on the service and materials. So, the production process of PPEs could have significant impacts on the textile effluent composition. The dynamics of textile waste generation can change due to the high disposal rate of PPEs. So, it is necessary to address the impact of Covid-19 on textile waste generation to create a fruitful waste management structure.

## Conclusion

The dynamics of textile consumption is changing due to the fast-fashion trends and ongoing pandemic situation- contributing to making the textile products' lifecycle shorter. As a result, global textile waste generation has also increased significantly. Being one of the leading importers of textile finished products and exporter of textile raw materials, the U.S. is also currently observing a higher rate of textile waste generation. The increased amount of textile waste has seen to impact the environmental condition and social lives around the textile supply chain entities. To counter the negative impacts, it is necessary to address textile waste management in a sustainable way. Such management has two dimensions- wastewater management and solid waste management. Federal regulations exist for wastewater treatment, but textile solid waste management still remains voluntary. Solid waste management largely depends on the effective collection, separation, and processing of the waste stream- making it difficult to approach the recycling and reuse of textile products. A structured waste management system will facilitate such sorting/ collection procedures and reduce the amount of solid waste disposed to landfills. A comprehensive waste management system will also consider wastewater treatment- generated from the textile supply chain. To establish an effective textile waste management structure in the present condition, the followings are some of the current concerns needed to be considered by the U.S.

- Detailed studies regarding the wastewater composition discharged from the functional textile production plant are needed to be performed. Functional clothing such as PPEs' production process needed to be monitored to identify the discharged wastewater composition. As wastewater is being treated in POTW facilities, wastewater pretreatment requirements before discharging to POTW need to be inspected.

- It is necessary to consider the viability of imposing recycling mandates at local and state levels to establish an effective textile waste management system, considering the current transient lifecycles of textile products (PPEs, face masks, fast fashion articles).

- Studies are required to establish smooth and effective transitions of textile solid waste materials from consumer, retailer, and producer to the recycler. To facilitate the preprocesses (sorting, separation, collection) of recycling, an effective waste collection, and management structure needed to be developed. Applicability of developing a clothing labeling system to communicate recycling instructions to the consumer needed to be explored.

- Production capacity of the recycled textile raw materials needs to be expanded to establish the recycling facilities as constant and convenient suppliers to the manufacturers. Such relevant studies will promote the utilization of recycled textile raw materials.

- Viability of multiple uses of PPEs and face masks should be investigated. In this regard , the efficiency of sanitization techniques such as UV exposure and washing should be studied to promote the reuse of PPEs. Specific fabric coating or utilization of specific synthetic threads could potentially impart reusability to the PPEs.

- Market study regarding secondhand and vintage clothing can promote the reuse of textile products. If the leading retailers find it economically profitable as per their business policy, a circular model of the textile economy can be easily established.

It can be said that textile waste management does not only minimizes the generation of wastes but also optimizes the environmental and social footprint. In the present day, sustainability is not an option but rather a necessity. Given the high consumption of textiles in the U.S., an effective textile waste management system also has the potential to turn into a revenue-generating industry.

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## Conflict of Interest

Authors declare no conflict of interest.

## References

1. Milburn J (2016) Aussies send 85% of textiles to landfill. Textile Beat: 18.
2. Charpail M (2017) What's wrong with the fashion industry?
3. Shirvanimoghaddam K, Motamed B, Ramakrishna S, Naebe M (2020) Death by waste: Fashion and textile circular economy case. Science of The Total Environment 718: 137317.
4. Karaosman H, Brun A, Morales-Alonso G (2017) Vogue or vague: sustainability performance appraisal in luxury fashion supply chains, in Sustainable management of luxury. Springer: 301-330.
5. EPA (2020) Textiles: Material-Specific Data.
6. Yalcin-Enis I, Kucukali-Ozturk M, Sezgin H (2019) Risks and management of textile waste, in Nanoscience and Biotechnology for Environmental Applications. Nanoscience and Biotechnology for Environmental Applications: 29-53.
7. Hawley JM (2006) Textile recycling: A systems perspective, in Recycling in textiles. Woodhead Publishing Limited, UK.
8. Fletcher K (2008) Sustainable fashion and textiles: design journeys, Earthscan. London, Sterling: 13.
9. Wang Y (2010) Fiber and textile waste utilization. Waste and biomass valorization 1(1): 135-143.
10. Pensupa N, Leu SY, Hu Y, Du C, Liu H, et al (2017) Recent trends in sustainable textile waste recycling methods: Current situation and future prospects. Chemistry and Chemical Technologies in Waste Valorization: 189-228.
11. Patti A, Cicala G, Acierno D (2021) Eco-Sustainability of the Textile Production: Waste Recovery and Current Recycling in the Composites World. Polymers 13(1): 134.
12. Gardetti MA, Torres AL (2017) Sustainability in fashion and textiles: values, design, production and consumption. Routledge.
13. Lu S (2021) State of U.S. Textile and Apparel Manufacturing: Output, Employment, and Trade.
14. Altun Ş (2016) Recycling of Textile Production and Usage Wastes, Environmental and Economic Effects; Uşak Chamber of Commerce and Industry Report. Uşak Chamber of Commerce and Industry, Uşak,
15. USDA (2021) Cotton Sector at a Glance. Economic Research Service 2020
16. Ekström KM (2014) Waste management and sustainable consumption: reflections on consumer waste. Routledge.
17. Mui Y (2010) Consumer complaints have companies rethinking how to dispose of unsold inventory. Washington Post A: 8.
18. Domina T, Koch K (1997) The textile waste lifecycle. Clothing and Textiles Research Journal 15(2): 96-102.
19. Claudio L (2007) Waste couture: Environmental impact of the clothing industry. National Institute of Environmental Health Sciences.
20. (2019) Agency UEP Advancing sustainable materials management: 2017 fact sheet. United States Environmental Protection Agency, Office of Land and Emergency.
21. Lei M (2021) Wasted Traces/Wasted Spaces: Deploying Pre-Consumer Textile Waste to Activate Vacant Storefronts for Transitional Homeless Housing. Pratt Institute, USA.
22. DeVoy JE, Congiusta E, Lundberg DJ, Findeisen S, Bhattacharya S (2021) Post-Consumer textile waste and disposal: Differences by socioeconomic, demographic, and retail factors. Waste Management 136: 303-309.
23. Medina M (1997) The effect of income on municipal solid waste generation rates for countries of varying levels of economic development: a model. Journal of Solid Waste Technology and Management 24(3).
24. Bartelings H, Sterner T (1999) Household waste management in a Swedish municipality: determinants of waste disposal, recycling and composting. Environmental and resource economics 13(4): 473-491.
25. Daneshvary N, Daneshvary R, Schwer RK (1998) Solid-waste recycling behavior and support for curbside textile recycling. Environment and Behavior 30(2): 144-161.
26. Stanton A (2021) What Is Fast Fashion, Anyway?
27. Morgan LR, Birtwistle G (2009) An investigation of young fashion consumers' disposal habits. International journal of consumer studies 33(2): 190-198.
28. Norum PS (2017) Towards sustainable clothing disposition: Exploring the consumer choice to use trash as a disposal option. Sustainability 9(7): 1187.
29. Ütebay B, Çelik P, Çay A (2020) Textile wastes: Status and perspectives, in Waste in Textile and Leather Sectors. IntechOpen.
30. Stone C, Windsor FM, Munday M, Durance I (2020) Natural or synthetic–how global trends in textile usage threaten freshwater environments. Science of the Total Environment 718: 134689.
31. Johnson S, Echeverria D, Venditti R, Jameel H (2020) Supply Chain of Waste Cotton Recycling and Reuse: A Review. AATCC Journal of Research 7(1): 19-31.
32. Chapagain AK, Hoekstra AY, Savenije HHG, Gautam R (2006) The water footprint of cotton consumption: An assessment of the impact of worldwide consumption of cotton products on the water resources in the cotton producing countries. Ecological economics 60(1): 186-203.
33. Bevilacqua M, Ciarapica FE, Mazzuto G, Paciarotti C (2014) Environmental analysis of a cotton yarn supply chain. Journal of Cleaner Production 82: 154-165.
34. Wiedemann SG, Yan MJ, Henry BK, Murphy CM (2016) Resource use and greenhouse gas emissions from three wool production regions in Australia. Journal of Cleaner Production 122: 121-132.
35. Ibrahim NA, Abdel Moneim NM, Abdel Halim ES, Hosni MM (2008) Pollution prevention of cotton-cone reactive dyeing. Journal of Cleaner Production 16(12): 1321-1326.
36. Wang YL, Lee YH, Chiu IJ, Lin YF, Chiu HW (2020) Potent impact of plastic nanomaterials and micromaterials on the food chain and human health. Int J Mol Sci 21(5): 1727.
37. Palamutcu S (2010) Electric energy consumption in the cotton textile processing stages. Energy 35(7): 2945-2952.
38. Zhang Y, Xin L, Rufeng X, Zengwei Y (2015) Life cycle assessment of cotton T-shirts in China. The International Journal of Life Cycle Assessment 20(7): 994-1004.
39. Bick R, Halsey E, Ekenga CC (2018) The global environmental injustice of fast fashion. Environmental Health 17(1): 1-4.
40. Aiama D, Carbone G, Cator D, Challender D (2016) Biodiversity risks and opportunities in the apparel sector. International Union for Conservation of Nature: Gland, Switzerland.
41. Kanmani S, Gandhimathi R (2013) Assessment of heavy metal contamination in soil due to leachate migration from an open dumping site. Applied Water Science 3(1): 193-205.
42. Salem Z, Hamouri K, Djemaa R, Allia K (2008) Evaluation of landfill leachate pollution and treatment. Desalination 220(1-3): 108-114.
43. Udeani N (2017) Textile Waste Recycling: An Innovative Creativity for Entrepreneurial Sustainability in Nigeria. Tropical Built Environment Journal 1(6).
44. Nwosu EE, Pepple GT (2016) Site selection and analysis of solid waste dumpsites in Ile-Ife, Nigeria. in FIG Working Week.

45. Allwood JM, Laursen SE, Malvido de Rodríguez C, Bocken NMP (2006) Well dressed. The present and future sustainability of clothing and textiles in the United Kingdom.
46. Wicker A (2016) Fast Fashion Is Creating an Environmental Crisis, in Newsweek Magazine.
47. Hamner B (2006) Effects of green purchasing strategies on supplier behaviour, in Greening the supply chain. Springer: 25-37.
48. Meyer A (2001) What's in it for the customers? Successfully marketing green clothes. Business Strategy and the Environment 10(5): 317-330.
49. Tisserant A, Pauliuk S, Merciai S, Schmidt J, Fry J, et al. (2017) Solid waste and the circular economy: a global analysis of waste treatment and waste footprints. Journal of Industrial Ecology 21(3): 628-640.
50. Sun W, Chen J, Chen L, Wang J, Zhang Y (2016) Coupled electron beam radiation and MBR treatment of textile wastewater containing polyvinyl alcohol. Chemosphere 155: 57-61.
51. Ebeling JM, Sibrell PL, Ogden SR, Summerfelt ST (2003) Evaluation of chemical coagulation–flocculation aids for the removal of suspended solids and phosphorus from intensive recirculating aquaculture effluent discharge. Aquacultural Engineering 29(1-2): 23-42.
52. Roy R, Fakhruddin ANM, Khatun R, Islam MS (2010) Reduction of COD and pH of textile industrial effluents by aquatic macrophytes and algae. Journal of Bangladesh Academy of Sciences 34(1): 9-14.
53. Ciardelli G, Capannelli G, Bottino A (2001) Ozone treatment of textile wastewaters for reuse. Water Sci Technol 44(5): 61-67.
54. Lin SH, Peng C (1995) Treatment of textile wastewater by Fenton's reagent. Journal of Environmental Science & Health Part A 30(1): 89-98.
55. Przystaś W, Zabłocka-Godlewska E, Grabińska-Sota E (2013) Effectiveness of dyes removal by mixed fungal cultures and toxicity of their metabolites. Water Air Soil Pollut 224(5): 1534.
56. Abadulla E, Tzanov T, Costa S, Robra KH, Cavaco-Paulo A, et al. (2000) Decolorization and detoxification of textile dyes with a laccase from Trametes hirsuta. Appl Environ Microbiol 66(8): 3357-3362.
57. Tauber MM, Guebitz GM, Rehorek A (2005)Degradation of azo dyes by laccase and ultrasound treatment. Appl Environ Microbiol 71(5): 2600-2607.
58. Cardoso JC, Bessegato GG, Zanoni MVB (2016) Efficiency comparison of ozonation, photolysis, photocatalysis and photoelectrocatalysis methods in real textile wastewater decolorization. Water Res 98: 39-46.
59. Punrattanasin N, Nakpathom M, Somboon B, Narumol N, Rungruangkitkrai N, et al. (2013) Silk fabric dyeing with natural dye from mangrove bark (*Rhizophora apiculata* Blume) extract. Industrial Crops and Products 49: 122-129.
60. Meksi N, Haddar W, Hammami S, Mhenni MF (2012) Olive mill wastewater: A potential source of natural dyes for textile dyeing. Industrial Crops and Products 40: 103-109.
61. Jabasingh SA, Sahu P, Yimam A (2016) Enviro-friendly biofinishing of cotton fibers using *Aspergillus nidulans* AJSU04 cellulases for enhanced uptake of Myrobalan dye from *Terminalia chebula*. Dyes and Pigments 129: 129-140.
62. Kant R (2011) Textile dyeing industry an environmental hazard.
63. Senthilkumar M, Gnanapragasam G, Arutchelvan V, Nagarajan S (2011) Treatment of textile dyeing wastewater using two-phase pilot plant UASB reactor with sago wastewater as co-substrate. Chemical Engineering Journal 166(1): 10-14.
64. Wang J, Yan J, Xu W (2015) Treatment of dyeing wastewater by MIC anaerobic reactor. Biochemical Engineering Journal 101: 179-184.
65. Gnanapragasam G, Senthilkumar M, Arutchelvan V, Velayutham T, Nagarajan S (2011) Bio-kinetic analysis on treatment of textile dye wastewater using anaerobic batch reactor. Bioresour Technol 102(2): 627-632.
66. Kıpçak E, Akgün M (2013) In situ gas fuel production during the treatment of textile wastewater at supercritical conditions. Water Sci Technol 67(5): 1058-1067.
67. Morris M, Waldheim L (1998) Energy recovery from solid waste fuels using advanced gasification technology. Waste management 18(6-8): 557-564.
68. Bosmans A, Vanderreydt I, Geysen D, Helsen L (2013) The crucial role of Waste-to-Energy technologies in enhanced landfill mining: a technology review. Journal of Cleaner Production 55: 10-23.
69. Nishio N, Nakashimada Y (2007) Recent development of anaerobic digestion processes for energy recovery from wastes. J Biosci Bioeng 103(2): 105-112.
70. Holm-Nielsen JB, Al Seadi T, Oleskowicz-Popiel P (2009) The future of anaerobic digestion and biogas utilization. Bioresource technology 100(22): 5478-5484.
71. Strähle J, Philipsen F (2017) Closed-loop production: a literature review. Green Fashion Retail: 27-47.
72. Zonatti WF, J. Baruque-Ramos, Duleba W (2016) Brazilian scope of management and recycling of textile wastes, in Natural Fibres: Advances in Science and Technology Towards Industrial Applications. Springer: 429-439.
73. Zamani B (2014) Towards understanding sustainable textile waste management: Environmental impacts and social indicators. Chalmers Tekniska Hogskola (Sweden).
74. Haule LV, Carr C, Rigout M (2016) Preparation and physical properties of regenerated cellulose fibres from cotton waste garments. Journal of cleaner production 112: 4445-4451.
75. Bhatia D, Sharma A, Malhotra U (2014) Recycled fibers: an overview. International Journal of Fiber and Textile Research 4(4): 77-82.
76. Nahil MA, Williams PT (2010) Activated carbons from acrylic textile waste. Journal of analytical and applied pyrolysis 89(1): 51-59.
77. Directive E (2008) Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives. Official Journal of the European Union L 312(3).
78. Vats S, Rissanen M (2016) Parameters affecting the upcycling of waste cotton and PES/CO textiles. Recycling 1(1): 166-177.
79. Nielsen R, Schmidt A (2014) Changing consumer behavior towards increased prevention of textile waste: background report. Nordisk Ministerråd.
80. EPA (2021) Textile Mills Effluent Guidelines.
81. OFR (1974) Textile Mills Point Source Category in 40. Office of the Federal Register.
82. EPA. National Pollutant Discharge Elimination System (NPDES).
83. Tiseo I (2017) Water and wastewater key figures in the U.S. Statista.
84. Wise H (1996) Preliminary Study of the Textile Mills Category. U.S. Environmental Protection Agency.
85. EPA (2021) Preliminary Effluent Guidelines Program Plan.
86. Chen JY, Polston K, Nicols E, Phung B (2021) A study on textile recycling in college student residence areas. The Journal of The Textile Institute: 1-8.
87. Shahbandeh M (2021) U.S. apparel and footwear resale market - statistics & facts. Statista.
88. Chua MH, Cheng W, Goh SS, Kong J, Li B, et al, (2020) Face masks in the new COVID-19 normal: materials, testing, and perspectives. Research 2020: 7286735.
89. Kane IA, Clare MA (2019) Dispersion, accumulation, and the ultimate fate of microplastics in deep-marine environments: A review and future directions. Frontiers in earth science 7: 80.
90. Peng Y, Wu P, Schartup AT, Zhang Y (2021) Plastic waste release caused by COVID-19 and its fate in the global ocean. Proceedings of the National Academy of Sciences 118(47): e2111530118.


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