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Textile Waste as a Future Resource: Sustainable Approaches toward Circular Fashion

A Comprehensive Review

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Abstract— **The global textile and apparel industry generates approximately 92 million tons of waste annually, positioning it as one of the most environmentally damaging industries worldwide. This review study comprehensively examines the multidimensional challenge of textile waste and explores sustainable pathways toward circular fashion economies. Drawing from over 80 peer-reviewed studies, industry reports, and life cycle assessments published between 2010 and 2025, the study systematically evaluates the sources, classifications, and environmental impacts of textile waste at the pre-consumer and post-consumer stages. Key circular economy strategies, including mechanical recycling, chemical recycling, upcycling, fiber-to-fibre regeneration, extended producer responsibility (EPR) frameworks, and digital traceability technologies, are critically reviewed. The review highlights significant advances in enzymatic and solvent-based textile deconstruction, smart sorting via near-infrared spectroscopy (NIR), and blockchain-enabled material tracking. Policy developments, particularly the European Union's Strategy for Sustainable and Circular Textiles (2022) and the revision of the Waste Framework Directive, are contextualized within global governance landscapes. Challenges including fiber blends, microplastic release, consumer behavior, and economic viability are discussed. The study concludes that transitioning from a linear take-make-dispose model to a truly circular fashion system demands integrated technological innovation, regulatory coherence, and transformative business models. This review provides researchers, policymakers, and industry practitioners with a structured evidence base to inform strategic decision-making.**

Index Terms— **Textile Waste, Circular Economy, Circular Fashion, Sustainable Textiles, Fibre Recycling, Upcycling, Extended Producer Responsibility, Waste Management**.

I. INTRODUCTION

The textile and fashion industry stands at a critical crossroads. Celebrated for its cultural significance and economic contributions, employing over 300 million people globally and representing a market valued at approximately USD 1.5 trillion, the industry simultaneously bears responsibility for severe environmental and social harm. The rapid proliferation of the fast fashion model since the 1990s, characterized by shortened design cycles, cheap synthetic materials, and disposable consumption patterns, has resulted in an unprecedented surge in textile waste generation worldwide.

According to the United Nations Environment Programme (UNEP), the fashion industry accounts for approximately 10% of annual global carbon dioxide emissions and is the second-largest consumer of the world's water supply. More alarming is its waste footprint: every second, the equivalent of one rubbish truck of textiles is landfilled or incinerated. Of the 100 billion garments produced each year, an estimated 73% end up in landfill or are incinerated, with less than 1% of the material used to produce clothing being recycled into new clothing at end of life.

These figures underscore a systemic failure of the prevailing linear economic model, one predicated on the extraction of virgin resources, manufacturing, consumption, and disposal. The concept of a circular economy, as articulated by the Ellen MacArthur Foundation, offers a compelling alternative: an industrial system designed to be restorative and regenerative by intention, eliminating waste through superior design, keeping materials in use, and regenerating natural systems.

Circular fashion, the application of circular economy principles to the textile and apparel sector, has gained considerable policy and research attention in the past decade. The European Green Deal, the EU Strategy for Sustainable and Circular Textiles (2022), and various national extended producer responsibility (EPR) regulations signal a growing regulatory impetus to shift the industry. Concurrently, technological breakthroughs in chemical recycling, fibre sorting, and digital traceability are beginning to challenge the technical and economic barriers that have long constrained textile recycling rates.

This review study aims to consolidate and critically synthesize the rapidly growing body of literature on textile waste management and circular fashion. The objectives are fourfold: (1) to characterize the sources, types, and environmental impacts of textile waste; (2) to review and evaluate current and emerging recycling and waste valorization technologies; (3) to examine policy instruments, business model innovations, and consumer behavior factors enabling circular transitions; and (4) to identify persistent challenges and propose directions for future research and practice. By doing so, this study seeks to serve as a comprehensive reference for academic researchers, industry stakeholders, and policymakers engaged in advancing sustainable fashion systems.

II. OVERVIEW OF TEXTILE WASTE: SOURCES, CLASSIFICATION, AND SCALE

2.1 Defining Textile Waste

Textile waste encompasses a wide range of discarded fibrous materials arising at various stages of the textile and garment value chain. It is broadly categorized into pre-consumer (or post-industrial) waste and post-consumer waste. Pre-consumer waste includes cutting scraps, damaged or off-specification fabrics, yarn residues, and unsold inventory generated during manufacturing. Post-consumer waste refers to garments and textile products discarded by end-users at the end of their useful life, including worn-out clothing, household textiles (bedding, towels, curtains), and footwear.

A secondary but significant category is pre-retail waste, new but unsold or returned goods that are disposed of by retailers, a practice that gained public notoriety with high-profile revelations from luxury brands and fast fashion retailers alike. The composition of textile waste is highly heterogeneous, comprising natural fibers (cotton, wool, linen, silk), synthetic fibers (polyester, nylon, acrylic, elastane), and blends thereof, alongside accessories such as zippers, buttons, dyes, and finishing chemicals.

2.2 Quantification and Global Flows

Quantifying global textile waste with precision remains methodologically challenging due to inconsistent national reporting frameworks, informal sector activity, and the diversity of textile product categories. Nevertheless, leading estimates indicate that global textile waste generation exceeds 92 million tonnes per year, with projections suggesting this figure could rise to 134 million tonnes annually by 2030 if current trends persist (Global Fashion Agenda, 2023).

The United States alone discards approximately 17 million tonnes of textile waste annually, with only about 15% collected for reuse or recycling (EPA, 2022). In the European Union, approximately 12.6 kg of textile waste per person is generated each year, with collection rates for post-consumer textiles averaging around 35-40%, though the share actually recycled into new fibres remains below 2% (European Environment Agency, 2023). In rapidly industrializing economies such as India, China, and Bangladesh, which are also the world's leading textile producers, waste generation is growing at accelerating rates alongside rising domestic consumption.

A critical concern is the physical export of textile waste under the guise of 'second-hand clothing' to Global South nations, particularly in sub-Saharan Africa and South and Southeast Asia. While such trade can provide economic opportunities and affordable clothing, it also transfers substantial waste burdens, including damaged or non-reusable garments, onto receiving countries with limited waste management infrastructure.

2.3 Environmental and Health Impacts

The environmental consequences of textile waste are multi-scalar and multidimensional. At the production stage, the cultivation of conventional cotton requires approximately 10,000–20,000 liters of water per kilogram and extensive use of pesticides and synthetic fertilizers, contributing to soil degradation and freshwater eutrophication. The dyeing and finishing of textiles releases approximately 20% of global industrial water pollution, with effluents containing heavy metals, azo dyes, chlorinated compounds, and endocrine-disrupting chemicals.

Synthetic fibres, which now constitute over 60% of global fiber production (dominated by polyester derived from petroleum), pose the additional challenge of microplastic release. Estimates suggest that a single domestic laundry cycle can release between 700,000 and 1.5 million microfibers into wastewater systems, many of which pass through conventional treatment infrastructure and accumulate in aquatic environments and ultimately in the food chain.

Landfilled textiles generate greenhouse gases (particularly methane from anaerobic decomposition of natural fibres), leach dyes and chemicals into soil and groundwater, and occupy significant land area. Incineration, while reducing volume, generates CO_2, dioxins, furans, and particulate matter if not conducted under controlled conditions with appropriate emission controls.

Table 1 Key Environmental Impacts of Textile Waste Across Life Cycle Stages

Life Cycle Stage	Primary Waste / Impact	Key Environmental Concern
Fibre Production	Pesticide runoff, water use (cotton); fossil fuel use (polyester)	Water scarcity, biodiversity loss, GHG emissions
Dyeing & Finishing	Chemical effluents, wastewater discharge	Water pollution, toxic exposure, endocrine disruption
Manufacturing	Cutting scraps, off-spec fabrics (pre-consumer waste)	Solid waste generation; material inefficiency
Consumer Use	Microfiber release during laundering	Microplastic pollution in aquatic ecosystems
End of Life	Landfill, incineration, illegal dumping	GHG emissions, leachate, land use, air pollution

III. CIRCULAR ECONOMY FRAMEWORK IN THE CONTEXT OF TEXTILE WASTE

3.1 Principles of Circular Economy Applied to Fashion

The circular economy (CE) model, as conceptualized by the Ellen MacArthur Foundation (2013) drawing on industrial ecology, biomimicry, and cradle-to-cradle design theory, seeks to decouple economic activity from resource consumption and waste generation. Applied to the fashion sector, CE principles manifest in three primary loops: (1) the inner loop of product life extension through repair, reuse, and resale; (2) the middle loop of material recovery through recycling and upcycling; and (3) the biological loop, wherein natural materials safely return to the biosphere.

Circular fashion challenges the foundational logic of the fast fashion model by redesigning products for longevity, modularity, and recyclability; shifting business models toward services (leasing, rental, subscription) rather than ownership; enabling reverse logistics for garment return and reprocessing; and creating transparent, traceable supply chains that support material recovery.

3.2 Hierarchy of Textile Waste Management

Analogous to the conventional waste management hierarchy (reduce, reuse, recycle, recover, dispose), a textile-specific hierarchy prioritizes interventions at the highest value retention level. Prevention, reducing overproduction and overconsumption through design minimalism, on-demand manufacturing, and consumer education, represents the most impactful strategy. Reuse and resale through second-hand markets preserve both material value and the embedded carbon of production. Repair and refurbishment extend product life. Recycling recovers material value, albeit with some degradation. Recovery (energy from waste via incineration) is positioned as a low-preference last resort before landfill.

Critically, the effectiveness of recycling depends heavily on upstream design decisions, including fiber composition, fibre blending, the use of permanent chemicals, and the integration of accessories. Design for circularity, encompassing mono-material design, avoidance of mixed blends, and use of detachable components, is therefore central to enabling downstream recovery.

IV. RECYCLING AND VALORIZATION TECHNOLOGIES FOR TEXTILE WASTE

4.1 Mechanical Recycling

Mechanical recycling represents the most established and commercially deployed textile recycling technology. The process involves shredding or tearing discarded textiles into fibres or flocks through a series of opening and carding machines. The resulting fibres are then used for lower-grade applications such as industrial wipes, insulation materials, geotextiles, or blended with virgin fibres for yarn spinning.

While mechanical recycling has the advantage of operational simplicity and relatively low capital cost, it significantly reduces fiber length and tenacity with each cycle, limiting its applicability for high-quality apparel production. Cotton fibres, for instance, lose approximately 40-50% of their original length after mechanical recycling, necessitating blending with virgin cotton or polyester to achieve acceptable yarn quality (Sandin & Peters, 2018). Nonetheless, advances in carding and rotor spinning technologies have improved the yarn quality obtainable from mechanically recycled fibres, and several commercial operations, including Recover (Spain) and Leigh Fibers (USA), have demonstrated viability at scale.

4.2 Chemical Recycling

Chemical recycling encompasses a range of processes that depolymerize or dissolve textile fibres to recover monomers, polymers, or other chemical feedstocks for re-polymerization into virgin-quality fibres. It holds the promise of closed-loop, fibre-to-fibre recycling with quality retention comparable to virgin materials, representing a significant advance over mechanical recycling.

For polyester (PET), glycolysis and metanalysis processes break down the polymer into dimethyl terephthalate (DMT) or ethylene glycol (EG) monomers, which can be re-polymerized into virgin-equivalent PET. Companies including Cabrios (France), Worn Again Technologies (UK), and Eastman (USA) have demonstrated pilot and pre-commercial scale operations. For cellulosic fibres (cotton, viscose), lyocell-type processes using ionic liquids or N-Methylmorpholine N-oxide (NMMO) solvents can dissolve and re-spin fibres; Ioncell-F (Finland) and Renewlonto (Sweden/Spinnova) represent notable research and commercial developments in this space.

Enzymatic hydrolysis, employing cellulase or protease enzymes to selectively degrade cellulosic or proteinaceous fibres, offers a milder, more selective alternative with lower energy requirements. Research groups have demonstrated the feasibility of using cellulases to hydrolyse cotton selectively from cotton-polyester blends, recovering both glucose (for bioethanol or platform chemical production) and the polyester component (Quartinello et al., 2017). However, enzyme cost, processing time, and scalability remain barriers to commercial adoption.

4.3 Upcycling and Design-Driven Valorisation

Upcycling, the transformation of waste textiles into products of equal or higher value without downgrading material properties, has attracted growing interest both in academic literature and among fashion innovators. Unlike recycling, which typically involves material reprocessing, upcycling often leverages design creativity to add aesthetic, functional, or cultural value to discarded materials.

Industrial upcycling initiatives include the use of post-consumer denim for acoustic panels and home furnishings, the conversion of cutting-room scraps into quilted panels or patchwork fabrics, and the integration of pre-consumer waste into luxury goods. Research by Niinimäki et al. (2020) and others documents the growing commercial ecosystem of upcycling-based fashion brands, alongside the challenges of scalability, supply chain reliability, and consumer price sensitivity.

4.4 Thermal and Thermochemical Conversion

For highly contaminated or multi-material blended textiles unsuitable for mechanical or chemical recycling, thermochemical conversion technologies, including pyrolysis, gasification, and hydrothermal processing, can recover energy or chemical feedstocks. Pyrolysis of synthetic textiles yields pyrolysis oil (a fuel feedstock or chemical precursor), carbon char (potentially useful in carbon black applications), and syngas. While these processes represent a step above incineration in value recovery, they do not maintain material circularity and are best considered as solutions for residual fractions not addressable through higher-value recycling routes.

Table 2: Comparison of Major Textile Recycling Technologies

Technology	Applicable Fibres	Output Quality	Maturity Level	Key Limitation
Mechanical Recycling	Cotton, wool, polyester	Degraded (lower grade)	Commercial (TRL 9)	Fibre shortening; blend issues
Glycolysis / Methanolysis	PET / polyester	Virgin-equivalent	Pilot–Commercial (TRL 6–8)	Energy intensity; blend separation
Ionic Liquid Dissolution	Cotton, cellulosics	High (regenerated fibre)	Pilot (TRL 5–6)	Solvent cost; scale-up complexity
Enzymatic Hydrolysis	Cotton, wool, protein fibres	Monomers / platform chemicals	Research–Pilot (TRL 4–5)	Enzyme cost; selectivity in blends
Upcycling (Design-based)	Mixed post-consumer	Variable (application-dependent)	Commercial (niche)	Supply reliability; scalability
Pyrolysis / Gasification	Synthetics, blends	Fuel / char (low value)	Commercial (TRL 7–8)	Not circular; residual only

V. SORTING, COLLECTION INFRASTRUCTURE, AND DIGITAL TRACEABILITY

5.1 Waste Collection Systems

Effective textile recycling is contingent upon robust collection infrastructure that ensures sufficient volumes of adequately sorted material reach recycling facilities. Collection models broadly fall into three categories: charity or resale-driven models (e.g., Oxfam, Humana), municipal take-back schemes, and brand-operated in-store take-back programmes. While charitable and resale models primarily target reusable garments, take-back schemes increasingly aim to capture garments beyond wearability for recycling.

The deployment of smart textile collection containers embedded with fill-level sensors and GPS tracking, pioneered in cities across the Netherlands, Sweden, and Germany, has demonstrated improvements in collection efficiency and logistics cost reduction. Extended producer responsibility (EPR) schemes, where producers bear financial or physical responsibility for end-of-life management, represent a key policy instrument to expand collection infrastructure. France implemented a mandatory EPR scheme for textiles (Refashion, formerly Eco-TLC) in 2007, the world's first, providing a policy model that the EU intends to mainstream across member states through revisions to the Waste Framework Directive.

5.2 Sorting Technologies

The automated sorting of mixed post-consumer textiles by fiber composition is a critical bottleneck in the recycling value chain. Manual sorting, the dominant method globally, is labor-intensive, slow, and imprecise, unable to distinguish fibre composition by visual inspection alone. Near-infrared spectroscopy (NIR) has emerged as the leading technology for automated fibre identification, capable of distinguishing between cotton, polyester, nylon, wool, and blended compositions in real time on conveyor-belt systems.

The FIBERSORT machine, developed by Wieland Textiles and extensively piloted in the Netherlands under the Resortex and Fibersort projects (2016–2020), demonstrated classification of post-consumer textiles by fibre type with high accuracy at commercially relevant throughput rates. Hyperspectral imaging, Raman spectroscopy, and machine learning-based pattern recognition are emerging complementary or alternative approaches. Multi-sensor fusion, combining NIR, colour, texture, and shape data, shows promise for sorting blended or contaminated materials more accurately.

5.3 Digital Traceability and Blockchain

Digital product passports (DPPs), mandated by the EU Ecodesign for Sustainable Products Regulation (ESPR) from 2025, represent a transformative development in textile traceability. DPPs provide machine-readable information on a product's material composition, origin, chemical content, and end-of-life instructions, enabling accurate sorting, recycling, and regulatory compliance. Blockchain technology has been explored as a mechanism to ensure data integrity and immutability across complex multi-tier supply chains, with pilot implementations by brands including H&M, Patagonia, and Stella McCartney.

RFID tags, QR codes, and NFC-enabled labels integrated into garments provide the physical interface for DPP data retrieval by consumers, recyclers, and regulators. Integration of DPP data with automated sorting infrastructure, such that NIR scanners can query passport data to confirm fibre composition, represents a near-future operational paradigm that could dramatically improve sorting accuracy and recycling yield.

VI. POLICY FRAMEWORKS, EXTENDED PRODUCER RESPONSIBILITY, AND GOVERNANCE

6.1 The European Union's Leadership

The European Union has positioned itself as the global leader in sustainable textiles policy. The EU Strategy for Sustainable and Circular Textiles (March 2022) articulates an ambition for all textiles placed on the EU market by 2030 to be durable, repairable, reusable, and recyclable, made largely from recycled fibres, free of hazardous substances, and produced in respect of social rights.

The strategy encompasses actions on ecodesign requirements, DPPs, EPR for textiles, green public procurement, tackling microplastics, and addressing unsustainable consumption.

The EU Taxonomy Regulation and Corporate Sustainability Reporting Directive (CSRD) further oblige large companies to disclose their environmental impacts and strategies, including textile waste management. The revision of the Waste Framework Directive is expected to mandate separate collection of textiles in all EU member states from 2025, a measure designed to significantly increase the volumes of post-consumer textiles available for reuse and recycling.

6.2 Extended Producer Responsibility Schemes

EPR schemes for textiles operate by making producers, brands and importers, financially responsible for the end-of-life management of the products they place on the market. France's Refashion scheme, operational since 2007, has collected over 700,000 tonnes of post-consumer textiles and distributed over EUR 300 million in funding to the reuse and recycling sector since its inception. The Netherlands, Sweden, and Italy have introduced or are developing analogous national EPR frameworks.

Key design parameters of effective EPR schemes include the scope of products covered, fee modulation based on Ecodesign criteria (rewarding recyclable, durable products), governance structures (industry-led vs. government-administered), and data reporting requirements. Evidence from the French model suggests that EPR can catalyze collection infrastructure expansion, market development for recycled materials, and research and innovation investment.

6.3 Global Governance Gaps

Outside the EU, policy frameworks for textile waste remain fragmented and often weak. The United States lacks federal legislation specific to textile waste, relying largely on voluntary brand initiatives and municipal solid waste regulations. In major textile-producing countries, Bangladesh, Vietnam, Cambodia, Pakistan, the rapid growth of domestic consumption adds to existing waste management challenges, while regulatory and enforcement capacity remains limited. The Basel Convention's 2019 amendment, extending controls to plastic waste trade, has prompted discussions on analogous provisions for textile waste exports, but binding international mechanisms remain absent.

VII. CIRCULAR BUSINESS MODELS AND CONSUMER BEHAVIOR

7.1 Circular Business Model Innovations

The transition to circular fashion necessitates fundamental rethinking of fashion business models beyond product sales. Clothing rental and subscription services, exemplified by Rent the Runway (USA), Hirestreet (UK), and Fjong (Norway), decouple garment ownership from use, enabling higher utilization rates, centralized maintenance and end-of-life management, and reduced per-use resource intensity. Peer-to-peer resale platforms, including Vinted, Depop, and ThredUp, have democratized the second-hand market, with ThredUp's 2023 Resale Report projecting the global second-hand apparel market to reach USD 350 billion by 2027.

Product-as-a-service (PaaS) models, wherein brands retain ownership of garments and offer access on a subscription or leasing basis with full responsibility for maintenance, repair, and end-of-life management, represent a more radical restructuring of the value chain with theoretically optimal circularity outcomes. Muddy Boots (workwear leasing, UK) and MUD Jeans (denim leasing, Netherlands) offer commercial precedents, though the financial viability and scalability of PaaS at mass-market scale remains an active research and business challenge.

7.2 Consumer Behavior and the Value-Action Gap

Despite widespread consumer awareness of environmental issues associated with fashion, behavioral change has lagged significantly behind stated preferences, a phenomenon known as the value-action or attitude-behaviour gap. Research consistently identifies price, convenience, aesthetic aspiration, and social identity as dominant determinants of purchasing behavior, frequently outweighing environmental considerations (Bly et al., 2015; Ritch & Schröder, 2012).

Behavioral interventions including social norms messaging, carbon footprint labelling, gamification of sustainable choices, and default nudges at point of purchase have demonstrated variable efficacy in controlled studies. Structural facilitators, including convenient and free garment return schemes, rental affordability, and robust second-hand market access, are increasingly recognized as more reliably effective than information-based approaches alone in driving sustainable consumption behaviors at scale.

VIII. PERSISTENT CHALLENGES AND RESEARCH GAPS

8.1 Technical Challenges: Fibre Blends and Contamination

The predominance of blended fibre textiles, particularly cotton-polyester blends that account for an estimated 40-50% of global textile production, represents one of the most significant technical barriers to circular textile recycling. Existing chemical recycling processes are largely fibre-specific, requiring prior separation of blend components. Selective dissolution systems that can preferentially separate cotton and polyester from blended fabrics are under active research development but have not yet achieved commercial viability.

Contamination of post-consumer textiles, from residual detergents, fabric softeners, biological matter, and intentionally added functional finishes (water repellents, flame retardants, antimicrobials), presents additional processing challenges, particularly for chemical recycling processes sensitive to impurities. Hazardous chemical substances including PFAS (per- and polyfluoroalkyl substances), used extensively as durable water repellent (DWR) treatments, complicate both recycling and composting pathways.

8.2 Economic Viability

The economics of textile recycling remain challenging relative to virgin material production, particularly in periods of low oil prices (which reduce the cost competitiveness of recycled polyester) and cotton price fluctuations. The costs of collection, sorting, transportation, and processing frequently exceed the market value of recovered materials, necessitating policy support, producer responsibility levies, or premium market positioning to bridge the economic gap.

Life cycle assessments consistently demonstrate that recycled textiles offer environmental advantages over virgin production, but these environmental benefits are not directly monetized under current market pricing, which externalizes environmental costs. Carbon pricing mechanisms, green public procurement criteria, and Ecodesign requirements that mandate minimum recycled content represent policy tools to internalise these externalities and improve the economic case for recycled textile materials.

8.3 Microplastic Pollution

The release of synthetic microfibers during washing of polyester, acrylic, and nylon garments represents a growing environmental challenge with significant implications for the viability of synthetic fibre recycling. Studies estimate that washing synthetic textiles releases between 0.3 and 1.5 g of microfibers per kg of fabric per wash cycle, and that approximately 35% of primary microplastics in the ocean originate from synthetic textile washing. Mitigation strategies include fibre finishing treatments to reduce shedding, in-machine microfiber capture filters (commercial examples include Cora Ball and Guppyfriend), and wastewater treatment upgrades.

The systemic shift toward a circular fashion system, which would involve a higher share of recycled synthetic fibres, must address microplastic shedding as an integral design and process challenge, not as a peripheral concern. Research on biodegradable synthetic alternatives and durable microfibre-reducing textile finishes is therefore a priority area.

IX. FUTURE DIRECTIONS AND RESEARCH PRIORITIES

The transition to circular fashion is not a single-technology or single-policy problem but requires coordinated innovation across the entire value chain. Based on this review, the following areas are identified as critical research and development priorities:

Selective separation chemistry for fibre blends is the highest-priority technical challenge. Breakthroughs in selective dissolution, enzymatic selectivity, or physical separation technologies that can address the cotton-polyester blend problem would unlock a vast stream of currently unrecyclable post-consumer textiles. Concurrently, industry adoption of mono-material and blend-free design must be accelerated through regulatory and EPR incentive structures.

Scaling chemical recycling to industrial volumes with economic competitiveness requires sustained public and private investment in demonstration plants, risk-sharing financing instruments, and long-term offtake agreements. The construction of fibre-to-fibre chemical recycling infrastructure at the scale required to address global textile waste flows represents an enormous but necessary capital mobilization challenge.

Digital infrastructure development, including universal adoption of digital product passports, standardized data protocols, and integration with automated sorting systems, requires public-private coordination and international standardization. The interoperability of DPP systems across jurisdictions will be critical to managing global textile flows.

Systems-level modelling using material flow analysis, agent-based modelling, and integrated assessment models is needed to evaluate the systemic impacts, trade-offs, and scalability of circular fashion interventions at national and global levels. Such modelling should incorporate geopolitical dimensions of textile trade and waste flows, equity implications for Global South producer and receiver countries, and the interaction between circular economy policies and sustainable development goals.

Finally, interdisciplinary research bridging materials science, environmental engineering, behavioral economics, business model innovation, and policy science is essential to advance circular fashion from niche experiment to mainstream reality. Establishing dedicated research centres, multi-stakeholder innovation platforms, and publicly funded demonstration projects will be instrumental in accelerating this transition.

X. CONCLUSION

Textile waste represents both an urgent environmental crisis and a transformative economic opportunity. The convergence of regulatory pressure, technological innovation, business model creativity, and growing consumer awareness creates an historically unprecedented window for restructuring the fashion industry along circular principles. This review has documented the scale and complexity of the textile waste challenge, catalogued the technological and policy toolkit available to address it, and identified the critical gaps that must be bridged to realise the vision of circular fashion at scale.

The evidence reviewed here demonstrates that no single technology, policy, or business model can independently achieve circularity in the fashion sector. Mechanical recycling, while established and scalable, cannot alone close the loop on fibre quality. Chemical recycling holds transformative promise but requires significant scale-up investment and blend-separation innovation. Extended producer responsibility provides essential economic and organisational infrastructure but must be designed carefully to avoid perverse incentives. Consumer behaviour change is necessary but insufficient without enabling structural conditions.

The circular fashion transition is ultimately a socio-technical transformation requiring coherence across design, manufacturing, business models, regulation, infrastructure, and culture. The European Union's regulatory momentum provides the most ambitious framework to date; its effective implementation, replication in other major markets, and amplification through international trade policy will determine whether circular fashion remains a niche aspiration or becomes the dominant paradigm of the global textile industry in the decades ahead.

This review contributes a structured synthesis of the current state of knowledge as a foundation for informed research, investment, and policy action. The urgency of the challenge demands commensurate ambition in the response.

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