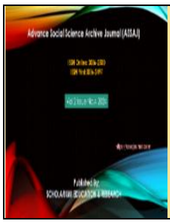

ADVANCE SOCIAL SCIENCE ARCHIVE JOURNAL
Available Online: https://assajournal.com
Vol. 04 No. 02. Oct-Dec 2025.Page#.3314-3327
Print ISSN: 3006-2497 Online ISSN: 3006-2500
Platform & Workflow by: Open Journal Systems

Recycling and Circular Economy Approaches in Technical Textiles: A Review

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ABSTRACT

The technical textile industry could be good for both Pakistan's economy and the environment. Pakistan's textile industry could benefit greatly from adopting circular economy strategies as recycling rates are below 1% and global textile production is expected to reach 149 million tons by 2030. This review analyzes technical textile recycling methodologies, drawing on peer reviewed research from Google Scholar, Nature Communications, Environmental Science &

Technology as well as reports from the National Institute of Standards and Technology and the U.S. Government Accountability Office. The textile industry in Pakistan is responsible for 60% of all exports and 8.5% of the country's GDP. However, it also produces more than 2 million tons of textile waste each year. The technical textiles industry can assist the circular economy in such areas as industrial fabrics, automotive textiles, medical textiles and geotextiles. Establishing recycling facilities would lead to the creation of 100,000 additional indirect employment opportunities and 50,000-75,000 direct employment opportunities in the collection, sorting, and processing. Economic benefits would contribute 0.5 to 1 per cent to the GDP of Pakistan by rendering exports competitive and creation of new industrial value chains. Scientists have discovered that the polyester content, and cotton recycling through alkaline hydrolysis and glycolysis can recover 85 to 95 percent of the polyester and cotton in mixed garments. In Pakistan, they tend to make stuff using these fabrics. There are still important gaps in research such as standards for the performance of recycled materials, cost effective ways to separate materials in South Asian settings and rules for dealing with contamination in local conditions. Teaching people how to use technology and training them are two very important things that make things happen. Laws about Extended Producer Responsibility, using blockchain and RFID (Radio Frequency Identification) technology to keep track of things digitally and public private partnerships to pay for infrastructure are all important policy changes. Using circular models in Pakistan's technical textile industry can create a lot of jobs and make the country a regional leader in textile sustainability innovation. This will also be good for the environment. Pakistani universities, international organizations, and business stakeholders can work together to speed up the use of technology.

Keywords: *Technical Textiles, Circular Economy, Textile Recycling, Chemical Recycling, Mechanical Recycling, Pakistan Textile Industry, Sustainable Manufacturing*

Introduction

The textile industry is going through a critical period. According to experts, global textile production will have risen from 113 million tons in 2021 to 149 million tons by 2030 (Grand View Research, 2024). After oil and gas and agriculture, this industry is the third most polluting in the world, with a recycling rate of less than 1% (Abdel-Rahman et al., 2021). With a projected value of $213.8 billion in 2024 and $284 billion by 2029, the fast-growing technical textiles market has unique recycling challenges that distinguish it from traditional clothing materials (Grand View Research, 2024).

Materials created for particular utilitarian uses as opposed to aesthetics are known as technical textiles. These include filtration fabrics for industrial processes, medical textiles for healthcare applications, geotextiles for infrastructure stability, and safety related protective materials (Al-Zubeidi et al., 2024). Even though technical textiles often last longer than regular clothes, recycling or properly disposing of them is difficult due to the intricate combination of components in them.

Recently, there has been a notable surge in the shift to a circular economy, which prioritizes ongoing material recovery over landfill disposal (Niinimäki et al., 2021). But attaining circularity in the technical textile industry necessitates overcoming obstacles including complex multi material constructions, environmental deterioration, and the need for premium recycled products. This study examines the existing recycling, evaluates the distinct challenges of the various textile types and explores the innovative best practices, known as circular, which can alter entirely the life cycle of such high-performance products.

Technical Textile Uses & Classifications

Technical textiles are categorized into twelve primary application categories by the Technical Textile Methodology. Each category requires distinct resources and serves different objectives.

Geotextiles (Geotech)

Geotextiles are intended to act in combination with soil as special purpose synthetic fabrics to regulate moisture and offer structural support. They are woven and nonwoven polyester and polypropylene materials which are highly in demand when it comes to the stabilization of infrastructure like roads and embankments besides erosion prevention. They must uphold their integrity in severe environments as UV rays, moisture and physical force of heavy soil and rock since they are covered or are exposed to the atmosphere. (Al-Zubeidi et al., 2024).

Medical textiles (Medtech)

Medical textiles encompass items such as surgical gowns, wound dressing, implantable materials as well as personal hygiene products (Medtech). These require sterility, biocompatibility and some barrier properties. Whereas a few are one use items and therefore discarded after a few minutes, implantable textiles can remain in the body over a number of years. In this case recycling is complicated with the pollution of biological materials and strict guidelines (Al-Zubeidi et al., 2024).

Industrial textiles/Industrial Tech.

Filtration, transportation, insulation, and reinforcement are all met by industrial textiles Filter fabrics are utilized to remove particles in the liquid or air streams; they are very dirty in some instances. Clothes are mixed with plastic or rubber covering conveyor belts. The properties of these materials may vary because of heat, chemicals, and abrasive conditions (Al-Zubeidi et al., 2024).

Protective textiles

Protective textiles (Protech) entail flame resistant garments, bulletproof vests, high visibility gears and chemical resistant suits. They can be applied in several protective roles as layers and they can hardly be separated to be recycled. The various technical textiles pose various degrees of difficulty with regards to recycling; a geotextile drainage fabric and a medical gown are two very different things at the end of their life. Such differences are quite significant to learn so that effective recycling strategies could be developed (Al-Zubeidi et al., 2024).

Textile Recycling's Current State

Statistics of Global Recycling

Only 2.5 million tons of 17 million tons of textile waste generated in the US itself in 2018 were recycled, which produced a recycling rate of only 14.7% (U.S. Environmental Protection Agency, 2018). Approximately 87% of textile fibers end up in landfills or incinerators, and less than 1% of clothing is recycled into new garments (Abdel-Rahman et al., 2021). With an estimated 92 million tons of textile waste produced annually, the situation is comparable globally (PICVISA, 2024).

The market for textile recycling is relatively small compared to the volume of waste generated, despite its growth. From its projected $4.85 billion in 2024 to $6.94 billion by 2033, the market is estimated to increase at a pace of 4.2% annually (Grand View Research, 2024). Even while this development is a sign of increased awareness and investment, the absolute amounts recycled are still much too low to address the rubbish problem.

With a recycling rate of just 20%, China, the world's biggest manufacturer and consumer of textiles, produced almost 22 million tons of garbage in 2020 (PICVISA, 2024). Approximately 11.3 million tons, or 66% of all unwanted textiles, were disposed of in landfills in the United States in 2018 (U.S. Environmental Protection Agency, 2018). Textile consumption rose 40%

between 2000 and 2009, surpassing recycling capacity even in Sweden, a country renowned for its progressive waste management.

Recycling Methods

There are two main methods for recycling textiles: chemical and mechanical.

Mechanical recycling

Separating fibers through grinding so they can be recycled into new yarns. This approach, which has been around since the Industrial Revolution, held a 70.4% market share in 2024 (Grand View Research, 2024). Textiles made entirely of one material, such as 100% polyester or cotton, function best with it. The procedure is more cost effective than chemical procedures since it is comparatively easy and uses less energy, but mechanical recycling has serious drawbacks. Every recycling cycle reduces the fiber's strength and length, producing lower quality materials that are only appropriate for less expensive uses like industrial wipes, insulation, and furniture stuffing (Abdel-Rahman et al., 2021). Blended materials cannot be successfully separated by the procedure. The fiber mix that is produced when cotton and polyester are mechanically recycled combined is not as good as either material alone. According to one study, the tensile strength of mechanically recycled cotton fibers was only 75% that of pure virgin cotton yarns, and they had to be blended with virgin fibers in order to be used (Kariuki et al., 2024).

Chemical recycling

Textiles are broken down at the molecular level through chemical recycling, which either dissolves polymers or depolymerizes them into monomers that can be repolymerized to create new materials (Palme et al., 2024). This method can yield superior fibers that are on par with virgin materials. In the case of polyester, techniques such as glycolysis break the polymer down into its constituent parts so that new polyester can be made without losing quality. Technologies for chemical recycling are developing quickly, and publications have significantly increased in recent years. Glycolysis, hydrolysis, methanolysis, aminolysis, and enzymatic reactions are some of the techniques. Chemical recycling still has a lot of obstacles to overcome. The procedures are unsuccessful for mixed material waste because they need particular conditions for each kind of polymer. Scalability is limited by high prices, energy needs, and the demand for chemical inputs. Instead of being used in industry, the majority of chemical recycling is still done in labs or on a small scale (Palme et al., 2024).

Critical Challenges in Technical Textile Recycling

The Blended Fiber Problem

The greatest challenge is likely to prevent recycling of textiles because of the use of mixed materials. Among the most common types of cloth that are widespread in the world, there are polycotton blends, which are the combinations of cotton and polyester (Bhattacharjee et al., 2023). Cotton accounts for roughly 24% of textile fiber output, polyester for 52%, and their mix appears everywhere from workwear to household textiles to industrial fabrics (PICVISA, 2024). The physical process of entangling of fibers in yarns and fabrics need to be destroyed to separate cotton and polyester. This is not something that can be achieved through the use of machinery. Cotton is a processed material made of cellulose and therefore requires very different treatment compared to polyester, which is a synthetic polymer. They have different chemical compositions and physical characteristics, that require totally different recycling methods (Bhattacharjee et al., 2023).

Elastane and Complexity of Multiple Materials

Spandex, another name for elastane, adds another level of complexity (Rana et al., 2024). Comfort and stretch are provided by this polyurethane elastomer, which is utilized in anything from business clothes to athletics. Elastane produces major problems even at 2.5% concentrations. Because it cannot be shredded like other materials, it clumps during processing, clogs machinery, and hinders the efficient recycling of other polymers. Elastane separation requires selective degradation or disintegration. To remove elastane while preserving other fibers, several solvents and chemical treatments have been studied. The already challenging recycling process is made more complex and costly by this additional processing step (Rana et al., 2024).

Technical textiles often have even more complex multi material systems. Protective clothing may include thermal liners, moisture barriers, flame resistant outer shells, and comfort layers. Woven reinforcement and nonwoven filtration layers can be geotextiles. The use of textiles, foam, adhesive and rigid material are used in automotive textiles. The separation is very much getting complex with every additional compound.

Deterioration of Quality and Contamination

Technical fabrics have different problems of contamination compared with fashion fabric. The particles, chemicals, and oils are gathered by an industrial filter textile. Geotextiles are exposed to soil, organic wastes, and groundwater wastes (Al-Zubeidi et al., 2024). Biological contaminants can be applied to medical textiles. These contaminants even when not biohazardous disrupt recycling.

Additional problems are the finishes and dyes. Various technical fabrics receive adding protection against UV, resistance to flames, waterproofing, or even an anti-bacterial property. They may contaminate the materials recovered and increase the difficulty in making the recycling of those materials. Vat dyes and most reactive dyes strongly reduce or do away with the spinnability of cellulose solutions. Melt spinning of dyed polyester leads to poor color quality and environmental concerns (Palme et al., 2024).

A study that examined the release of microplastic fibres during the process of chemical recycling polyester cotton blends has reported that dye release was the most frequent to generate the highest count of microplastic fibres with an average of 10,055 microplastic fibres/gram of textile waste. This is the demonstration that processing techniques aimed at equipping the materials with suitable recycling can lead to the emergence of further environmental issues.

Infrastructure and Financial Obstacles

Inadequate infrastructure makes it difficult to implement technological recycling solutions. Sorting is one of the most significant problems. Manual sorting is labor intensive, time consuming, and prone to mistakes. Automated systems that employ infrared spectroscopy or other identification methods are being developed, albeit they are not yet widely utilized. Accurate identification of technical textiles is particularly difficult due to their complexity and variety of compositions and treatments (Frontiers in Sustainability, 2022).

Technical textile waste collection systems are not as advanced as those for municipal solid waste streams. Because of its established composition and low level of contamination, post-industrial trash from production is simpler to collect. However, post-consumer technical textiles are scattered across several end users and lack a systematic infrastructure for collecting (Frontiers in Sustainability,2022). Many recycling strategies have dubious economic feasibility. Although promising, chemical recycling technologies are still expensive on current scales. Recycled materials' market value frequently falls short of their processing expenses. Until laws or consumer preferences create demand, virgin polyester and cotton are very inexpensive, which lessens the motivation to employ more costly recycled alternatives.

Lack of designed in recyclability is perhaps the most fundamental barrier. Current technical textiles are optimized for performance during use with little consideration for end of life. Design for recycling would require material selection, construction methods, and component attachment that facilitate disassembly and material recovery. This shift requires collaboration among designers, material suppliers, manufacturers, and recyclers, collaboration that currently barely exists (Frontiers in Sustainability, 2022).

New Innovations and Technologies

Advanced Sorting Systems

The technology for sorting is developing quickly. Near infrared (NIR) spectroscopy could be used to ascertain the composition of fiber by looking at the absorption and reflection of light by materials in specific wavelengths. All types of fibres produce distinctive spectral signature. Recently, the U.S. National Institute of Standards and Technology developed a database containing molecular fingerprints of various textile fibers to be able to sort them faster and more effectively. The aims of this reference data are to enhance the sorting algorithms and to make automated systems high throughput. (National Institute of Standards and Technology, 2025).

Radiofrequency identification (RFID) tags, incorporated in textiles during the manufacturing process, not only give information on composition upon the expiry of their useful life, but also give the possibility to track an object in the course of its life. RFID technology can make possible closed loop systems, where the producers can recycle their products at an additional cost. Machine learning and artificial intelligence are used to increase sorting accuracy. Computer vision systems may use visual cues to classify textiles, and machine learning algorithms improve with more samples. Commercial use of these technologies is replacing research labs (U.S. Government Accountability Office, 2024).

Innovative Ideas for Recycling Chemicals

Research is ongoing to develop more efficient, focused chemical recycling methods. Mixed fabrics are likely to be separated under the influence of polymers because not all of them can be dissolved in ionic liquids. Both cotton polyester mixtures were recycled successfully by conducting a successful experiment on isolating them with the help of ionic solutions. Supercritical fluids are capable of obtaining an unprecedented level of selectivity when extracting or dissolving a given compound and can do so at temperatures and pressures above the critical point of a substance. Supercritical CO2 has been studied to remove pollutants and colors on textiles before recycling them (Palme et al., 2024).

It can be more ecologically friendly by recycling that with biological techniques involving the use of microbes or enzymes. Polyester is broken down by enzymes known as Katinases, cellulose is broken down by cellulases and other polymers can be specifically broken down by various enzymes. Even though the commercial applicability is currently limited due to the high cost of enzymes, further research efforts are trying to produce more cost efficient and effective enzymatic systems (Bhattacharjee et al., 2023).

One of the particularly interesting strategies is sequential therapy. First, the preservation of polyester and hydrolysis of cotton by acid is done to yield glucose. To recover monomers, the polyester residue is further subjected to glycolysis. Both aspects of polycotton blends are addressed by this phased approach, although economics and scale are still issues (Li et al., 2025).

Table. 1. Technical Textile Recycling: Current Status and Research Gaps

Technical Textile Category	Primary Materials	Current Recycling Rate	Main Challenges	Research Gaps
Geotextiles (Geotech)	Polypropylene, Polyester, Polyethylene	< 5%	Soil contamination, UV degradation, large item handling, embedded in infrastructure	**Contamination tolerance of recycling processes, in situ recycling methods, performance standards for recycled geotextiles**
Medical Textiles (Medtech)	Cotton, Polyester, Polypropylene (nonwovens)	< 1%	Biological contamination, sterility requirements, single use design, regulatory constraints	**Safe decontamination protocols, closed loop systems for non-contaminated items, materials compatible with sterilization and recycling**
Industrial Textiles (Indu tech)	Polyester, Aramids, Glass fiber, Carbon fiber	10-15%	Chemical contamination (filtration), composite structures, performance requirements	**Methods for filter media recycling, composite separation technologies, quality assessment of recycled industrial textiles**
Protective Textiles (Protech)	Aramids, PBI, Modacrylic, Multi- layer laminates	< 5%	Multi material layers, protective treatments, certification requirements	**Nondestructive testing of recycled protective materials, separation of laminated structures, maintaining protective properties**
Automotive Textiles (Mobil tech)	Polyester, Polyamide, Polypropylene	15-20%	Foam attachment, adhesives, mixed materials, large volume handling	**Efficient adhesive removal, scalable separation processes, applications for mixed automotive textile waste**
Home Textiles (Home tech)	**Cotton, Polyester, Blends**	**15-20%**	**Blended fabrics, diverse treatments (stain resistance, flame retardants), contamination**	**Cost effective blend separation at scale, removal of functional finishes, color sorting and dye removal**

According to data (presented in table 1) recycling rates are generally low but vary greatly among technical textile categories. Because packaging textiles are frequently single material, collected using current techniques, and less polluted, they have the highest recycling rates. Because of contamination, safety regulations, and intricate construction, medical and protective textiles have very poor recycling rates.

There are significant research gaps in every category. Contamination tolerance, or the amount of contamination recycling systems can withstand while still creating useable materials, is a topic that is seldom studied. Although processing technologies attract more research focus than collection and logistics, inadequate collection techniques prevent potentially recyclable materials from ever reaching processing plants. The lack of established performance requirements for recycled materials raises questions regarding the safe use of recycled technical textiles.

Table 2. Performance Information and Process Parameters

Recycling Method	Process Conditions	Material Applicability	Fiber Recovery Rate	Quality of Recovered Material	Energy Consumption	Scalability Status
Mechanical Shredding	Ambient temperature, mechanical force	Single material cotton, wool, some synthetics	70-85%	Low to medium (shorter fibers, reduced strength)	Low (0.5-1.0 MJ/kg)	Commercial scale
Acid Hydrolysis (Cotton)	43% HCl, 2025°C, 24 hours	Cotton from polycotton blends	75-85% (as glucose)	High (pure glucose for other uses)	Medium (2-3 MJ/kg)	Pilot scale
Alkaline Hydrolysis (PET)	5-15% NaOH, 80-90°C, 20-120 min	Polyester from blends	85-95%	High (terephthalic acid, ethylene glycol)	Medium (2.5-3.5 MJ/kg)	Pilot scale
Glycolysis (PET)	Ethylene glycol, 180220°C, 2-8 hours, catalyst	Pure polyester or polyester rich blends	70-90% (as BHET)	High (recycled PET comparable to virgin)	High (4-5 MJ/kg)	Small commercial scale
Enzymatic Hydrolysis	Cellulase/ cutinase, 4060°C, 24-72 hours	Cotton or polyester, potentially selective	60-85%	High (Maintains polymer integrity)	Low (1-2 MJ/kg)	Laboratory/ pilot scale

Ionic Liquid Dissolution	Ionic liquid, 80-120°C, 1-4 hours	Cellulosic, selective for some synthetics	75-90%	High (polymer dissolution and regeneration)	Medium (2.5-3 MJ/kg)	Laboratory scale
Hydrothermal Treatment	Water, 220230°C, 10-30 min, high pressure	Cotton from polycotton	60-75%	Medium (partial degradation possible)	High (5-6 MJ/kg due to pressure)	Laboratory scale

The data (Table 2) clearly demonstrates tradeoffs. Commercial mechanical recycling uses the least amount of energy, but the materials it generates are of lesser quality. High quality materials may be recovered by chemical processes, although they are typically limited to laboratory or pilot size and demand more energy (Palme et al., 2024). Although enzymatic methods have great selectivity and low energy consumption, they are currently unable to scale because to their lengthy reaction durations and expensive enzyme prices (Bhattacharjee et al., 2023).

Recovery rates are quite variable. 15 to 30% of the material used in mechanical recycling is lost during processing (Kariuki et al., 2024). Higher recovery is achieved by chemical processes; however, the recovered material may have different uses than the original cloth due to the change from polymer to monomer. For instance, instead of producing fresh cotton fibers, cotton that has been converted to glucose might be utilized to make chemicals or biofuels (Li et al., 2025).

Circular Economy Strategies for Technical Textiles

Circular economy studies extend beyond recycling to include the whole life cycle of a product. For technical textiles, there are a number of ways to promote circularity.

Extended Producer Responsibility

Manufacturers bear responsibilities of end-of-life management through Extended Producer Responsibility (EPR). In some European countries, EPR of textiles is or has been installed. France introduced EPR To the textiles in 2007 with a collection of approximately 40 percent. Sweden and the Netherlands also have similar initiatives (Niinimäki et al., 2021). Manufacturers are encouraged by EPR to make items that are easy to recycle. Materials that are costly or difficult to recycle lose appeal when manufacturers are required to pay for end-of-life processing. Innovation in recyclable technical textiles may be stimulated by this market signal. Implementing EPR in technical fabrics is difficult. During manufacture and usage, many technical fabrics go across international boundaries several times. It is possible for a geotextile to be produced in one nation, utilized in another, and produce trash in a third. It becomes difficult to assign responsibilities. Because many technical textiles have a lengthy service life, producer traceability can be challenging because decades may pass between manufacturing and disposal (Niinimäki et al., 2021).

Industrial Symbiosis and Upcycling

Industrial symbiosis involves using one industry's waste as another industry's input. Technical textile waste might serve non textile applications. For example:

- Shredded carpet fibers reinforce concrete
- Cut offs from geotextile production serve as filtration media

- Recycled aramid fibers from protective clothing reinforce composite materials
- Cotton waste from medical textiles becomes raw material for paper production

Traceability and Digital Technologies

The application of the circular economy is improved by digital instruments. Blockchain technology can be used to trace textiles across its supply chain, including the fiber content, treatments, and circumstances of use. This knowledge ensures that proper recycling is done at the end of life (U.S. Government Accountability Office, 2024).

Digital product passports could have a life-long presence with products and will contain information regarding the composition and characteristics of a cloth. Recyclers would know exactly what they're processing instead of relying on potentially inaccurate or missing labels. Technical textiles can also have Internet of Things (IoT) sensors to detect condition and estimate end of service so that materials can be salvaged before disintegration. In the case of geotextiles in the infrastructure, this type of monitoring could maximize the recovery and replacement time of materials.

Policy Frameworks and Regional Approaches

The circular economy Infrastructure, culture, and politics all play a role in the progress of textiles worldwide.

Europe

In terms of textile recycling policies, Europe is in the forefront. The EU Circular Economy Action Plan includes specific measures relating to textiles. The EU Strategy for Sustainable and Circular Textiles was adopted in 2022 with the goal of making all textile products supplied in the EU more durable, repairable, reusable, and recyclable by 2030. By 2025, separate collection of textile waste will be required throughout the EUIn several countries of the EU, there are developed programs. France has a system named EPR whose purpose is to gather over 240,000 tons of textiles annually, which have been in operation since 2007. The Netherlands has embarked on collaboration of municipalities, organizations, and recyclers to enhance collection and processing. In Sweden, the waste management system gathers over 95 percent of the textile waste (Niinimäki et al., 2021).

Asia Pacific

Asia Pacific, particularly China and Pakistan, generates massive volumes of textile waste due to increasing manufacturing and population. Pakistan's textile sector is a vital component of the country's economy, accounting for 58% of its total exports and employing more than 40% of its industrial workers. The country generates approximately 887 kilotons of pre consumer textile waste (spinning, weaving, and clothing manufacturing) each year; 68% of the waste is fabricated of cotton-based type products. Furthermore, Pakistan imports 809 kilotons of used apparel annually, most of which is reexported to African markets and some of which is recycled domestically (Batool et al., 2025).

Pakistan's position is distinct due to its long-standing recycling culture, especially in Faisalabad, which is the main hub for the processing textile waste and has about 100 recycling facilities in the Satiana region alone. Pakistan has been practicing an "organic circular economy" for decades, according to Minister Musadik Malik in December 2024. Used textile exports reached $283 million in 2024, up from $255 million in the last year (Texfash ,2025).

North America

North America uses a lot of textiles, while having lower recycling rates. The bulk of textiles in the US are disposed of in landfills; just 15% are recycled or given away. However, the emphasis on policy has increased recently. California and other governments are considering EPR programs for textiles (U.S. Environmental Protection Agency, 2018).

Prospects for the Future and Suggestions

For technical textiles, meaningful circularity requires coordinated efforts on several fronts in Pakistan.

Research Based Strategic Pathways

As part of the UK funded Sustainable Manufacturing and Environmental Pollution program, Reverse Resources recently carried out extensive research in partnership with National Textile University Faisalabad and Know Tex. The study produced specific strategic recommendations to the textile recycling ecosystem of Pakistan. Published in early 2025, these findings provide feasible answers and represent the most in-depth analysis of the situation with textile waste in Pakistan. (Batool et al., 2025).

Requirements for Modernizing Infrastructure

It is greatly clear in the study that the recycling system that Pakistan has is in dire need of technical enhancements. In the present scenario, the Satiana region of Faisalabad, with approximately 100 recycling plants, undergoes the use of the outdated mechanical recycling methods. A pilot study was conducted to determine the three intervention strategies based on the introduction of standard operating procedures, retrofitting of the current machines with better components and a combination strategy of both strategies in twelve recycling facilities. The results also showed that modified machinery increased the safety of the workers, the quality of the product, and the production of the materials. There were complications during the initial stage, however. The quality and efficiency had some issues in the first hours or even days after retrofitting, and this required strict changes and fine tuning in the machine settings or specific kinds of fabric waste. The transition period tested the patience of recyclers who incurred losses during the transition period because of low quality bales but those who stayed the course realized great profits (Batool et al., 2025).

The report argument is that significant investments in fiber recovery technology are required by Pakistan to produce recovered fiber of better grade. The most challenging part of the current mechanical systems of recycling (polymerized systems are most effective with mono materials) is blended textiles that are the largest part of the waste stream. The recycled resources are limited to low quality things like filler materials rather than new textiles since they frequently result in lower quality products with shorter fiber lengths. Pakistan has to make investments in chemical recycling technology that can efficiently handle cotton polyester blends in order to transition to true textile to textile recycling (Fibre2Fashion, 2025; Hussain et al., 2022).

Digital tracking systems and transparency

The absence of traceability and transparency in Pakistan's textile waste flows is one of the most important gaps found in several research. Because the recycling industry is informal, garbage transportation is not well recorded, which makes supply and demand balance all but impossible. Participants in the study frequently mentioned this as a significant obstacle to productivity (Batool et al., 2025).

Development of Collection Systems

The results of the research highlight Pakistan's lack of structured procedures for collecting textile waste. Despite the nation's long history of recycling, garbage collection is still ineffective, and processing can lead to contamination and quality degradation. As a fundamental prerequisite, the thorough study report expressly suggests setting up a trash collecting and material sorting system (Hussain et al., 2022).

Collection issues are more serious for post-consumer textiles, especially the 809 kilotons of imported used apparel that enter Pakistan each year. A large portion of this material comes through the seaport in Karachi and passes through the Karachi Export Processing Zone. While some are recycled, the majority go straight to disposal sites or resale markets. According to research, recycling and redesigning both locally produced and imported worn clothing may represent a major commercial potential for Pakistan if industries were directed more successfully into recycled fashion marketplaces productivity (Batool et al., 2025).

Economics and Policy

The introduction of tax exemptions in the Textile Policy 2023 to 2028 to accelerate the shift to a circular economy and the decision of the State Bank of Pakistan to provide the green finance projects with 500 million dollars are both positive aspects. Studies do indicate that narrower economic tools are needed though. To discourage wasteful designs, studies recommend charging for the disposal of non-recyclable materials. Demand for recycled textiles would be ensured by public procurement preferences. If carbon pricing took into account the whole environmental cost of generating virgin materials rather than recycling, economic calculations would shift in favor of circular systems (Fibre2Fashion, 2025; Hussain et al., 2022).

Small and medium-sized enterprises, the backbone of Pakistan's textile sector, face particular financial challenges (Hussain et al., 2022). Financial limitations, inadequate information diffusion, restricted access to technology, and a lack of government understanding and support were shown to be major obstacles. The majority of Pakistani textile companies cannot afford the $2.5 million cost of a single waterless dying equipment (Batool et al., 2025).

Industry Cooperation and Capacity Development

The report presents a strong argument for more stakeholder collaboration (Batool et al., 2025). The SMEP program has fostered partnerships between National Textile University, Reverse Resources, UK government agencies, and private sector firms. These collaborations have produced research driven ideas and proven practical strategies. These collaborations must, however, grow significantly. The first and second National Conferences on Recycling in Textiles, which provided forums for knowledge exchange, were held in Pakistan. Interactions with industry experts and field excursions to recycling facilities improved research findings. Such frequent get togethers might maintain momentum and encourage further knowledge if they were institutionalized as an annual event (Abdel-Rahman et al., 2021).

Research Gaps

Several areas need more research attention:

- Long term performance of recycled technical textiles in demanding applications
- Life cycle assessments comparing virgin and recycled materials across different technical textile categories
- Contamination management strategies for textiles exposed to chemicals, biological materials, or environmental degradation
- Social and economic dimensions of technical textile recycling, including workforce development and informal sector integration
- Systems level analysis of optimal recycling pathways considering local context, material flows, and available infrastructure

Collaboration and Knowledge Sharing

Unprecedented cooperation between textile producers, technical textile consumers, waste management firms, recycling technology developers, legislators, and researchers is necessary for progress. Industry consortiums, like those that are forming in Europe, offer venues for information exchange and action coordination. Efforts to standardize must pick up speed. Standards for the quality of recycled materials, recyclability test methods, recyclable textile marking, and digital tracking communication protocols would all contribute to the growth of the circular economy (Frontiers in Sustainability, 2022).

Conclusion

The use of recycling and circular economy strategies in technical textiles is critically important for Pakistan's textile industry, which accounts for 60% of exports and 8.5% of GDP, while producing over 2 million tons of waste each year. These strategies tackle the industry's global recycling rates, which are below 1% and range from 1 to 20% across technical textile categories such as geotextiles, MedTech, & Protech, by converting waste into valuable resources and reducing environmental pollution from the third most polluting industry after oil and gas. Circularity ensures sustained performance in high value applications like industrial fabrics and automotive textiles by addressing issues like blended fibers, contamination, and multi material complexity through mechanical, chemical, and enzymatic methods, positioning Pakistan as a regional leader in sustainable innovation.

The waste utilization should be increased by the regulatory changes, including Extended Producer Responsibility (EPR), blockchain/RFID traceability, public-private cooperation with recycling systems, and investments in the recycling of polycotton blends through chemical recycling (recovering 85 to 95 percent of resources). Recycling textiles can generate 50000 to 75000 direct processing employment and 100000 indirect employments through collection sorting systems in centers such as Satiana district of Faisalabad, modernizing machinery, and green financing as exemplified by 500million investment by the State Bank. This circular shift could boost the GDP by 0.5 to 1% by enhancing the competitiveness of exports, building value chains, and utilizing 887 kilotons of pre consumer waste and 809 kilotons of imported used clothing within Pakistan

There are still major gaps in R&D including, defining long term performance standards of recycled materials in demanding services, cost efficient separation processes of South Asian pollutants and life cycle analysis of virgin and recycled technical textile. Medical technology and geotextile contamination resistant procedures, mixes scalability through enzyme processes, socioeconomic assessment of integration into informal sector and in situ recycling of embedded infrastructure are other requirements. Professional business partnerships, including with National Textile University, would solve the problem of inadequate infrastructure and encourage true circularity.

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