Advancing the Circular Economy: The Role of Policy, Innovation, and Sustainable Finance in Mitigating Textile Microplastic Pollution

A Master's thesis submitted by

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in partial fulfillment of the requirements for the degree of

Master of Science

in

Environmental Engineering Policy and Planning

Tufts University

August 2025

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Abstract

The textile industry is a major contributor to global microplastic pollution, primarily through the release of synthetic microfibers into aquatic environments during production, use, and disposal. Microplastic fiber pollution poses ecological and human health risks while remaining largely unaddressed in existing waste management systems. Policy, innovation, and sustainable finance are explored as important drivers in mitigating microplastic fiber pollution. Extended Producer Responsibility schemes that consider circular economy frameworks, targeted technological innovation, and impact investments are critical to systemic change. The research highlights the need for integrated strategies across governance, industry, and capital flows to achieve a sustainable and equitable textile sector while minimizing impacts on water quality.

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Introduction

The textile industry is a significant contributor to global environmental degradation, particularly through the release of synthetic microfibers into aquatic and terrestrial ecosystems. These fibers, primarily derived from polyester, nylon, acrylic, and other synthetic materials, are non-biodegradable and persist in the environment for decades. Microfiber pollution occurs throughout the textile life cycle, including manufacturing, consumer use, laundering, and disposal. Once released, these plastic microfibers enter wastewater systems, soils, and the atmosphere, eventually accumulating in marine and freshwater environments. This form of pollution presents ecological risks, such as ingestion by aquatic organisms, trophic transfer through food webs, and the transportation of chemical contaminants and pathogens. Wastewater treatment plants can capture a portion of these particles, but current infrastructure and filtration technologies are insufficient to prevent their release at scale. Regions with limited wastewater treatment capacity experience higher levels of microfiber contamination, often in areas that also serve as global centers for textile production. Addressing this problem requires systemic interventions that act across the entire value chain of the textile industry.

The circular economy framework offers a structured approach to mitigating microfiber pollution. It emphasizes three core principles: eliminating waste and pollution, circulating products and materials at their highest value, and regenerating nature. In the context of the textile industry, in combination with conscious efforts towards responsible consumption, these principles promote low-shedding or biodegradable materials, extended product lifespans, improved recycling processes, and reduced reliance on synthetic fibers. This thesis will demonstrate that effective implementation requires coordinated action from multiple sectors.

Policy frameworks can shift accountability upstream to producers, incentivizing sustainable design and establishing requirements for microfiber reduction. Innovation in biodegradable fibers, advanced textile recycling, and microfiber filtration technologies provides the technical capacity to reduce emissions at the source and during product use. Sustainable finance, particularly impact investing, can employ early-stage capital to scale these solutions, ensuring they reach commercial viability and widespread adoption. As such, this thesis examines policy, innovation, and sustainable finance as pathways for addressing microfiber pollution from the textile industry, with a specific focus on water quality impacts. It is guided by the following research questions:

How are global trends in policy, innovation, and sustainable investing supporting a transition toward a circular economy-aligned textile industry, particularly in relation to water quality and related microplastic pollution?

- ➔ What emerging technologies are driving the transition to a more circular textile industry, particularly regarding microplastic pollution and water quality?
- ➔ How are current and emerging policy and regulatory frameworks addressing the environmental impacts of the textile industry and associated microplastic emissions?
- ➔ Is sustainable finance supporting innovation in textile technologies that address microfiber pollution, and how have investment patterns evolved over time?

By analyzing legislative trends, technological developments, and investment patterns, this research aims to explore the transition toward a circular and sustainable textile economy and assess the current state of progress in these pathways.

Literature Review

The Circular Economy

The circular economy serves as an alternative framework to the traditional linear economic model, which is based on a “take-make-waste” system where resources are extracted, transformed into products, and ultimately discarded as waste. The circular economy, in contrast, seeks to “decouple economic growth from the consumption of finite resources” (Ellen MacArthur Foundation, n.d). As such, the circular economy framework recognizes that natural resources are limited and that linear consumption patterns contribute to environmental degradation, greenhouse gas emissions, and resource insecurity.

The circular economy framework is structured around three main principles: eliminating waste and pollution, circulating products and materials at their highest value, and regenerating nature. Each principle reflects a reimagining of how products are designed, used, and disposed of.

1. Eliminating Waste and Pollution: Unlike natural ecosystems, where waste does not exist, many industrial products are designed without considering the disposal of a product. The circular economy model reenvisions waste as a design flaw rather than an inevitability. In a circular system, products are designed so that their materials remain useful at the end of their life cycle. Waste can be seen as an untapped resource that, if better managed, could retain economic value and reduce reliance on raw materials and resources for production.
2. Circulating Products and Materials: Circular economy emphasizes keeping resources in use for as long as possible through reuse, repair, refurbishment, remanufacturing, and recycling. There are two key material flow cycles that facilitate keeping products and

materials in circulation. In the technical cycle, non-biodegradable materials remain in circulation through maintenance, reuse, and eventual disassembly for recycling. In the biological cycle, biodegradable materials are returned to the earth via composting or anaerobic digestion, supporting soil health and regeneration.

For both of these principles, the design of a product is central. Product disposal must be integrated into design considerations.

3. Regenerating Nature: Circular economy also incorporates principles of ecological restoration, such as regenerative agriculture. This goes beyond minimizing harm to actively enhancing natural systems.

A defining goal of the circular economy is to create new value by repurposing a product's end-of-life. This can be done by replacing production with "sufficiency," with reusing, repairing, recycling, and remanufacturing as default processes for disposal (Stahel, 2016). A study across seven European nations revealed that a full circular economy transition could cut GHG emissions by up to 70% and increase employment by about 4%, indicating both environmental and socioeconomic benefits.

Velenturf and Purnell (2021) offer a critique of circular economy frameworks, arguing that circular economy risks becoming a technology-focused market-centric approach unless sustainability is appropriately valued with considerations of social equity, intergenerational justice, or ecological regeneration. A sustainable circular economy, including systemic understanding, waste prevention, regenerative design, intergenerational equity, and inclusive governance are all integral to a more holistic and effective circular economy approach. The implementation of circular economy principles often disagrees with existing linear business models, where profitability depends on high-volume sales of short-lifespan goods. Overcoming this challenge requires not only technological innovation but also shifts in policy, business models, investor expectations, and cultural attitudes.

As such, policy interventions also play a critical role. Internalizing environmental costs, promoting credits for emission prevention, and incentivizing design for circularity can encourage broader adoption. Consumer education and awareness, both at the manufacturer level and among consumers is just as important. Professional and academic training should reflect circular principles to encourage a generational shift in business thinking and operational practices. The circular economy framework offers a vision for production and consumption that can contribute meaningfully to sustainability goals. However, its success depends on integration with social and environmental values, systemic change across sectors, and governance mechanisms that prioritize long-term well-being over short-term gains. As the literature increasingly suggests, a truly circular economy must be not only economically viable but also socially just and ecologically regenerative.

A Circular Textile Industry

The textile industry, particularly the fast fashion sector, is representative of the current linear economic model and is among the most environmentally damaging industries globally. Fast fashion is characterized by the rapid production of inexpensive garments designed for short-term use, creating vast quantities of waste and pollution. SHEIN, for example, introduced over 300,000 new items in just four months in 2022, which demonstrates the scale and speed of overproduction and obsolescence (Richardson, 2024). This model encourages excessive consumption and results in garments being worn and washed only a handful of times before disposal, accelerating the release of microplastic fibers, defined as particles under 5 mm in size, into the environment (Richardson, 2024, Niinimäki et al., 2020).

Approximately 60-65% of textile fibers globally are synthetic, with polyester being the most common material (Henry et al., 2019; Niinimäki et al., 2020). These fibers are non-biodegradable and can persist in the environment for decades. Synthetic microfibers, a significant form of microplastic pollution, are released throughout the garment life cycle, during manufacturing, consumer use (particularly during laundering), and disposal. Microfibers make up 16-35% of primary microplastics in oceans globally, and in Europe alone, synthetic textiles are responsible for 8% of ocean microplastics (European Environment Agency, 2023). Domestic laundering is a particularly significant source, as a single wash can release thousands to millions of fibers, influenced by variables like fabric type, detergent, washing temperature, and machine design (Niinimäki et al., 2020).

The environmental footprint of textile production is immense and begins upstream. During manufacturing, 25-40% of fabric is discarded as waste, and emissions from fiber production, weaving, and dyeing are often unaccounted for, especially in regions lacking proper wastewater treatment (European Commission, n.d., Niinimäki et al., 2020). Moreover, 80% of a garment's environmental impact is determined at the design stage, demonstrating the importance of sustainable design principles (European Commission, n.d.). At the end-of-life phase, many fast fashion garments are either exported to regions with inadequate waste infrastructure or landfilled, where they degrade and release secondary microplastics (European Environment Agency, 2023; European Commission, n.d.). Even incineration is not a fully effective solution, as it can emit other harmful pollutants (Niinimäki et al., 2020).

While wastewater treatment plants serve as a partial barrier to microplastic pollution, their efficiency varies. In the EU, only 56% of households are connected to tertiary treatment, the most effective stage for microplastic removal (European Environment Agency, 2023). Furthermore, microplastics that are captured in wastewater sludge can be reintroduced into the environment through land application, creating a secondary pathway of contamination through soil (European Environment Agency, 2023).

Given the vast environmental impact of the linear nature of the textile industry, the circular economy model offers a systemic solution to fast fashion's linear "take-make-waste" model. It involves rethinking every stage of a garment's lifecycle to minimize waste, optimize resource use, and extend product longevity. Sustainable design and production can be integrated through the advancement and use of low-shedding textiles, pre-washing in factories, and redesigning fabrics to reduce friction. In the consumer use and care phase, strategies focus on encouraging behaviors such as using gentler detergents and installing microfiber filters (European Environment Agency, 2023; Richardson, 2024). For end-of-life management, efforts aim to improve textile sorting, expand recycling capacity, and eliminate the export of textile waste to regions lacking adequate infrastructure (European Environment Agency, 2023; European Commission, n.d.). Additionally, a shift in business model plays a crucial role by promoting rental, resale, repair, and reuse platforms to extend the lifespan of garments (European Environment Agency, 2023).

Effective policy intervention plays a critical role in advancing circularity. Governments must enact producer responsibility laws to ensure proper management of textile waste and require brands to disclose their microfiber policies, which is an area where most still fall short (Richardson, 2024). Regulators should also establish standardized metrics to assess and control microplastic emissions, especially from synthetic textiles (Periyasamy, 2023). Although awareness is increasing, many current life cycle assessment tools fail to include microfiber pollution, which hinders accurate impact assessments. To close this gap, researchers recommend adding microfiber shedding as a measurable factor in life cycle assessment, accounting for variables such as environmental persistence, consumer washing habits, and filter effectiveness (Henry et al., 2019).

There are significant gaps in understanding and addressing microfiber pollution, requiring focused research and innovation. One significant gap includes quantifying fiber shedding throughout the textile lifecycle, and the development of analytical methods that can accurately detect and quantify microfibers across water, soil, and air is important for developing appropriate life cycle analysis tools (Henry et al., 2019). Researchers also need to conduct ecotoxicological studies to better understand the impacts of microplastics on human health and ecosystems (European Environment Agency, 2023). Advancing innovation in low-shedding materials, biodegradable alternatives, and effective fiber-capture technologies is essential to reducing microfiber release (Periyasamy, 2023).

Many consumers remain unaware of the connection between fast fashion and plastic pollution. Although synthetic garments can be akin to single-use plastics, people rarely perceive clothing as a plastic product (Richardson, 2024). Educational efforts should aim to promote smart laundering habits such as washing less frequently and using filters, raise awareness of the environmental impact of synthetic clothing, and encourage conscious consumption and support for circular business models (European Environment Agency, 2023; Richardson, 2024; Periyasamy, 2023). However, it is important not to place too much emphasis on individual responsibility. Consumers have limited control over the materials used in garments, so meaningful change must come from policy interventions, industry standards, and improved infrastructure (Richardson, 2024).

Addressing the environmental toll of the textile industry, particularly from fast fashion and synthetic microfiber pollution, requires coordinated interventions across sectors. A circular economy is not simply a waste management solution, rather, it is a proactive framework designed to reduce pollution affecting both ecosystems and human health (European Environment Agency, 2023). This transformation calls for several interconnected efforts in advancing scientific research and standardized monitoring, promoting consumer education and behavior change, ensuring corporate accountability and supply chain transparency, implementing legislative reform, and investing in sustainable infrastructure and innovation. Most importantly, it requires a cultural shift in how clothing is designed, produced, and valued. Only an integrated and collaborative approach can transition the textile industry into a truly circular system that respects ecological boundaries while meeting human needs.

Environmental Impacts of Microplastic Fiber Pollution

Since the popularization of synthetic textiles and the globalization of the textile industry, microplastic fibers have been found present in many aquatic and terrestrial ecosystems as a persistent pollutant with significant ecological consequences. Microplastic fibers from textiles enter aquatic systems through various pathways. Synthetic textiles are responsible for approximately 16-35% of total microplastic pollution in marine environments, equating to an estimated 500,000 tons of microplastic emissions annually, or 50 billion plastic bottles (European Commission, n.d.). A primary contributor to this pollution is domestic laundry, where the mechanical agitation of synthetic garments during washing releases microfibers. Once detached, these fibers enter domestic wastewater streams. High-efficiency wastewater treatment plants are capable of removing 90-99% of microplastic fibers. However, due to the immense volume of water processed, significant quantities of microfibers still escape into aquatic environments (Henry et al., 2019; Periyasamy, 2023). Despite partial retention within wastewater treatment plants, a substantial proportion of microfibers are discharged in treated effluent, ultimately reaching freshwater and marine ecosystems. For example, a single urban area with a population of 100,000 can release approximately one kilogram of microfibers per day through wastewater effluent alone (Henry et al., 2019). Furthermore, many regions around the world lack the infrastructure or technology to effectively mitigate microplastic pollution through wastewater treatment. This is particularly evident in parts of the Global South, which face challenges in clean water access and sanitation infrastructure. Unfortunately, many of these regions are also major centers of textile manufacturing and exhibit some of the highest levels of microplastic fiber pollution in their water bodies.

In addition to effluent discharge, the application of sludge on agricultural land constitutes another significant indirect pathway for microfiber contamination. When sludge from wastewater treatment plants, which often contains high concentrations of retained microfibers, is repurposed as fertilizer, it becomes a direct source of microplastics in terrestrial ecosystems. Soil organisms such as earthworms, as well as hydrological processes like infiltration and surface runoff, contribute to the transport of these microfibers into deeper soil layers. Precipitation and irrigation can further mobilize microfibers from treated soils into surface runoff, carrying them into nearby rivers and lakes.

Atmospheric transport also contributes to microfiber pollution, as fibers released into the air through activities such as drying clothes or industrial processes can travel long distances before being deposited into aquatic environments through rainfall or dry deposition (Niinimäki et al., 2020). Improper disposal of textile waste in landfills is another route of contamination. When exposed to environmental elements, synthetic particles from degrading textiles can leach into landfill leachate, which can then infiltrate surrounding water systems (Henry et al., 2019). Atmospheric deposition and landfill leakage thus represent additional sources of microfiber pollution in both terrestrial and aquatic environments (Henry et al., 2019; Niinimäki et al., 2020).

If current production and disposal practices persist, up to 22 million tons of microfibers are projected to accumulate in marine environments by the year 2050 (Richardson, 2024). These microplastic fibers have been discovered well beyond surface waters throughout marine ecosystems, including deep sea habitats and the tissues of marine organisms (Henry et al., 2019; Niinimäki et al., 2020). Freshwater systems, soils, and the atmosphere are similarly impacted, demonstrating the pervasive nature of microplastic pollution.

The ecological implications of microplastic fiber pollution are extensive. Microfibers have been documented in over 100 aquatic species, ranging from zooplankton and bivalves to fish and marine mammals (Niinimäki et al., 2020). Ingestion of these particles can lead to physical harm through gut blockage and internal inflammation, while also causing behavioral changes like false satiation that results in reduced food intake and depleted energy reserves (Henry et al., 2019; Niinimäki et al., 2020). Nanoplastics, resulting from further degradation of microplastics, are even more concerning, as they can translocate across biological membranes and accumulate in vital organs, potentially affecting neural and physiological functions in aquatic organisms (Henry et al., 2019). The trophic transfer of microfibers has also been observed, where fibers ingested by lower organisms such as plankton are subsequently consumed by larger predators, culminating in human exposure through seafood consumption (European

Commission, n.d.). This not only raises ecological concerns but also introduces potential public health risks associated with long-term, low-level exposure to microplastic-associated chemicals.

In addition to their physical impacts, microfibers serve as vectors for chemical contaminants. These fibers often carry additives such as plasticizers (phthalates), stabilizers (cadmium and lead compounds), flame retardants, and colorants that can leach into the surrounding environment and biota (Campanale, 2020). Microfibers can adsorb persistent organic pollutants and heavy metals from the water column, which become co-contaminants that amplify toxicological stress on exposed organisms (Henry et al., 2019; Campanale, 2020). Once ingested, these combined chemical and physical stressors can lead to endocrine disruption, reproductive toxicity, and bioaccumulation within food webs, posing risks to biodiversity and ecosystem functioning.

The environmental impact of microplastic pollution originating from synthetic textiles is persistent and globally pervasive. Synthetic microfibers, once released into the environment, travel through complex pathways and accumulate in terrestrial, freshwater, and marine ecosystems. The pollution resulting from microplastic fibers is not only physical debris but also a vector for a variety of chemical contaminants that threaten ecological and human health. Projections indicate that microfiber pollution will escalate in the absence of systemic change, and urgent measures are required to regulate the life cycle of synthetic textiles and mitigate microfiber release at the source to protect environmental integrity.

Human Health Impacts from Microplastic Fiber Pollution

The marine environment serves as a major reservoir for textile-derived microplastics. Studies have shown that seafood, including fish and shellfish, commonly contains microplastics, which are then ingested by humans through consumption (Campanale, 2020). Salt and bottled water also present ingestion pathways, and recent estimates suggest that humans may consume thousands of microplastic particles annually through food and drink. Once ingested, particles smaller than 150 micrometers, or microns, can potentially penetrate the gastrointestinal lining, while even smaller particles may reach systemic circulation and accumulate in organs, including the liver and brain. These findings emphasize the permeability of biological barriers and the potential for widespread distribution within the human body.

Once in the human body, microplastics are not biologically inert, as they act as vectors for a range of chemical additives and environmental pollutants. Many of these additives, such as bisphenol A (BPA), phthalates, and various heavy metals, are known endocrine disruptors, carcinogens, and neurotoxic or reproductive toxins. These compounds are not chemically bound to the plastic and may leach readily upon ingestion or inhalation. This property elevates the risk associated with chronic low-level exposure, which is increasingly likely given the prevalence of microplastics in daily life. Microplastics have the capacity to absorb and transport persistent organic pollutants from the environment, further intensifying their toxicological potential. In addition to chemical risks, biological interactions with microplastics raise further concern. Fibers can serve as mobile habitats for microbes, including potentially pathogenic bacteria (Henry et al., 2019). This "plastisphere" concept introduces the possibility that microplastics could serve as vectors for disease transmission, particularly in aquatic environments. The ingestion of microplastic-laden seafood may not only expose humans to synthetic polymers and their associated chemicals but also to harmful microorganisms attached to these particles.

While these various exposure pathways highlight the multifaceted risks of microplastics, a critical gap remains in our understanding of their long-term health impacts. Current evidence indicates that microplastics can cause inflammation, bioaccumulation of toxins, and potential endocrine disruption (Periyasamy, 2023). However, human studies remain limited, and much of the existing knowledge is gained from in vitro experiments or animal models. The chronic nature of exposure and the likelihood of bioaccumulation suggest that subtle but significant hormonal, reproductive, and neurological effects may emerge over time. The lack of standardized methodologies for detecting and quantifying microplastics in human tissues also hinders risk assessment efforts. Differences in particle size, shape, polymer composition, and surface chemistry all influence associated impacts, complicating generalizations about their health effects. Further interdisciplinary research is needed to understand the full spectrum of risks posed by microplastics, particularly those originating from textile sources, and to establish regulatory frameworks to mitigate exposure.

Innovation and Emerging Technologies

Microplastic pollution from the textile industry is increasingly recognized as a significant contributor to the global water quality crisis. Innovation and emerging technologies offer a promising pathway to mitigate this environmental challenge. These innovations can be broadly categorized into biodegradable and biobased fiber technologies, microplastic filtration systems, and synthetic textile recycling, all of which are essential for reducing microplastic release throughout the textile lifecycle.

Biodegradable and Biobased Fiber Technologies:

One of the most promising solutions is the development and adoption of biodegradable and low-shedding textile fibers. Sustainable fiber innovations at the material level focus on integrating true biodegradable materials, such as cellulose-based fibers, which break down naturally in the environment without contributing to persistent microplastic pollution

(Periyasamy, 2023). These fibers, derived from renewable resources like bamboo, hemp, or sustainably sourced wood pulp, reduce environmental burden during degradation. Biodegradable synthetic alternatives are under research, aiming to replicate the performance characteristics of conventional plastics while being less environmentally persistent (De Falco, 2019).

Microplastic Filtration Technologies:

Technological interventions aimed at capturing microplastics during laundering processes are also gaining traction. At the consumer level, washing bags and integrated filters capture microfibers before they exit washing machines into wastewater streams (European Commission, n.d.). Appliance level integrated filters can be installed directly on washing machines to trap fibers released during washing cycles. The integration of these technologies into household appliances is an integral way to reduce microplastic entry into aquatic systems at scale. At the industrial level, water filtration systems designed for textile manufacturing facilities are essential for preventing the release of microplastics during pre-treatment, dyeing, and finishing stages. Smart manufacturing systems that include prewashing protocols and integrated filtration units can reduce shedding at the source.

Recycling and Closed-Loop Systems:

The implementation of closed-loop recycling technologies also has potential for mitigating microplastic pollution. Traditional textile recycling often involves mechanical processes that degrade fiber quality and lead to increased shedding in subsequent product life cycles. However, emerging chemical recycling technologies can break down synthetic fibers into their monomers, which can then be re-polymerized into high-quality fibers with reduced shedding potential (Celys, n.d.). These technologies help maintain fiber integrity and can potentially eliminate the new production of synthetic fibers, thereby closing the loop on textile life cycles. While recycled polyester reduces the demand for petroleum-based feedstocks, it still contributes to microplastic pollution through mechanical shedding. As such, a dual focus on both improved recycling technologies and transitioning toward biodegradable fiber systems is necessary (Periyasamy, 2023).

Lastly, while not as commonly determined as a core intervention for reducing microfiber pollution, innovations at the yarn and fabric construction stages further support microplastic mitigation. For instance, compact spinning techniques and the use of continuous filament yarns can significantly reduce the number of loose fiber ends, thereby lowering shedding during use and washing (European Commission, n.d.). Denser weaves and knits reduce inter-fiber movement and surface abrasion, which are primary causes of microfiber release.

Impact Investing in Sustainable Textiles

The textile and apparel industry, a sector valued at almost $2 trillion representing over 2% of global GDP, is a major contributor to environmental degradation, particularly through microplastic pollution derived from synthetic fibers such as polyester and nylon (Fashion For Good, n.d.). Despite its grand economic scale, the industry remains entrenched in outdated, linear, and inefficient supply chain models that are ill-equipped to meet the sustainability challenges of the 21st century. Over 73% of textiles are discarded into landfills or incinerated, and less than 1% are recycled in closed-loop systems. These figures highlight the environmental urgency and the corresponding opportunity for investment-driven transformation.

Innovation in textile technologies has been slow, with few disruptive shifts since the industrial revolution. However, this inertia has created a rare window for high-impact, low-competition investment, especially as the sector undergoes mounting pressure from consumer preferences, regulatory frameworks, and sustainability commitments by global brands. Emerging technologies have begun to tackle the microplastic challenge indirectly by targeting the materials and production methods used in textile manufacturing as the core of the problem. Innovations in resource efficiency, such as closed-loop water systems and low-impact dyeing, as well as material science breakthroughs like biodegradable polymers and natural fiber blends, are gaining traction. While such innovations don’t directly eliminate microplastic shedding, they represent a shift toward cleaner, more sustainable textile processing methods that contribute to the reduction of overall pollution.

As outlined, the fashion industry has a significant and considerable environmental footprint, which has driven growth in consumer and policy demand for more responsible and sustainable practices (Fashion For Good, 2020). Despite this growing demand, the textile innovation sector remains critically underfunded, particularly at early and mid-stage venture capital levels. For example, over 1,500 innovators have been identified by Fashion for Good, yet only about 80 have received direct program support, and just $75 million has been raised collectively by these supported ventures (Fashion For Good, n.d.). The slow capital deployment rate impedes progress, especially in scaling technologies from the lab to industrial implementation. The fashion industry requires an estimated $20-30 billion annually in order to significantly mitigate environmental impacts and transition to sustainable and circular business models (Fashion For Good, 2020). This gap can be attributed to lack of awareness, as many investors remain unaware of emerging opportunities and their capacity for potential impact. A significant gap also exists in technical knowledge among investors, who often underestimate or misunderstand sustainable textile technologies. Many perceive these technologies as non-cost-competitive and tend to favor predictable and rapid returns, much like the current fast fashion model. However, dedicated investment platforms such as Textile Innovation Fund, Closed Loop Partners, and Alante Capital are working to close this gap, with strategies ranging from early-stage equity investments to debt financing for small and medium sized enterprises in Asia (Fashion For Good, n.d.).

Nonetheless, with the current $2 trillion valuation of the global fashion industry, there still remains substantial untapped opportunity for investors who are looking to drive sustainable innovations (Fashion For Good, 2020). As such, impact investing offers a compelling framework for addressing these challenges. The impact investing framework strategically directs capital towards companies and solutions explicitly designed to address pressing global challenges by prioritizing measurable social and environmental outcomes alongside financial returns (PRI, 2024). Impact investing is an important approach for accelerating and supporting sustainable innovation and stands as an emerging pathway for creating and inciting meaningful change. Unlike philanthropy and grants, or traditional Environmental, Social, and Governance (ESG) investing, which primarily evaluates risk, impact investing actively targets measurable environmental and social outcomes alongside financial returns. This dual-purpose strategy not only accelerates sustainable innovation but also supports systemic transformation by providing the long-term capital needed to scale impactful technologies.

Growth in impact investing within this sector is crucial for challenging misconceptions around sustainable fashion, validating market demand for responsible products, and driving meaningful change (Fashion For Good, 2020). This strategic approach ensures that innovative, sustainable textile technologies receive the long-term capital necessary for measurable environmental and financial impact. However, the textile innovation landscape remains underfunded, despite its potential. Bridging this gap will require collaborative efforts among investors, brands, supply chain, innovators, and public sector entities. Financing structures, such as corporate venture capital and specialized sustainability funds, offer a viable pathway toward greater investment and associated impact. Regulatory momentum, shifting consumer values, and brand-level climate commitments suggests a growing alignment between innovation in textiles and the objectives of impact investors. Addressing microplastic pollution specifically will likely require a continued push for disruptive materials, advances in filtration and fiber capture technologies, and broad adoption of circular economy principles. Innovation and emerging technologies represent a core pathway to mitigating microplastic pollution in textiles, not only for mitigating the environmental footprint of textiles, but for substantial financial returns and systemic transformation.

Methods

Through a comprehensive literature review, the study defined the Circular Economy Framework, examined the environmental impact of microplastics, and explored this impact specifically through the lens of the textile industry. The review also identified how this environmental impact is currently being addressed through policy intervention, innovation and technology, and sustainable finance. To align policy intervention with innovation and technological advancement, the sustainable textiles sector was examined using a two-part mixed methods approach:

1. An in-depth policy analysis
2. A data-driven analysis on sustainable finance trends

Policy Analysis

The policy analysis investigated federal, state, and international legislative efforts addressing microfiber pollution from the textile industry, employing a qualitative, document-based research methodology. Primary sources included enacted and proposed legislation, government strategy documents, and agency reports. State-level legislation was reviewed for New York, New Jersey, Connecticut, Oregon, and California. International policy frameworks and legislative documents were examined for France, Canada, the United Kingdom, and Australia, as well as for the broader European Union.

The policy analysis focused on Extended Producer Responsibility (EPR) and recycling policies, as well as measures aimed at mitigating microplastic pollution. These policy types were selected because they are directly relevant to the technologies identified through the literature review. In particular, EPR policies are foundational to advancing the transition toward a circular economy in the textile industry, as they create structural incentives for waste reduction and sustainable production practices.

State-level policies addressing microfiber pollution were categorized and coded according to common signals to facilitate comparison across legislative tactics. Six common policy strategies or components were identified: Financial Incentive, Mandated Adoption, Standardization, Consumer Protection, Enforcement, and Research and Development. Upon identifying common themes and recurring approaches, each bill was reviewed and categorized accordingly to highlight patterns in regulatory approaches and priorities.

Descriptive analysis was used to identify the prevalence and distribution of policy types across US states and international contexts. The analysis focused on how each policy addressed microfiber pollution sources, mechanisms for implementation, and levels of producer versus consumer responsibility. International comparisons were included to contextualize US policy approaches within global best practices, particularly with respect to circular economy principles and EPR frameworks.

No original data collection was performed for this analysis, as it is based entirely on publicly available legislative texts, government reports, and policy documents.

Sustainable Finance Analysis

In the context of microplastic pollution from the textile industry, as determined by the most commonly identified and most effective innovative and technological approaches to mitigate this environmental impact according to the explored literature, the most prominent sources are fibers released from synthetic textiles and microplastics generated through the breakdown of synthetic fibers and textiles during use and after disposal. While the release of these plastic particles affects both air and water quality, the primary pathways for water-related impacts include wastewater from personal and commercial laundering, as well as runoff from landfills and other disposal sites into surface waters. Once released, these particles ultimately make their way into waterways, where they impact aquatic and marine ecosystems and, in turn, human health.

As such, in addition to policy intervention, technological advancement and consumer awareness and education are important strategies for addressing this environmental impact. While consumer awareness and a shift in consumer behavior is equally as important for transitioning to a circular textile industry, this thesis is focused on technological and legislative approaches to mitigating microplastic pollution from the textile industry. The most prominent technological advancements in this area include innovations in bio-based fibers and textiles, textile recycling, and microplastic and microfiber filtration. Synthetic textiles remain a key component of the current economic model in the textile industry because of their affordability and accessibility, despite their inherently pollutive nature. In contrast, natural fibers can often be more labor and resource intensive to produce. Innovation in bio-based fibers and textiles offers an opportunity to bridge this gap, making non-plastic textiles more accessible and competitive. Microfiber filtration technologies for wastewater treatment facilities or in personal and commercial laundering help maintain water quality by capturing fibers close to the point of release. Textile recycling technologies extend the lifecycle of textile products and mitigate pollution associated with textile waste and improper disposal, both of which are critical to reducing the industry's environmental footprint.

Informed by the literature review and associated market research, the identification of three key technologies, bio-based fibers and textiles, textile recycling, and microfiber filtration, as the most prominent practices in sustainable textiles for addressing microplastic pollution in water quality guided the subsequent data analysis. This focus provided the basis for examining how impact investing in sustainable textiles is contributing to addressing this environmental impact.

A comprehensive list of innovative companies within these technological sectors was compiled through secondary research methods, drawing from multiple sources to identify relevant market actors. The primary tool for this process was PitchBook, a financial data and software platform that provides detailed insights into global capital markets. Pitchbook was founded in 2006, and was acquired by Morningstar, an American financial services firm, in 2016 (Wikimedia Foundation, 2010). PitchBook specializes in private and public equity, including venture capital, private equity, and mergers and acquisitions, and offers access to comprehensive datasets, research, and analytical tools relevant for deal sourcing, due diligence, fund analysis, and market research. PitchBook is widely used by professionals in venture capital, private equity, and investment banking to identify startups, investors, and deal flows, as well as to conduct due diligence and market assessments (Research Guides at Purdue University Libraries, n.d.). For this analysis, PitchBook was particularly valuable for collecting detailed information on companies and associated deal flows within the sustainable textiles sector. This allowed for the exploration of trends in early-stage sustainable finance and impact investments.

The first step in compiling this list was to identify as many innovative companies as possible that are addressing the environmental impact of microplastic pollution from the textile industry. ChatGPT Model GPT-4o was used as a research tool to streamline this process and assist in identifying relevant companies (OpenAI, 2023). A total of four iterations of chats were conducted. The first two sessions began with broader prompts, while the final two used more detailed inputs specifying the target technologies to search for.

An initial attempt was made to conduct these searches directly in PitchBook, which yielded a small number of relevant lists. However, the technologies being targeted were too specific for PitchBook's search capabilities. While the platform offers a comprehensive Advanced Search tool, it proved challenging to generate an adequate list of companies that met the precise criteria required. The search parameters needed to identify companies working at the intersection of three elements: specific technologies (bio-based fabrics, textile recycling, and microfiber filtration), the industry (sustainable textiles), and the environmental impact (reduction of microplastic pollution). Because of these constraints, additional sources were required to construct a customized database. Pre-constructed lists from external sources were incorporated, and ChatGPT was used to input more tailored criteria, allowing for the identification of additional companies. This approach was particularly important in the context of impact investing, where measurable positive environmental outcomes are valued alongside financial returns. PitchBook's filtering options were limited in this respect, as the platform does not allow for effective screening based on a company's capacity for environmental impact. ChatGPT, in comparison to Pitchbook, allows for more descriptive inputs, where specific descriptions of technologies that address particular impacts are allowed. Less descriptive and more descriptive inputs were used, with the more descriptive inputs drawn from the development of the literature review where the core technologies were identified. By having more flexibility with the input criteria, ChatGPT allowed for the companies searched for to have a particular environmental impact. By being able to define environmental impact alongside the technology developed by the company, the output company list was more likely to meet impact investing criteria, as the output set of businesses were defined to be targeting key environmental impacts.

It was necessary to identify a sufficient number of companies to ensure enough data points for meaningful statistical analysis. A larger dataset increases the accuracy, reliability, and generalizability of the findings, allowing for stronger conclusions to be drawn from the analysis.

Chat 1:

This chat was initiated with the prompt "can you give me a list of the fifty most innovative companies focusing on biodegradable and biobased alternatives to synthetic textiles." The output was a list of 32 companies defined into four groups of Biotech & Biofabrication Leaders, Plant-Based & Agricultural Waste Innovators, Circular Economy & Recycling Pioneers, and Large-Scale Sustainable Textile Manufacturers. This list included the country of the company's headquarters and a short description of their technology. The chat continued to generate more companies with the prompt “What about companies that focus on innovation that reduces Microfiber pollution from laundry, like filtration technologies.” The output was a list of nine relevant companies with details on the headquarters location, product, function, usage, and website link.

Chat 2:

The first prompt of Chat 2 was “give me a list of 100 most innovative companies focusing on biodegradable and biobased alternatives to synthetic textiles.” The output was a list of 50 companies with brief descriptions defined into two groups as Leading Material Innovators and Emerging Startups & Innovators. The chat continued with a prompt to combine this list with the 32 company list output from Chat 1. The output was a list of 90 companies with country of headquarters and a brief product description, grouped under Biotech & Biofabrication Leaders, Plant-Based & Agricultural Waste Innovators, Circular Economy & Recycling Pioneers, Large-Scale Sustainable Textile Manufacturers, Emerging Startups & Disrupters, Innovative Material Developers, Specialty Biobased Textiles & Next-Gen Materials. In order to narrow down on the environmental impact addressed by these companies, the next prompt introduced was “Do all of these technologies reduce plastic microfibers from synthetic textiles? Beware that mechanical recycling processes actually increase microplastics rather than decrease.” The chat output a breakdown summary of technologies that avoid microplastic shedding altogether and technologies that might still produce microplastics. Once that definition was established, the current list was again attempted to be expanded with the prompt “Can you add to this list with any other technologies you can find for microplastic-free textile technologies?” This prompt gave an output of 10 companies with descriptions on the technology, benefit, and a source link. Attempts to expand the list continued with the prompt “Can you find another 100?” that gave an output of another 10 companies with descriptions of technology, benefit, and source. The chat continued to consolidate all output lists, find headquarter locations, and create a .csv file with columns for company name and headquarters location, with a total of 110 companies.

Chat 3:

A more descriptive approach was taken for this chat, with the initial prompt being "Give me a list of 100 companies innovating technologies that fit this description: Technological interventions aimed at capturing microplastics during laundering processes are also gaining traction. At the consumer level, washing bags and integrated filters capture microfibers before they exit washing machines into wastewater systems (European Commission, n.d.). Appliance level integrated filters can be installed directly on washing machines to trap fibers released during washing cycles. The integration of these technologies into household appliances is an integral way to reduce microplastic entry into aquatic systems at scale. At the industrial level, water filtration systems designed for textile manufacturing facilities are essential for preventing the release of microplastics during pre-treatment, dyeing, and finishing stages. Smart manufacturing systems that include prewashing protocols and integrated filtration units can reduce shedding at the source." This gave an output list of 20 companies with descriptions, sorted into the categories of Consumer-Level & Retrofit Filters, Washing Machine Manufacturer Integrations, Industrial-Scale & Textile-Facility Solutions, and Material & Pre-Shedding Innovators. The next prompt was "Create a list of 100 companies focusing on filtration technologies for microplastic fibers." The final output was a list of 63 companies with their headquarters locations, downloaded as a .csv file.

Chat 4:

The initial prompt for this chat was "Give me a list of 100 companies innovating technologies that fit this description: The implementation of closed-loop recycling technologies also holds promise for mitigating microplastic pollution. Traditional textile recycling often involves mechanical processes that degrade fiber quality and lead to increased shedding in subsequent product life cycles. However, emerging chemical recycling technologies can break down synthetic fibers into their monomers, which can then be re-polymerized into high-quality fibers with reduced shedding potential (Campanale, 2020). These technologies help maintain fiber integrity and can potentially eliminate the new production of synthetic fibers, thereby closing the loop on textile life cycles. While recycled polyester reduces the demand for petroleum-based feedstocks, it still contributes to microplastic pollution through mechanical shedding. As such, a dual focus on both improved recycling technologies and transitioning toward biodegradable fiber systems is necessary (9)." This gave an output of 20 companies with descriptions, which was then expanded with the prompt "Aim for a list of 100." This gave a list of 100 companies, falling under the categories of Chemical Depolymerization & Closed-Loop Recycling, Enzyme/Biotech Recycling, Biodegradable/Biosynthetic Fibers, Sustainable/Natural Fiber Producers, Textile-to-Textile (Mechanical + Chemical Combined), and Sorting, Dyeing, and Microplastic Prevention Tech. This list was exported as a .csv file with names of companies and their location.

Another data source was Tracxn's list of Top Sustainable Fabrics startups, which gave a list of 253 innovators in the sustainable fabrics sector (Tracxn, 2024) that was downloaded as an xslx. file. Tracxn is a market intelligence platform that specializes in data for private companies, with a strong focus on startups. It is often used by venture capital firms, private equity investors, and corporate development teams to monitor and evaluate startups across a wide range of technology sectors. The platform provides an extensive database of private companies and helps users in source investment opportunities, identify mergers and acquisition prospects, and track industry trends.

Lastly, PitchBook's Advanced Search function was used to identify relevant companies operating within the textile and innovation sectors, particularly those developing plant-based and synthetic textile technologies. Three separate search queries were conducted. The first search applied filters for the industry "Plant Textiles" and included all venture capital deal stages, which yielded a total of 132 companies. The second search filtered for companies in the "Synthetic Textiles" industry with an additional vertical filter for "CleanTech," resulting in 83 companies. A third query used the keywords "Textiles" and "Innovation" within the "Textiles" industry and employed a less restrictive OR-based logic, which identified 420 companies.

The lists obtained from ChatGPT and Tracxn were uploaded to Pitchbook and combined with the lists from Pitchbook's Advanced Search function to create a custom list. After cleaning and combining the results from all three sources, as well as filtering for companies in early financing stages, a list of 265 companies was compiled for further analysis.

From there, Pitchbook's descriptions for companies were manually reviewed to determine the accuracy of the compiled list and the relevancy of the company. Only companies that seemed to fall under the distinguished technology categories of Biobased Fibers and Textiles, Textile Recycling, and Microplastic and Microfiber Filtration. Each company was labeled according to sector. The final list consisted of 127 companies, and can be found in the appendix, with 94 companies in Biobased Fibers and Textiles, 7 companies in Microplastic and Microfiber Filtration, and 26 companies in Textile Recycling. Between these companies, there were a total of 692 deals.

The data used in this analysis was downloaded from Pitchbook as two .xslx files, one containing company information and another containing deal transaction data for the companies listed in the first file. These files were imported into a Jupyter Lab environment (Jupyter 4.4.0, Python 3.7.1) and analyzed using Python. The Python libraries used for this analysis are pandas, matplotlib, seaborn, numpy, statsmodels, and scikit-learn. The company and deal datasets were read into separate data frames and merged on the company name to create a unified dataset that included both the deal transactions and the textile technology sector information previously identified. All date values were standardized to datetime format, and entries with missing or invalid dates were excluded. A Year column was derived from each deal's date to facilitate time-series analysis, and the dataset was filtered to include only deals from the years 2000 to 2024, since 2025 is currently ongoing.

Exploratory analysis and visualizations were conducted using matplotlib and seaborn with consistent styling applied using the whitegrid theme and tab20 colormap. Stacked bar charts were used to illustrate how deal volume varied across sectors and deal types over time. A line plot was also created to highlight trends in specific deal types, including Accelerator/Incubator, Grant, Seed Round, Early Stage VC and Later Stage VC financing. Two additional stacked bar charts were created, grouping deal volume of Accelerator/Incubator and Grant in one and Seed Round, Early Stage VC, and Later Stage VC in the other to compare public and private market financing.

To analyze long-term trends in deal volume, three regression models were developed: linear, log-linear (exponential), and quadratic. For each model, annual deal counts were regressed against time using ordinary least squares (OLS), which is a method commonly used to find a best-fitting like. The linear model assumed a constant rate of change, while the log-linear model applied a logarithmic transformation to the response variable to model exponential growth. The quadratic model, on the other hand, introduced a squared time term to account for potential curvature in the trend. RMSE (root mean squared error) calculations were used to evaluate model performance and fit, where a lower value indicates a better fit. While both linear and log-linear models provided a reasonable approximation of the data, the quadratic model ended up as the best fit based on visual inspection and better RMSE value. As such, it was selected as the preferred model for interpreting the evolution of deal activity over time. The residuals for each model were also plotted, where residuals are the difference between the observed value of a data point and the value predicted by a statistical model. Residuals can be an indicator of model fit, where a random scatter of plotted residual points indicate a good fit.

Based on a visually identified inflection point, the time frame was segmented into two periods of before and after the inflection point. Regression analyses were then performed for each segment to better understand the trends within these distinct phases. A polynomial regression quadratic fit was determined to be the best model for the first segment, while a simple linear regression was most appropriate for the second.

Policy Analysis

Policy is a key driver in holding companies accountable for their environmental impact, which makes the policy landscape surrounding textile waste highly relevant to this analysis. This section explores state and federal legislation in the US related to textile recycling infrastructure and microfiber pollution, in order to understand which types of policies are most prevalent, where they have been most effective, and where gaps remain. In addition to domestic policy, this analysis also considers international approaches to textile regulation. These global comparisons help contextualize the US policy landscape and highlight examples of better-integrated frameworks that could inform future strategies.

Extended Producer Responsibility

Legislation targeting textile recycling and textile waste management, while not directly targeting microfiber pollution, are important and relevant in mitigating the environmental impact of microfiber pollution on water quality by limiting microfibers collected in runoff from textile waste and disposal and increasing the lifecycle of textile products. Legislation on textile recycling was pioneered by France in 2007, introducing the Extended Producer Responsibility (EPR) principle in the textile industry, which integrated the circular economy framework into processes for dealing with textile waste (Lüttin, 2025). EPR is an environmental policy framework intended to place accountability for waste and a product's lifecycle on the producer rather than the consumer. The producer is held responsible for the entire lifecycle of a product, primarily concerning the end of a product's lifecycle, which can be accounted for through waste management and recycling considerations. Particularly for the textile industry, fashion brands are responsible for collection, recycling, and reporting of textile waste. The key requirements of EPR is reporting the amount of textile products entering the market by quantity or weight, implementing collection schemes to take back used items from consumers, and fees for producers based on the amount of textiles sold, which are then used to fund and maintain textile waste management and recycling infrastructure. These fees are often eco-modulated, where the fees can be very demanding on the environmental performance and impact of a product. This component provides a financial incentive to companies to integrate more sustainable design in their products. Producer Responsibility Organizations (PROs) are often another important part of the EPR framework. PROs are tasked to handle the logistics of waste collection, recycling, and disposal for producers. Joining a PRO is not always legally required as a part of EPR policy scheme, but in general it is highly recommended for efficiency in compliance and operations according to the requirements of an EPR scheme.

Legislation on Extended Producer Responsibility

As mentioned, France was the first country in the world to implement an EPR scheme for textiles in 2007, where the primary goal was waste collection and sorting, which was managed by Refashion, as France’s sole PRO for textiles. With this legislation, brands are required to finance the collection, sorting, and recycling of their products, and are required to reuse and recycle unsold products with the prohibition of unsold products. In February 2020, the Anti-Waste Law for a Circular Economy (AGEC) was enacted and greatly expanded on the 2007 law, where the ecomodulation component awards companies for using recycled materials, environmental certifications, and enhanced durability features, while penalizing companies for using materials that are difficult to recycle (The AGEC Law and European Regulations, n.d.). France’s EPR system has increased the budget for supporting textile recycling, in efforts to increase recycling capabilities and efficiency of collection points. As such, they are demonstrating how EPR can go beyond being a tool to manage waste, but also to promote circular business models where waste creation is prevented and more than just managed. The ecomodulation component is important for promoting technological advancements and adoption of new technologies.

Beyond legislation targeting textile recycling practices and infrastructure, France has emerged as a global leader in regulating microfiber pollution through AGEC. Aligned with Europe's Green Deal commitment to climate neutrality by 2050, AGEC emphasizes reducing waste and pollution through circular economy principles. The law mandates environmental labeling for textiles, requiring garments composed of more than 50% synthetic fibers to include clear warnings about microfiber shedding, disposal instructions, and recycling options. Manufacturers are financially responsible for environmental damage under a "polluter pays" model, facing penalties of up to 5% of annual revenue for repeat violations. From January 2025, all new washing machines sold in France must be equipped with microfiber filters.

In March 2020, the European Commission released the Circular Economy Action Plan (CEAP) as a key component of the European Green Deal (Lüttin, 2025). The CEAP outlines a plan with an aim to minimize waste generation and prevent pollution by centering around the promotion of sustainable product design, efficient waste management, and using recycled materials. The European Green Deal's goal is to achieve climate neutrality by 2050, reduce resource consumption, and enhance economic resilience. The textile industry is a key sector that the plan targets. The CEAP addresses textiles through the EU Strategy for Sustainable and Circular Textiles. This strategy outlines the EU's path for reforming the textile industry by 2030, by outlining goals for discouraging fast fashion and overproduction, addressing microplastic pollution, increasing supply chain responsibility, and increasing durability, reusability, and recyclability of textile products. This strategy laid the foundation for the Ecodesign for Sustainable Products Regulation (ESPR).

The ESPR legislation was approved in July 2024, where the adoption and implementation of sustainable design in textiles is greatly encouraged, recognizing that 80% of a product's environmental impact is determined during its design phase. This law ensures that the products placed on the EU markets are more durable, repairable, reusable, and recyclable, with specific ecodesign criteria geared towards this goal. The ESPR also introduced the Digital Product Passport (DPP), which is a mandated QR code label on garments that provides details on a product's carbon footprint, amount of recycled content, and other details. This labeling supports transparency and traceability while streamlining recycling efforts, informing consumers, and supporting supply chain transparency.

The Waste Framework Directive (WFD), an EU legislation adopted in 2021, requires member states to establish textile waste collection systems by January 2025. The WFD was amended in 2023 to be a more robust EPR scheme similar to France's, where textile producers are required to finance the infrastructure for post-consumer textiles, with fees calculated based on ecomodulation and requirements for producers to report the amount of textiles they are placing on the market. With this legislation, compliance to a circular textile industry is mandated, as there is strong financial incentive for brands to embrace circularity.

The CEAP, ESP, and WFD outline a comprehensive regulatory framework that has the potential to effectively shape the EU textile industry. As such, this framework allows brands and the textile industry as a whole to move beyond managing waste to actively preventing it, as brands are required to integrate sustainability into product design, production, marketing, and post-consumer management.

In the United States, notable legislative action comes at a state-level where California and Massachusetts are paving the way. In September 2024, California enacted the Responsible Textile Recovery Act of 2024 (SB 707) and became the first US state to establish a comprehensive EPR framework for clothing (Sidman et al., 2024). Under this law, all apparel producers selling in California are required to join a PRO, and each PRO is required to implement a textile stewardship program by 2030, geared towards creating a circular system for textile waste. These programs will include clothing drop-off sites and mail-back collections, with garment collections to have processing protocols for reuse and recycling pathways, thus minimizing landfill disposal. These PROs are also to be in charge of consumer education and outreach to increase awareness of proper disposal behavior. Funding for this program comes from civil penalties for violations of this regulation, and from participating producers with fee levels based on the company's sales volume within California. This is different from the EU and France, as the funding for the PRO systems in California comes from the company's volume rather than the environmental impact of the garment, with ecomodulation factored in. The fees based on environmental impact, alongside ecomodulation of fees, better incentivizes companies to adopt sustainable textile technologies and give greater consideration to the environmental impact of their clothing.

Massachusetts has legislation banning the disposal of textile waste (Mass.gov, n.d.). Instead, textiles must be recycled at designated textile drop-off boxes. This ban was implemented in November 2022. It is part of a larger plan to reduce overall waste disposal in Massachusetts by 30% by 2030. This ban prohibits textiles from being disposed of in general landfills. Instead, textiles must be donated or recycled in designated textile collection bins and textile recyclers. The Massachusetts Department of Environmental Protection (MassDEP) has a Beyond the Bin recycling directory with a list of drop off locations and organizations that will resell, reuse, recycle, or repurpose textiles. MassDEP has a statewide education initiative called Recycle Smart Massachusetts that educates consumers on recycling practices, including for textiles. MassDEP has also awarded grants to businesses and municipalities to develop and expand textile collection programs. Many communities in Massachusetts have established collection sites, drop-off bins, and curbside collection programs. While this ban still promotes textile recycling and attempts to create circularity within the textile industry through better waste disposal practices, it cannot be considered an EPR scheme, as the responsibility largely lies on local governments to facilitate the education of consumers, rather than the textile producers. The state government is in charge of financing this system, which can be a limited source of funding and does not promote a circular pathway for reducing pollution from the textile industry.

The table below organizes the components of each discussed EPR framework to better understand and compare the components of each.

Region	**Name of Strategy**	**Date Introduced**	**Components**
European Union	Circular Economy Action Plan	2020	Labeling for consumer awareness
			Incentivized ecodesign of products
	Waste Framework Directive	2021, 2023	Producers finance textile recycling infrastructure
			Producer Responsibility Organizations
			Ecomodulation
			Microfiber pollution control
			Penalties for non-compliance
France	Anti-Waste Law for a Circular Economy	2020	Labeling for consumer awareness
			Producers finance textile recycling infrastructure
			Producer Responsibility Organizations
			Ecomodulation

			Microfiber pollution control
			Penalties for non-compliance
California, United States	Responsible Textile Recovery Act	2024	Producer Responsibility Organizations
			Consumer awareness campaigns
			Penalties for non-compliance

Table 1. Extended Producer Responsibility Schemes and Components

The AGEC in France, especially compared to policy frameworks prevalent in the United States, takes a more Extended Producer Responsibility (EPR) approach, where producers bear the burden of being more financially and physically responsible for environmental impacts and end-of-life management of products (How to Build a Circular Economy, 2022; RSS, 2025). However, US policies focus on washing machine filtration, less so on upstream textile manufacturing practices, while France holds manufacturers financially liable for shedding through the "polluter pays" model and mandated labeling on garments on proper care and disposal, accounting for the product's entire life cycle.

Targeted Microfiber Filtration Legislation

At the federal level, the United States currently does not have active, comprehensive legislation specifically regulating microfibers and microplastic pollution generated by the textile industry. However, since 2020, there has been a push for more research and policy development in this area to inform scientists, policy makers, and consumers of environmental impacts from microfiber pollution and the textile industry.

The Save Our Seas 2.0 Act, enacted in December 2020, was a significant legislative step towards addressing marine debris and plastic pollution, which explicitly included microfiber pollution (Save Our Seas 2.0, 2020). Save Our Seas 2.0 was an amendment to the Marine Debris Act of 2006, which prompted legislative action for addressing marine debris in US waters by authorizing NOAA to identify, assess, prevent, and remove marine debris and to mitigate its harmful impacts on the marine environment, economy, and navigational safety (NOAA, n.d.). Building upon this framework, the Save Our Seas 2.0 Act promoted federal efforts through establishment of a Marine Debris Foundation, allocation of grant funding for innovative solutions, mandated studies, pilot projects, and reports to facilitate evidence-based policymaking, and by integrating circular economy principles. Particularly addressing microplastic pollution, the Act mandates the Interagency Marine Debris Coordinating Committee (IMDCC) to develop a comprehensive report for Congress on microfiber pollution. In July 2024, the IMDCC, alongside the EPA's Trash Free Waters program and NOAA's Marine Debris Program, published the 2024 IMDCC Microfiber Pollution Report (IMDCC, 2024). This report clearly defines microfiber pollution, identifies its major sources and causes, assesses its prevalence, recommends standardized accounting methods for measurement, and proposes concrete actions and policy strategies for reducing microfiber emissions. As such, this report was an important step toward defining the issue and informing legislative and regulatory actions (Microplastic Marine Debris Fact Sheet, n.d.).

In addition to the Save Our Seas 2.0 Act, in 2023, the US EPA released a Draft National Strategy to Prevent Plastic Pollution, which acknowledged microfiber plastics as an emerging issue, recognizing the textile industry as a significant polluter of marine ecosystems. A final draft of the strategy was submitted in November 2024, demonstrating commitment to addressing this issue. The strategy emphasized a need for investment in research, particularly into microfiber capture technologies, such as filtration systems for washing machines (National Strategy to Prevent Plastic Pollution, n.d.).

Beyond federal actions, significant strides have been made at the state level across the United States to address microfiber pollution, with California leading the movement since 2018. States including New Jersey, New York, Connecticut, Illinois, and Oregon have all proposed legislation aimed at monitoring and mitigating microfiber pollution (Kupec, 2022). These legislations fall under six categories of policy strategy or component: Financial Reward/Incentive , Mandated Adoption, Standardization, Consumer Protection, Enforcement, Research and Development.

The most common type of policy strategy or component is Mandated Adoption, with the most common type of policy being a requirement for all new washing machines sold to have an installed microfiber filter, typically after a defined date. This policy typically has associated Standardization and Consumer Protection components, with these categories being the subsequent most common policy. The Standardization policy component typically is defined as a standard requirement of a 100 micron mesh size for filters, while the Consumer Protection component is a labeling requirement to inform consumers of proper maintenance of microfiber filters on washing machines, as well as to inform consumers of occurrence of microfiber shedding and associated impacts. While it is unclear exact determination of the 100 micron mesh size standardization (where and how it was first defined), it is defined in California's Statewide Microplastic Strategy, released in February 2022 by the California Ocean Protection Council, as the "science-based standard for microfiber filtration systems" (Statewide Microplastics Strategy, n.d.).

While most of these bills have not been ratified into law, they demonstrate the increase in awareness and concern regarding this environmental issue. California's most recent push towards this legislation, AB 1628, or Microfiber Filtration Bill, had passed the state senate and assembly but was eventually vetoed by the Governor, who suggested an incentivization over a mandate due to potential financial burdens on consumers. Interestingly, Financial Incentive was the least common strategy across the proposed legislation addressing microfiber pollution in the United States (Bill 1628, 2023).

Aside from Financial Incentive strategy, the least common types of policy are Enforcement and Research and Development. However, enforcement strategy has garnered increasing traction in recent years, 2024 and 2025, as the overall push and drive for legislation on microfiber regulation has increased across the country and gained prominence in more states. Despite the limited number policy on Research and Development, this category has seen the most success with Connecticut's HB 5360, or the Act Concerning Clothing Fiber Pollution, being the only state level legislation that has been ratified into law. HB 5360, ratified in February 2018, established a working group to promote consumer awareness regarding microfiber pollution. The group's 2020 report recommended capturing microfibers closer to their source and urged clothing manufacturers to innovate in fabric production, shedding reduction, and consumer education. The report further suggested appliance manufacturers explore options for internal washing machine filters to effectively capture microfibers (Jenner & Block, 2020).

The numerous attempts at state-level legislation for regulating microfiber pollution, especially the increased attempted movements as the years have gone on, demonstrates that overall interest and push for this legislation has increased while federal legislation has stagnated and is limited in efforts. Within the state-level attempted legislation, financial incentivization and funding for research and development to advance innovation and technology, as well as scientific research on human health impacts, is limited. These initiatives may gain more traction if consumer interests and concerns align, which increased consumer protection would allow for, where consumers would be more informed on prevalence, impacts, and mitigation of microfiber pollution.

The table below categorizes and color-codes the policy strategies and components of the proposed state-level legislation: Financial Reward/Incentive (red), Mandated Adoption (orange), Standardization (yellow), Consumer Protection (green), Enforcement (blue), Research and Development (purple).

State	**Bill Name**	**Date Introduced**	**Policy Strategy**
New Jersey	SB 3281	October 2022	Consumer rebates for washing machine filter purchases (S3281, n.d.)
	SB 3619	September 2024	Prohibits sale of new washing machines without microfiber filters from January 2023 (NJ S332, n.d.)
			Defines filter mesh size requirement of 100 microns (NJ S332, n.d.)
			Labeling requirements to inform consumers on purpose and maintenance of filters (NJ S332, n.d.)
			Monetary penalties for non-compliance (NJ S332, n.d.)

Oregon	SB 405	June 2025	Prohibits sale of new washing machines without microfiber filters from January 2026 (SB405, n.d.)
	SB 526	January 2025	Prohibits sale of new washing machines without microfiber filters from January 2023 (SB405, n.d.)
California	AB 2379	February 2018	Labeling requirements to inform consumers on microfiber shedding on garments made of more than 50% synthetic fabric (AB 2379, n.d.)
	AB 129	December 2018	Require microfiber filtration systems for public entities and private industrial or commercial users of washing machines (CA AB129, n.d.)
			Provide funding for research and pilot programs for microfiber filtration technology (CA AB129, n.d.)
			State-level identification of best practices for reduction of microfiber release (CA AB129, n.d.)
	AB 802	February 2021	State board mandated to consult field experts and other stakeholders to

			inform technology identification and adoption (AB 802, n.d.)
			State-level identification of best available control technology for microfiber filtration (AB 802, n.d.)
			Mandated adoption of best available control technology for microfiber filtration (AB 802, n.d.)
	AB 622	February 2021	Require all new washing machines sold to contain microfiber filtration systems (AB622, n.d.)
			Defines filter mesh size requirement of 100 microns (AB622, n.d.)
	AB 1628	February 2023	Require all new washing machines sold to contain microfiber filtration system by 2029 (Ocean Conservancy, 2024)
			Defines filter mesh size requirement of 100 microns (Ocean Conservancy, 2024)
New York	AB A10599	May 2018	Labeling requirements to inform consumers on microfiber shedding

			on garments made of more than 50% synthetic fabric (NYSenate.gov, n.d.)
	AB A04716	February 2025	Prohibits sale of new washing machines without microfiber filters from January 2023 (A04716, n.d.)
			Defines filter mesh size requirement of 100 microns (A04716, n.d.)
			Labeling requirements to inform consumers on purpose and maintenance of filters (A04716, n.d.)
			Monetary penalties for non-compliance (A04716, n.d.)
Illinois	HB 1284	January 2023	Requires all state-owned washing machines to have microfiber filtration by 2024 (HB1284, n.d.)
			Prohibits manufacturing of washing machines without microfiber filtration by 2028 (HB1284, n.d.)
			Prohibits sale of washing machines without microfiber filtration by 2030 (HB1284, n.d.)

			Defines “microfiber,” “microfiber filtration system,” and “microplastic” (HB1284, n.d.)
	HB 4269	January 2024	Prohibits sale of new washing machines without microfiber filters from January 2023 (HB4269, n.d.)
			Defines filter mesh size requirement of 100 microns (HB4269, n.d.)
			Labeling requirements to inform consumers on purpose and maintenance of filters (HB4269, n.d.)
			Monetary penalties for non-compliance (HB4269, n.d.)
	HB 1370 / SB 0030	January 2025	Prohibits sale of new washing machines without microfiber filters from January 2023 (Illinois Legislature, n.d.; HB1370, n.d.)
			Defines filter mesh size requirement of 100 microns (Illinois Legislature, n.d.; HB1370, n.d.)
			Labeling requirements to inform consumers on purpose and maintenance of filters

			(Illinois Legislature, n.d.; HB1370, n.d.)
			Monetary penalties for non-compliance (Illinois Legislature, n.d.; HB1370, n.d.)
Connecticut	HB 5360	February 2018	Establishes a working group to focus on synthetic microfiber pollution (CT.gov, 2020)

Table 2. State-level Targeted Microfiber Pollution Legislation in the United States

With legislative action in the US being limited, international policy regarding microfiber pollution regulation has followed a similar path in terms of proposed measures and actions, where fragmented approaches to microfiber pollution mitigated lack mandated implementation or fail to be ratified. Australia announced its National Plastics Plan in March 2021, setting a target for microfiber filters in all commercial and residential washing machines by July 2030 (National Plastics Plan, 2021). This initiative encourages collaboration between the government, textile, and appliance sectors for an industry-led phase-in approach. While this was an important action for defining an approach to mitigate plastic pollution, the Plan adopted a voluntary approach rather than a mandated legislation (MRA Consulting Group, 2024). In Canada, legislative efforts included Ontario's Bill 279 in 2021 and Bill 102 in 2022, both proposing requirements for washing machines sold in Ontario to incorporate microfiber filters with a maximum mesh size of 100 microns (Legislative Assembly of Ontario, n.d.; Legislative Assembly of Ontario, n.d.). However, neither bill successfully passed into law. The United Kingdom introduced Bill 114 (2024-2025), mandating manufacturers to fit microfiber filters on washing machines by January 2029 (Microplastic Filters Bill, n.d.). The bill also aims to raise public awareness about microplastic pollution. Similar legislation was previously introduced in

2021, although it was not passed, demonstrating continued interest in addressing microfiber pollution at a national level.

Common elements across these legislations include mandates for microfiber filtration systems on domestic and commercial washing machines, specifying filter mesh sizes of 100 microns, and penalties for non-compliance. Additionally, these legislative efforts often require labeling to inform consumers about filter maintenance and the environmental impacts of microplastic fibers.

The circular economy holistic approach, particularly when applied through robust EPR frameworks, has demonstrated greater traction globally than policies that narrowly target individual sources of microfiber pollution. Circular economy policies shift responsibility from consumers and local governments to the producers who shape product characteristics and supply chains by embedding sustainability into the entire lifecycle of textile products. This systematic approach not only incentivizes innovation in sustainable materials and manufacturing practices but also promotes more upstream solutions that reduce microfiber shedding before it begins. In comparison, mandating filters in washing machines or enacting consumer labeling laws seem like more fragmented approaches.

France's AGEC law and the European Union's CEAP demonstrate how a cohesive and mandated EPR framework, particularly when paired with ecomodulated producer fees and labelling for transparency, can be successful in transitioning to a circular economy while maintaining consumer satisfaction and industry compliance. In contrast, the United States' state-level initiatives reveal both the growing urgency of microfiber pollution and the limitations of voluntary, incentive-based, or narrowly scoped regulatory approaches. While legislation like California's SB 707 and Massachusetts' textile waste ban are important steps toward circularity, the lack of a unified national EPR standard and limited engagement with upstream manufacturing practices weaken the overall impact and scalability of these efforts. As such, to properly address microfiber pollution, US policy must move beyond fragmented mitigation strategies and toward a national regulatory framework grounded in circular economy principles. While microfiber filtration mandates are a crucial component, they are insufficient on their own. Only a comprehensive, system-wide approach can effectively reduce microfiber pollution and ensure long-term ecological and economic resilience.

Sustainable Finance

In the textile industry, an impact investing framework can be a powerful tool for scaling innovations that reduce microfiber pollution and advance a circular economy. The global fashion industry is valued at nearly $2 trillion, yet over 73% of textiles end up in landfills or incinerators, with less than 1% recycled in closed-loop systems. Through a circular economy lens, this waste becomes an opportunity, but one that requires substantial capital. According to a 2020 report by Fashion for Good, the industry needs $20-30 billion annually in sustainable investment. Around 15% of this funding is required for technologies that improve water efficiency and reduce water pollution, while roughly 20% is needed for innovations that reduce waste through recycling, reuse, or biodegradable solutions. This translates to about $7-10.5 billion needed for water and waste related innovation in fashion. In comparison, the extracted Pitchbook data indicates that since 2000, only about $3.5 billion has been invested in these areas, highlighting that current funding is just a fraction of what’s required.

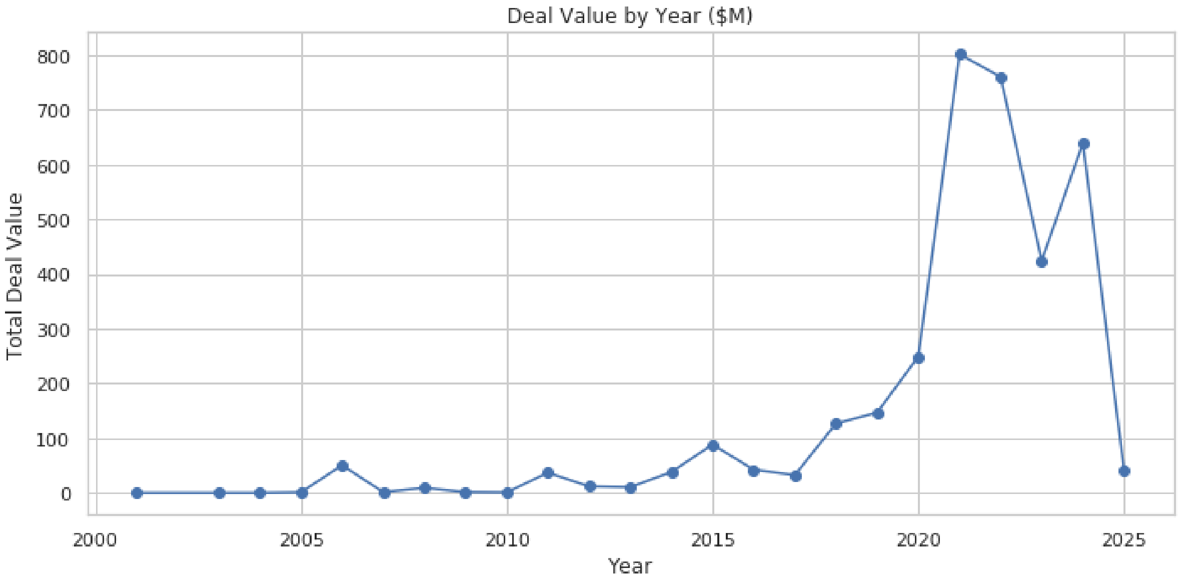


Figure 1. Deal Value Over Time for Core Innovations

Closing this gap through targeted impact investments could accelerate the development and scale-up of sustainable textile technologies, align innovation with emerging policy frameworks, and drive the transition toward a circular economy. Due to limitations in PitchBook's data on company revenue or activity and the relatively small monetary scale of many deals, the analysis focuses on investment deal volumes rather than total deal value to better reveal patterns over time, identifying where momentum exists and where gaps remain.

The environmental impacts of synthetic textiles are becoming increasingly prominent, especially with the inherently pollutive current linear economic model of fast fashion in the textile industry. As awareness and concern grows regarding this issue, innovation in this sector has become integral to combat this environmental impact while suiting the modern waste disposal practices and fashion practices. Sustainable finance has emerged as a critical mechanism for accelerating innovation in the textile industry. Sustainable finance, particularly in the form of impact investing, is based on directing capital towards businesses that have a strong capacity for measurable environmental change alongside financial returns, which is why this field is the one chosen to be explored. In the textile industry, the identified technologies of biobased textiles and fibers, textile recycling technologies, and microfiber filtration technologies represent the most promising and impactful innovation pathways for mitigating microfiber pollution across the product lifecycle.

Upon identifying 127 innovative companies that are addressing microplastic pollution in the textile industry through the three prominent technologies, and their respective deal flows, the conducted Python-based time series analysis aims to highlight the role of financial capital in supporting the development and deployment of technologies that address microplastic fiber pollution from textiles. The conducted analysis of sustainable investment trends in textile technologies focuses on deal volume across different innovation sectors and financing types. Deal volume is analyzed over total deal value since we are looking at early stage capital flows and number of deals may be a better indicator of the industry garnering interest than monetary value of investment. A time-series regression model is used to explore how capital deployment relates to the innovation landscape and how investment activity has changed over time. As such, sustainable finance is assessed as a funding mechanism that is a driver for a circular and equitable textile economy.

The chart below demonstrates that the industry has garnered increasing interest over the years, with a growing number of investments made across a wide range of deal types. While 2025 is still ongoing, the presence of capital flows suggests that the industry continues to attract some attention, despite the noticeable downward trend since 2022. The deal types with the largest volume are Accelerator/Incubator, Grants, Seed Round, Early Stage VC, and Later Stage VC, indicating that the market for textile technologies remains in its early stages, where impact investments can still play a critical and influential role. The chart highlights how, since 2001, this sector has seen rapid growth in interest and investment. However, 2022 appears to mark an inflection point, where that growth trend begins to reverse. The decrease in 2023 and 2024 may be most indicative of a drop in grant-type funding, which often has a time frame tied to institutional or government programs. This shift leaves an open question around whether there has been enough field-building to sustain positive capital flows through other, longer-term forms of financing.

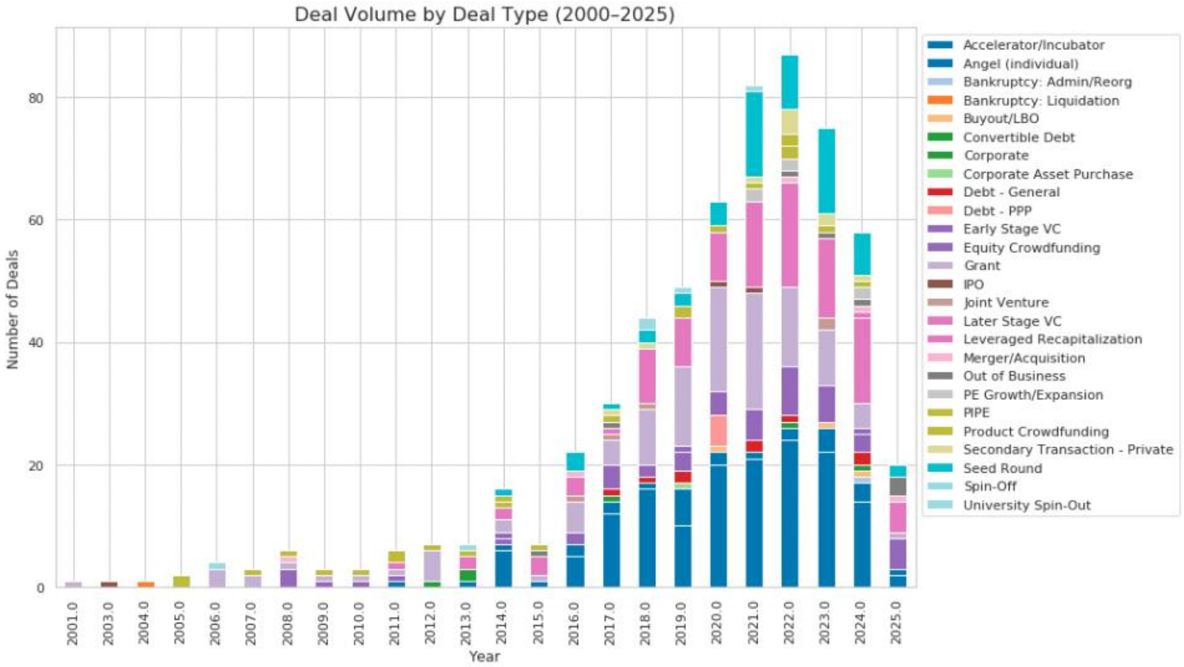


Figure 2. Deal Activity in Core Innovations (2000-2025)

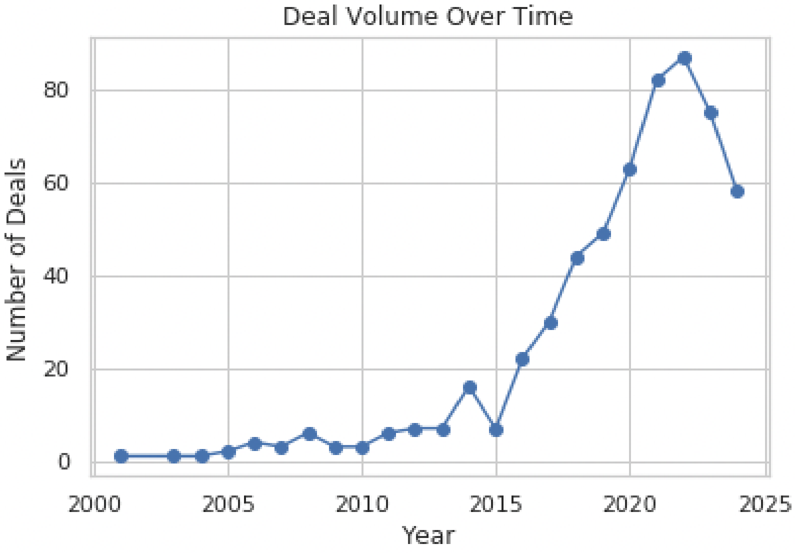


Figure 3. Deal Volume for Core Innovations Over Time (2000-2024)

Only deals from 2000 to 2024 were considered, as 2025 is still ongoing and may not yet reflect the full year's investment activity. To better understand the patterns observed in the deal volume over time, a statistical exploration of the trend was conducted.

The first model comparison chart shows the actual deal volume plotted against both linear and exponential fits. While both models capture the general upward trend, the log-linear model demonstrates a stronger fit with an R-squared of 0.94, compared to 0.76 for the standard linear model. The root mean square error (RMSE) is also slightly lower for the exponential model (13.80 vs. 14.18), suggesting it better captures the acceleration in deal activity, especially leading up to the 2021 peak.

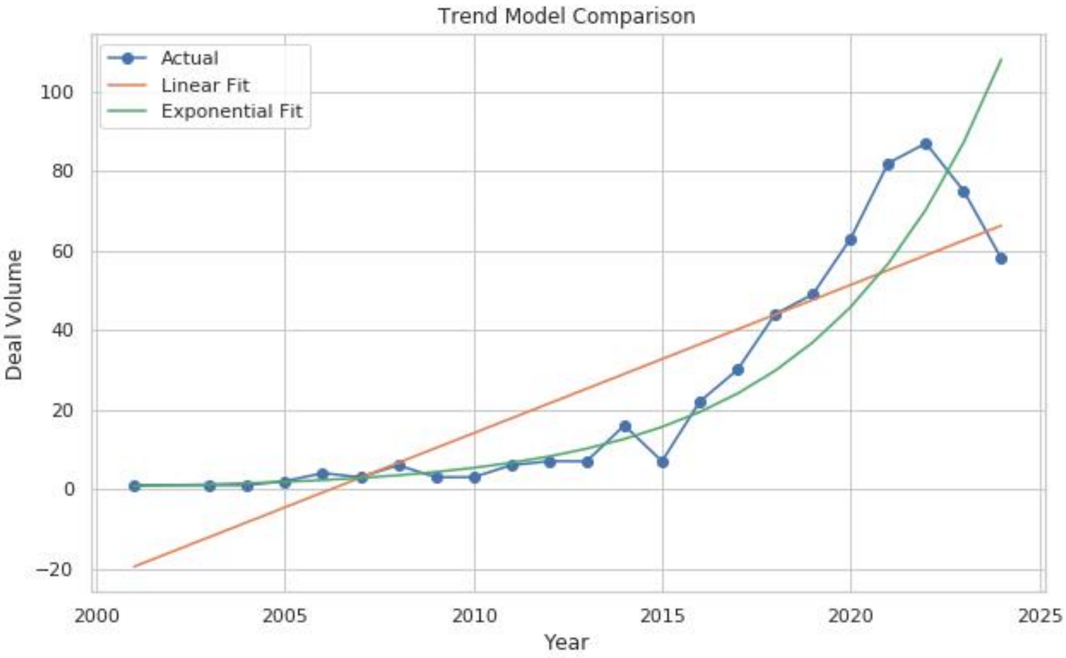


Figure 4. Linear and Exponential Regressions for Deal Volume

However, considering that the residuals are not randomly distributed, it indicates that neither of these models are an appropriate model.

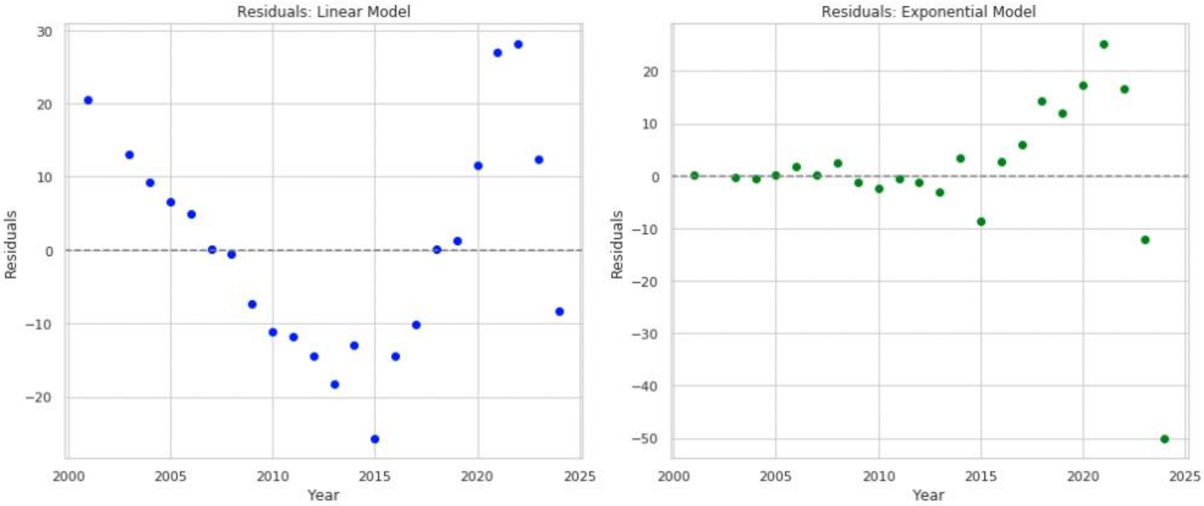


Figure 5. Residuals of Linear and Exponential Models

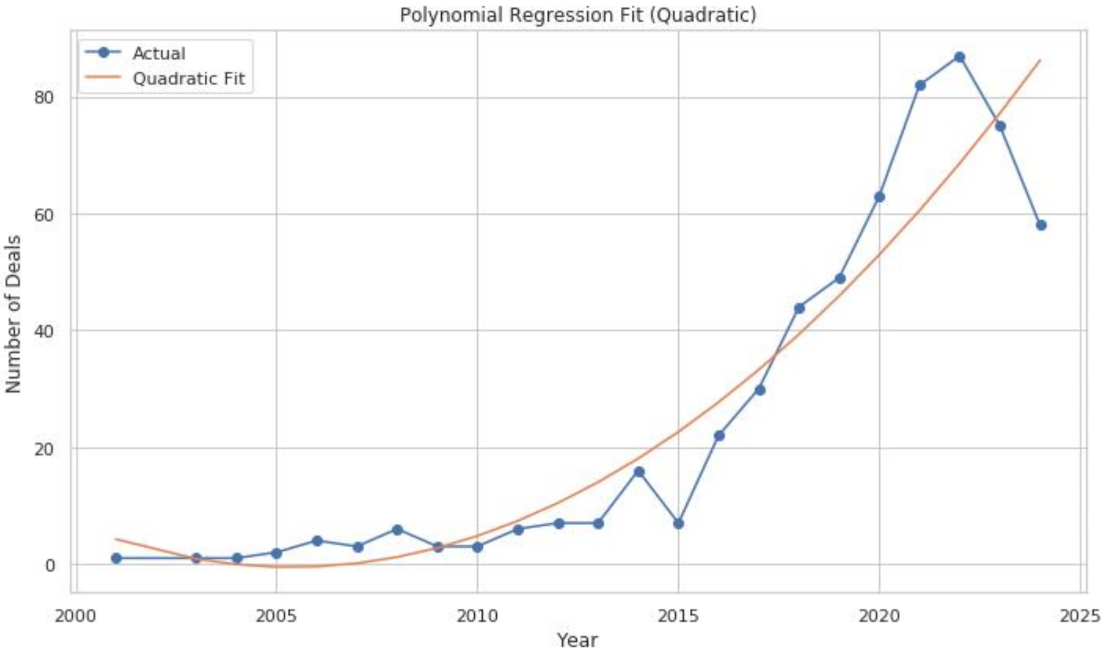
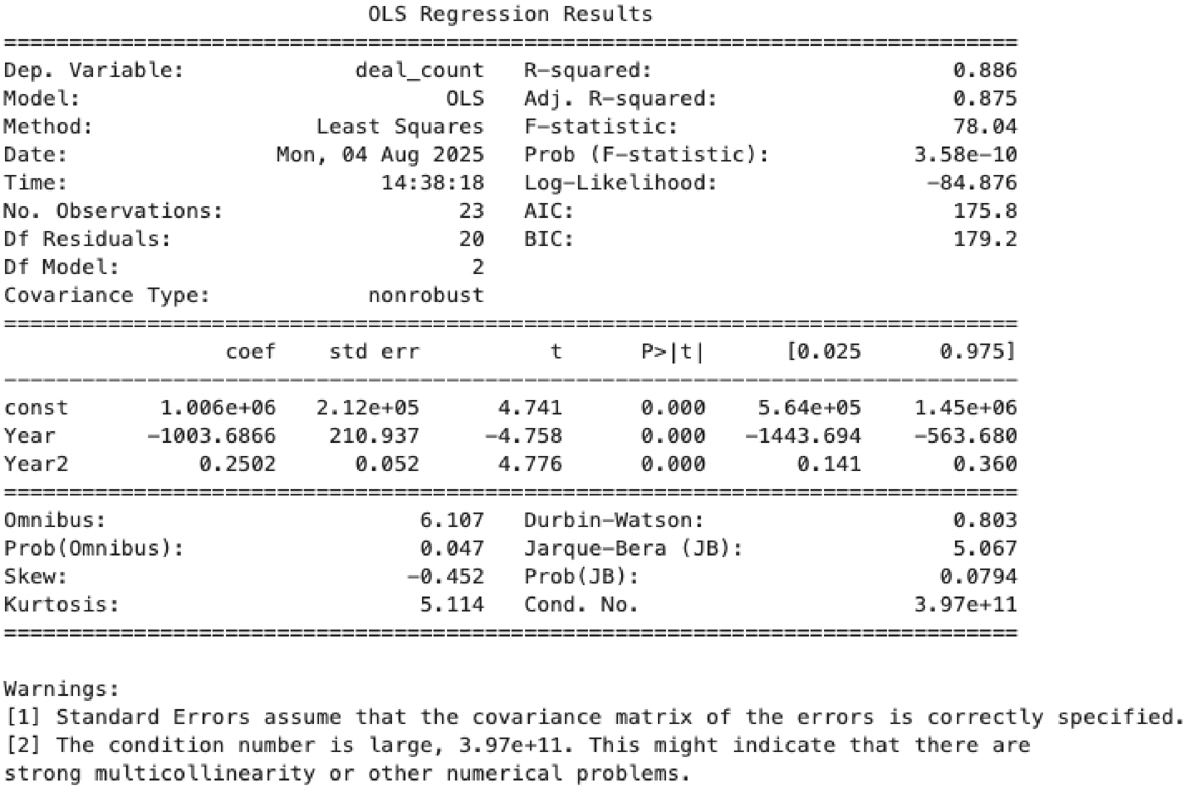


Figure 6. Quadratic Fit of Deal Volume Trend (2000-2024)



```
                            OLS Regression Results
==============================================================================
Dep. Variable:             deal_count   R-squared:                       0.886
Model:                            OLS   Adj. R-squared:                  0.875
Method:                 Least Squares   F-statistic:                     78.04
Date:                Mon, 04 Aug 2025   Prob (F-statistic):           3.58e-10
Time:                        14:38:18   Log-Likelihood:                -84.876
No. Observations:                  23   AIC:                             175.8
Df Residuals:                      20   BIC:                             179.2
Df Model:                           2
Covariance Type:            nonrobust
==============================================================================
                 coef    std err          t      P>|t|      [0.025      0.975]
------------------------------------------------------------------------------
const       1.006e+06   2.12e+05      4.741      0.000    5.64e+05    1.45e+06
Year       -1003.6866    210.937     -4.758      0.000   -1443.694    -563.680
Year2          0.2502      0.052      4.776      0.000       0.141       0.360
==============================================================================
Omnibus:                        6.107   Durbin-Watson:                   0.803
Prob(Omnibus):                  0.047   Jarque-Bera (JB):                5.067
Skew:                          -0.452   Prob(JB):                       0.0794
Kurtosis:                       5.114   Cond. No.                     3.97e+11
==============================================================================

Warnings:
[1] Standard Errors assume that the covariance matrix of the errors is correctly specified.
[2] The condition number is large, 3.97e+11. This might indicate that there are
strong multicollinearity or other numerical problems.
```

Figure 7. OLS Regression for Quadratic Fit of Deal Volume Trend (2000-2024)

To further investigate the shape of the trend in deal volume, a quadratic polynomial regression model was fitted. Compared to the linear and exponential models, the quadratic fit offers the lowest RMSE (9.69), indicating that it captures the data with higher precision.

The quadratic regression model demonstrates a strong overall fit to the data, with an R-squared value of 0.886, indicating that approximately 88.6% of the variance in deal count is explained by the model. Both the linear (Year) and quadratic (Year2) terms are statistically significant, with p-values less than 0.001. This confirms that the trend over time is not just present but meaningfully nonlinear. Specifically, the negative coefficient on the Year variable, combined with the positive coefficient on Year2, suggests a U-shaped trend, where a leveling out or decline in activity is followed by a sharp increase. This pattern aligns well with the observed data, where there is slow growth in the early years, rapid acceleration after 2015. However, the curvature and structural shift after 2022 point to the need for potential segmented or piecewise modeling to capture recent dynamics more precisely. This would allow for better identification of whether the observed downturn is part of a short-term variation or indicative of a longer-term trend.

Given the inflection point observed in 2022, the data was split into two timeframes to better understand the underlying trends. To improve model fit and reveal more granular insights, a quadratic regression was applied to the pre-2022 period.

This segmented quadratic model achieved an R-squared value of 0.96, significantly higher than the 0.886 fit for the full 2000-2024 dataset. The reduced RMSE (5.16) further supports this improved fit. These metrics indicate that the increase in deal volume leading up to 2022 is not only visually apparent but also statistically robust. By narrowing the timeframe, the model more accurately captures the accelerated growth phase in the sector and avoids distortion from the post-2022 downturn, which may follow a different pattern.

This modeling choice reinforces the idea that the industry experienced sustained momentum and rising investor confidence leading into 2022, and provides a clearer baseline from which to assess the significance of the recent shift.

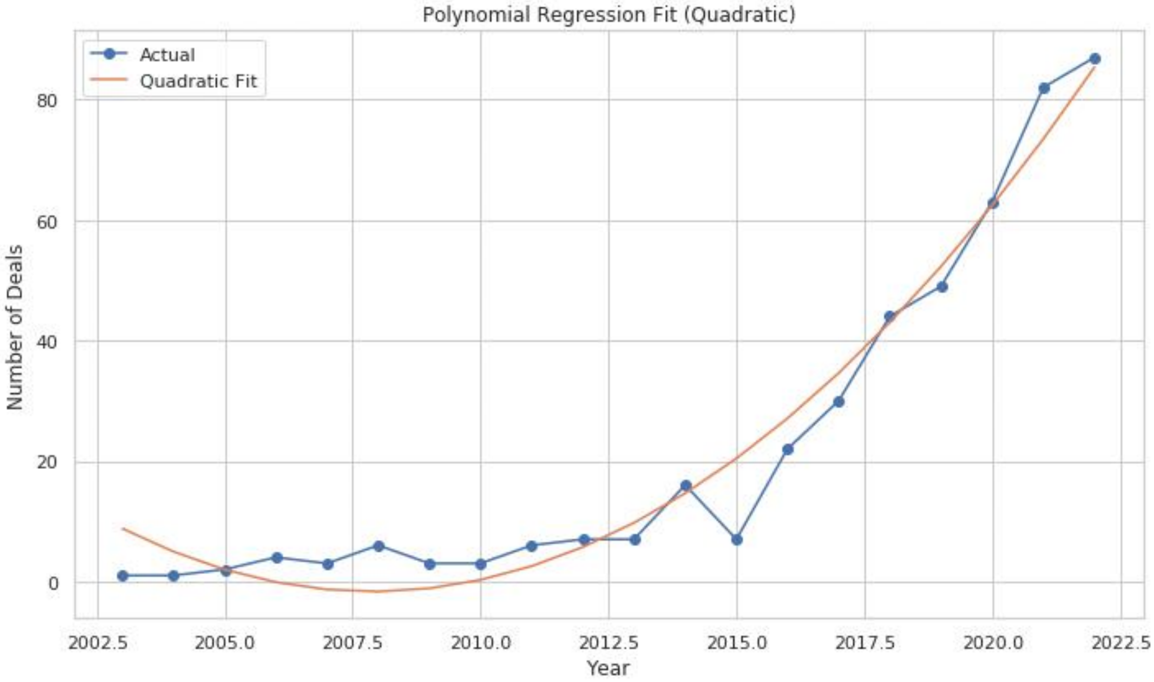


Figure 8. Quadratic Fit of Deal Volume Trend (2000-2022)

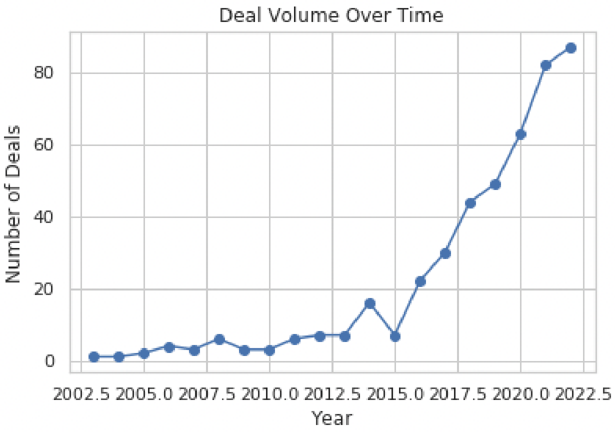


Figure 9. Deal Volume for Core Innovations Over Time (2000-2022)

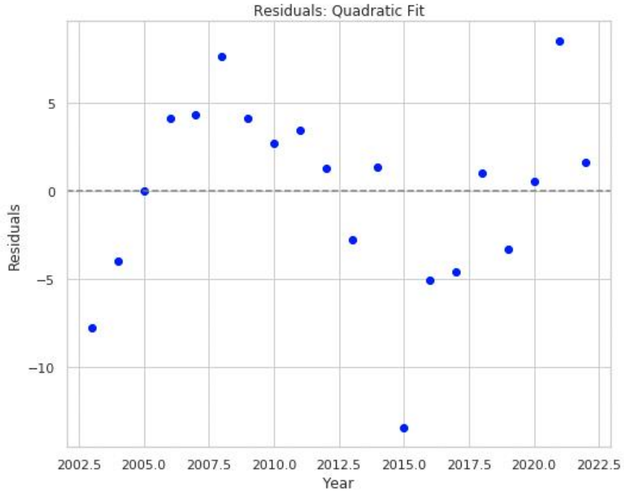
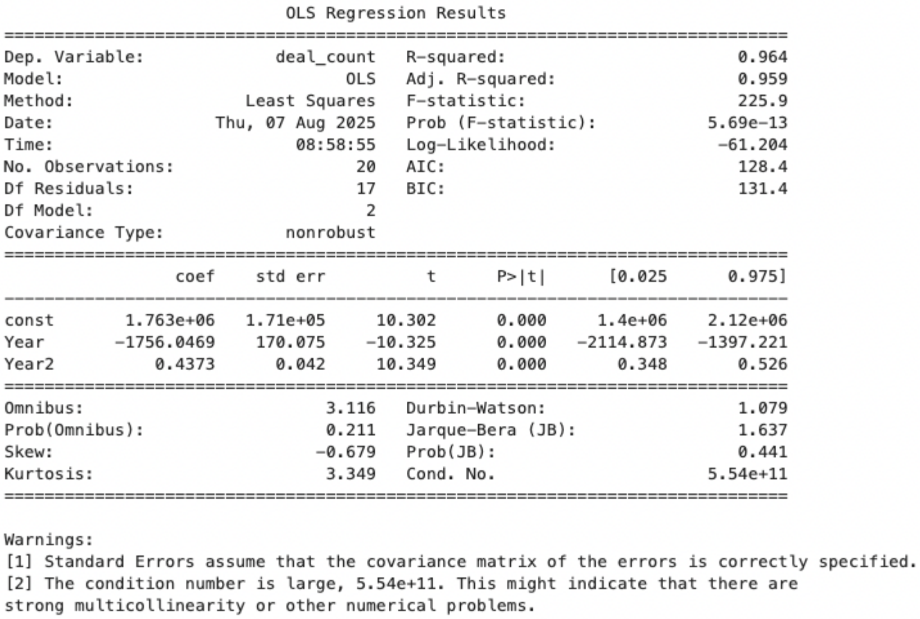


Figure 10. Residuals of Quadratic Fit (2000-2022)



```
                            OLS Regression Results                            
==============================================================================
Dep. Variable:             deal_count   R-squared:                       0.964
Model:                            OLS   Adj. R-squared:                  0.959
Method:                 Least Squares   F-statistic:                     225.9
Date:                Thu, 07 Aug 2025   Prob (F-statistic):           5.69e-13
Time:                        08:58:55   Log-Likelihood:                -61.204
No. Observations:                  20   AIC:                             128.4
Df Residuals:                      17   BIC:                             131.4
Df Model:                           2                                         
Covariance Type:            nonrobust                                         
==============================================================================
                 coef    std err          t      P>|t|      [0.025      0.975]
------------------------------------------------------------------------------
const       1.763e+06   1.71e+05     10.302      0.000     1.4e+06    2.12e+06
Year       -1756.0469    170.075    -10.325      0.000   -2114.873   -1397.221
Year2          0.4373      0.042     10.349      0.000       0.348       0.526
==============================================================================
Omnibus:                        3.116   Durbin-Watson:                   1.079
Prob(Omnibus):                  0.211   Jarque-Bera (JB):                1.637
Skew:                          -0.679   Prob(JB):                        0.441
Kurtosis:                       3.349   Cond. No.                     5.54e+11
==============================================================================

Warnings:
[1] Standard Errors assume that the covariance matrix of the errors is correctly specified.
[2] The condition number is large, 5.54e+11. This might indicate that there are
strong multicollinearity or other numerical problems.
```

Figure 11. OLS Regression for Quadratic Fit of Deal Volume Trend (2000-2022)

Despite the statistical significance, there is still autocorrelation according to the residuals, shown by the slight curve demonstrated, which means that while the general growth pattern is reliable, the precision of the significance tests remains uncertain. For further analysis, a time-series model that takes into account autocorrelation, like the ARIMA model, in order to have a more statistically significant fit, and potentially predict future trends in the market.

The 2022-2024 timeframe was modeled separately using a simple linear regression, which demonstrates a statistically significant relationship between time and deal volume. The model yields a very high R-squared value of 0.99, indicating a strong linear fit and suggesting a consistent decline in the number of deals over this period.

However, while the statistical fit appears appropriate, the model is based on only three data points, which limits the strength and generalizability of any conclusions drawn. The linearity may reflect short-term momentum rather than a long-term structural shift. As such, while the downward trend is visually and statistically supported, it remains unclear whether this marks the beginning of a broader market contraction, a temporary correction, or simply noise within a limited dataset. Further data in subsequent years will be necessary to determine whether this decline persists or stabilizes.

Figure 12. Deal Volume for Core Innovations Over Time (2022-2024)

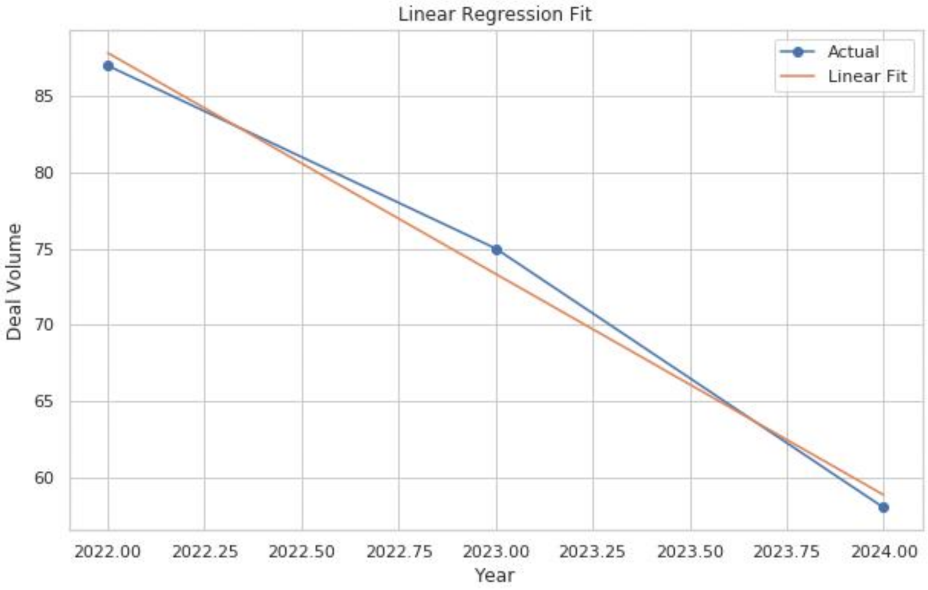


Figure 13. Linear Fit of Deal Volume Trend (2022-2024)

Next, a closer look was taken at capital flows across innovation sectors and deal types.

This chart demonstrates that Biobased Textiles and Fibers represent the largest and most rapidly growing sector. One possible explanation for this is the greater availability and scalability of raw materials for biobased production, which lowers entry barriers and enables faster commercialization. Textile Recycling technologies began to emerge in deal data around 2008, notably following France’s introduction of pioneering textile recycling legislation in 2007. This suggests a potential regulatory influence on innovation and investment. In contrast, microplastic and Microfiber Filtration technologies only started to appear around 2017, likely reflecting the more recent emergence of scientific awareness and public concern around microfiber pollution and its ecological impacts.

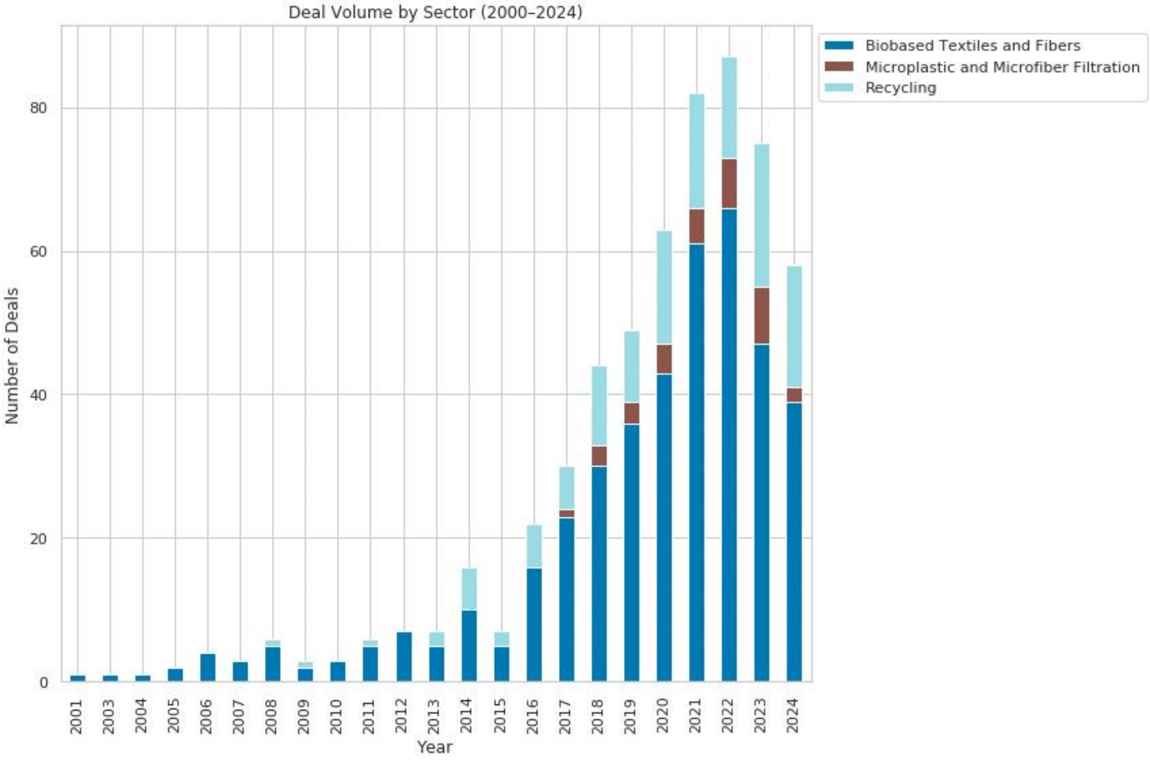


Figure 14. Deal Volume According to Sector (2000-2024)

All five deal types show a general increase in investment activity over time, with noticeable growth from the early 2000s through the early 2020s. While each has experienced a downturn in recent years, the overall upward trajectory is evident. Interestingly, Late Stage VC shows the least pronounced decline, which could indicate that the field is progressing beyond its nascent phase and now requires larger capital segments to scale and commercialize technologies. In contrast, deal types such as Grants and Seed Rounds show sharper declines, possibly reflecting the conclusion of early-stage funding cycles or shifts in institutional support. Despite recent fluctuations, the data reveals a clear period of accelerated growth across all funding types, signaling that meaningful progress has occurred within the industry. This trend underscores a broader maturing of the sustainable textile innovation space, while also raising questions about how and at what stage capital will continue to flow in the upcoming years.

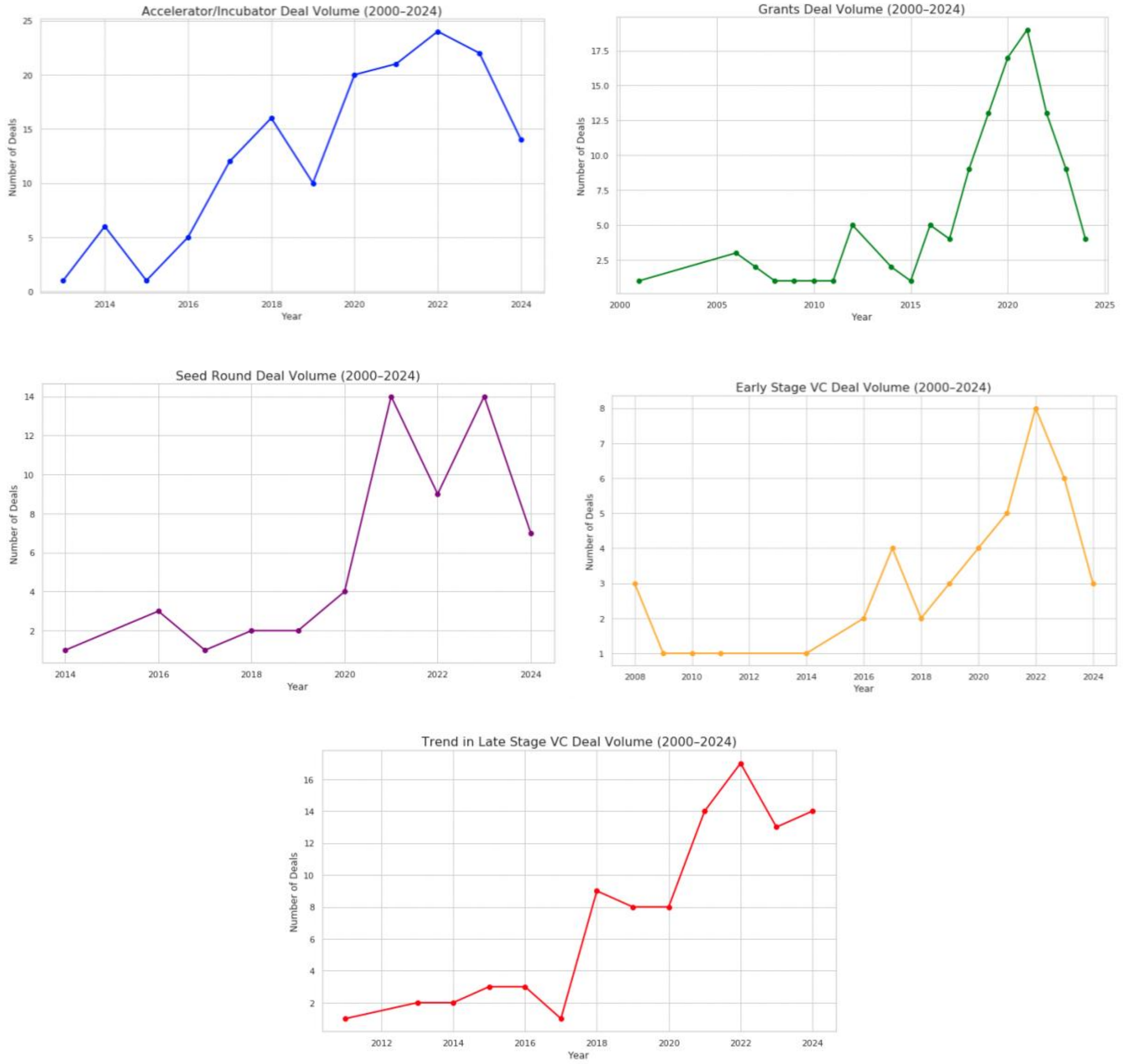


Figure 15. Deal Volume for Each Major Deal Type (2000-2024)

The two charts below demonstrate the relationship between public field-building capital and private market capital in the sustainable textile innovation ecosystem.

There has been a consistent flow of public capital since 2001, starting with grant funding, followed by accelerator/incubator funding, which began to appear around 2013. From 2010 onward, both categories show steady growth, with a noticeable peak between 2019 and 2022. In the early years, grants, which are typically provided by governments, philanthropic foundations, or universities, were the dominant form of support. Accelerator/incubator funding started later and experienced rapid growth post-2015, reflecting an increasing institutional effort to support startup development. Field-building investments are non-dilutive and typically do not come with return expectations. Their role is to lay the infrastructure for innovation, reduce barriers to entry, and create the conditions under which private capital can be more effective. As such, public capital can de-risk private investments, illustrating how public field-building is a prerequisite for strong private market activity and is essential for ecosystem development.

The second chart illustrates private market deal volume, encompassing seed, early stage, and late stage venture capital investments. These deals are equity-based and return-driven, targeting scalable, high-growth startups. Early Stage VC activity began around 2008, with Late Stage VC following in 2011. The private market deal volumes reached a peak between 2021 and 2023, which was a few years after the public capital peak. This time lag is both expected and strategic, as ventures need time to mature and develop proof of concept in order to become viable for growth-stage investment. This pattern demonstrates the complementary relationship between public and private capital within the innovation pipeline, where field-building efforts lay the groundwork for effective private investments. The observed timing and sequencing between the two types of capital suggest that the industry is maturing, and that the startups receiving VC funding are building on the foundation laid by public investment.

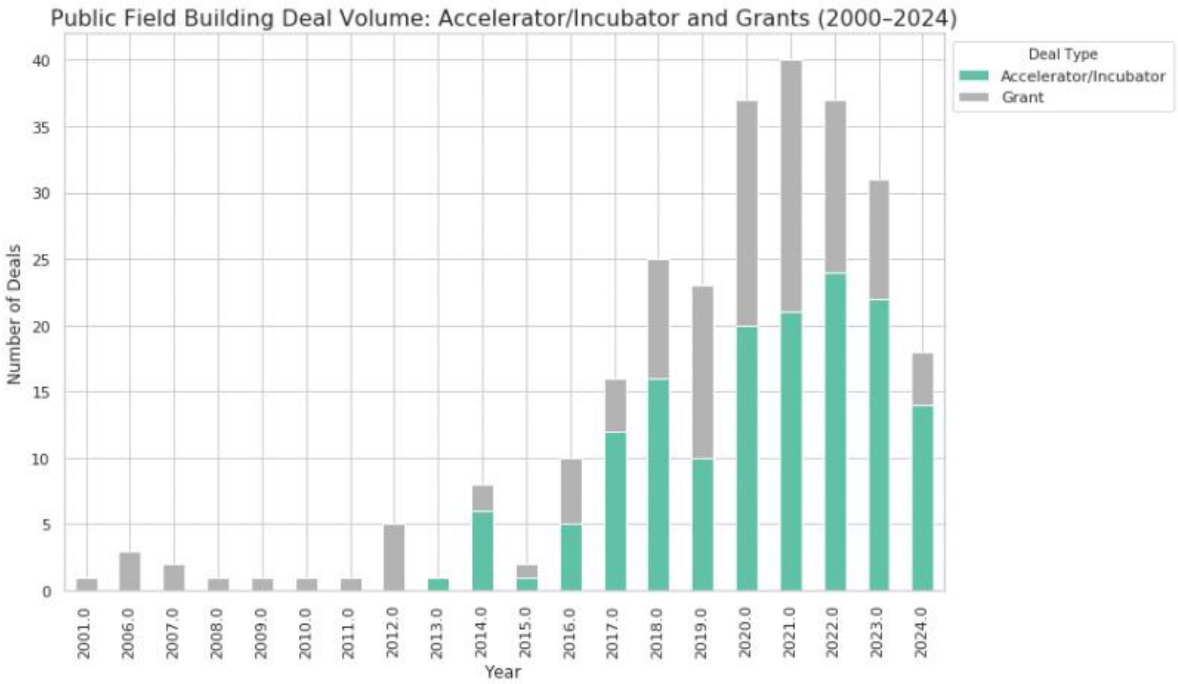


Figure 16. Deal Volume for Public Field Building Deal Types (2000-2024)

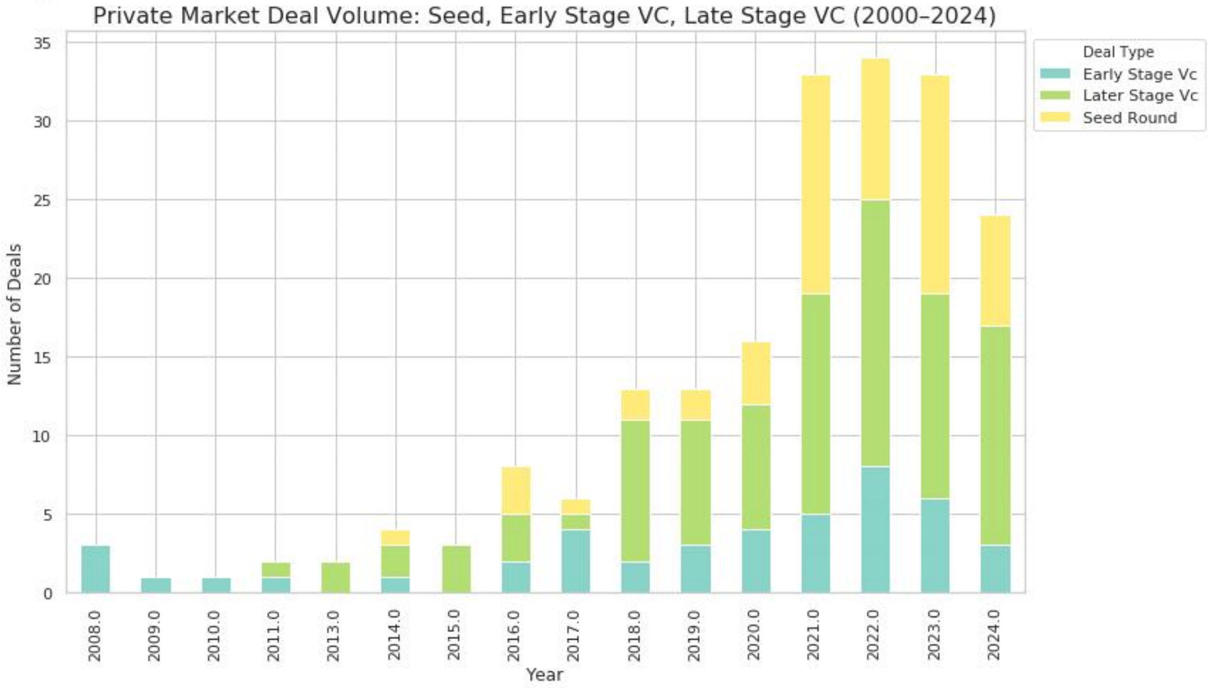


Figure 17. Deal Volume for Private Market Deal Types (2000-2024)

As such, the capital flowing from the companies developing technology addressing the identified environmental impact was explored.

Limitations

While this analysis offers valuable insights into sustainable finance, innovation, and policy development in the textile industry, there are several limitations and sources of error that must be considered. The process of compiling the dataset, for example, pulled information from many different sources and required manual verification of relevant companies. All companies were manually reviewed and categorized by sector based on publicly available descriptions on Pitchbook. This process may have been subject to potential error from human interpretation, especially when company descriptions were vague or outdated. In addition to human error, some companies included in the dataset produce a variety of materials beyond biobased textile fibers and may operate across multiple sectors, including other plastic alternatives and non-fabric products. It was not always possible to isolate the portion of their operations specifically dedicated to textile-related solutions. When distinguishing textile recycling technologies, the available descriptions did not always distinguish between mechanical and chemical recycling, which was a notable source of error, as mechanical recycling can degrade fiber quality and potentially increase microplastic shedding, whereas chemical recycling does not have similar adverse effects. Due to this lack of granularity, the environmental impact from the recycling technologies, and relevancy, may be affected. Additionally, since the list was compiled through secondary sources, the company data and deal list may be outdated, since funding rounds and sector focus of the company may have changed since the information was last updated. Additionally, finding secondary sources that are very recently released that include information for companies and technologies and investment that have started in the most recent years.

Generative AI tools were also used to compile the dataset, and while AI allowed for broadly and quickly coming up with a range of potentially relevant companies, it occasionally introduced inaccurate or tangential results. Some companies may not have been directly relevant to microplastic mitigation or textile innovation but were inadvertently included due to limitations in the AI's contextual accuracy and subsequent oversight during manual review. As a result, these sources of error may have affected the accuracy of sector classification and the interpretation of investment trends.

During the data processing phase, some entries were excluded due to missing or inconsistent values, particularly with regard to deal dates or funding stages. While necessary for methodological consistency, this filtering may have unintentionally removed valid but incomplete data, potentially skewing the representation of certain time periods or deal types.

The scope of the policy analysis was limited by time constraints. While this study reviewed key federal, state, and international legislative efforts, not all relevant policy developments could be explored. Additional research into regional, municipal, or private sector policy responses would further refine or enhance the understanding of the regulatory landscape.

Conclusions and Recommendations

Three core areas of innovation were identified that are crucial to reducing microplastic pollution from textiles: biobased and biodegradable fiber technologies, textile recycling systems, and microfiber filtration solutions. These technologies represent the most prominent and scalable interventions currently available to mitigate fiber shedding and reduce synthetic textile pollution.

The policy analysis component revealed that there is a growing regulatory response to microfiber pollution. In the United States, no comprehensive federal legislation directly addresses microfiber emissions from textiles, though recent bills and reports indicate growing awareness and a foundational shift toward legislative action. At the state level, California, New York, New Jersey, Oregon, and Connecticut have each introduced bills aimed at regulating microfiber emissions, primarily through filter implementation mandates and labeling requirements for washing machines. However, the most comprehensive and effective legislative frameworks have emerged internationally, particularly in the European Union and France. France's AGEC and the EU's CEAP have not only addressed microfiber pollution but also integrated sustainability into the broader lifecycle of textile products. These policies operate under a robust Extended Producer Responsibility model that shifts the burden of textile waste and pollution onto producers, creating structural incentives for sustainable innovation. These international frameworks also highlight that whereas US policy often focuses on downstream interventions, European policies are systemic and upstream, emphasizing product design, manufacturing accountability, and full life-cycle impact reduction.

The sustainable finance component of this thesis explored whether sustainable investing is effectively supporting innovation and aligning with emerging policies. Using time-series data from PitchBook, this research documented 127 companies across the three main innovation sectors, with 94 in biobased fibers and textiles, 26 in textile recycling, and 7 in microfiber filtration technologies. Over 692 deals were identified, with capital flowing primarily into early-stage ventures through accelerators, grants, seed funding, and venture capital. The data reveal a compelling pattern, where while investment in sustainable textiles has grown substantially since 2000, the strongest growth occurred after 2015. Interestingly, textile recycling technologies emerged shortly after France's 2007 EPR policy, suggesting that regulation can be an important market signal. Microfiber filtration technologies appeared later, potentially attributed to the timeline of increased global awareness about microplastic pollution.

A quadratic regression model fit the time-series data well, showing an initial period of stagnation followed by significant acceleration, although recent years have shown a slight decline. As such, the field is still nascent, and early-stage capital has great potential to influence the direction and priorities of innovation. Policy and finance are both important drivers that can catalyze rapid progress. While sustainable investing is emerging as a critical enabler, it is not yet sufficient to drive a full-scale industry transformation without more robust policy frameworks and capital direction.

One of the most significant, and often overlooked, aspects of textile pollution is its disproportionate impact on the Global South. Many of the largest exporters of textiles and recipients of textile waste are countries with limited waste management infrastructure and lower environmental governance capacity. These regions, while contributing the least to global pollution historically, face the highest environmental and public health burdens from textile-related microplastic contamination. This inequity raises important questions about global responsibility and justice. If this research were to be extended, it could examine the geographic distribution of funding for these technologies and the locations of the companies developing them. Such an analysis could explore whether these geographic patterns align with regions where policy interventions have demonstrated success and generated interest, or whether they correspond more closely with global waste management needs, especially in areas where the environmental impact of textile waste and microplastic pollution is most severe.

Consumer patterns, where garments are often worn and washed only a few times before disposal, continue to accelerate microplastic pollution and counteract the positive measures being taken. Fast fashion is a massive industry, but current levels of impact investing are nowhere near the scale needed to address its footprint. A globally adopted Extended Producer Responsibility policy modeled on France's approach could hold textile producers accountable for the full lifecycle impacts of their products while including phased requirements to reduce synthetic textile content and increase the share of bio-based, biodegradable alternatives. This staged approach would give producers time to adapt supply chains while creating predictable demand for sustainable fibers. Of the available solutions, biobased textiles and fabrics are the only ones that fully remove microplastics from the equation. Filtration technologies can keep particles out of wastewater but still leave the disposal problem, and recycling extends the life of synthetics without eliminating their eventual breakdown into microplastics. Embedding bio-based production targets into EPR frameworks is the most direct way to scale biodegradable fibers and reduce dependence on high-impact synthetics.

A strong and predictable regulatory framework not only drives corporate compliance, but also gives investors confidence that there will be consistent demand for sustainable alternatives, and in turn help promising technologies move from pilot to commercial scale. A globally aligned EPR policy with bio-based adoption targets would open clear revenue opportunities for sustainable textile producers, making the sector more appealing to impact investors who are looking for both measurable environmental outcomes and solid financial returns. The fashion industry's environmental impact alone justifies $20-30 billion in targeted investment, with substantial potential for economic return when factoring in avoided environmental damage, reduced waste management costs, and the benefits of scaling sustainable manufacturing. By integrating these incentives in a coordinated global EPR framework, policy makers can help to reach the level of private capital needed to shift the industry’s trajectory and turn fashion from a driver of microplastic pollution into a catalyst for sustainable innovation. Above all, there must be a cultural shift in how clothing is produced, used, and valued, so that durability, repair, and reuse become the norm. Without this shift, even the best policies and technologies will struggle to offset the pace and scale of fast fashion’s environmental impact.

The transition to a circular textile industry will not be driven by a single intervention but rather by the combined efforts of regulation, innovation, investment, and cultural transformation. The circular economy framework, when applied holistically, offers the most viable pathway forward. However, for it to succeed, it must be supported by strong enforcement, equitable financial support, and widespread public and industry engagement. Overall, sustainable investing is playing a growing role in supporting best practices within the sustainable textile sector, but it is not yet doing so at the necessary scale or speed. The technologies exist, the frameworks are emerging, and the investment tools are in place, but alignment and acceleration are needed. As the impacts of microplastic pollution intensify, and as textile production continues to grow globally, it becomes increasingly imperative to act. Continued research, cross-sector collaboration, and global equity must be prioritized in the next phase of development, because the cost of inaction is one that ecosystems, communities, and future generations cannot afford.

Appendix

List of Companies of Core Technologies (Biobased Fibers and Textiles, Microfiber Filtration, Textile Recycling)

Companies	Sector
1. 3F	Biobased Textiles and Fibers
2. Agraloop	Biobased Textiles and Fibers
3. ALT TEX	Biobased Textiles and Fibers
4. Alt.	Biobased Textiles and Fibers
5. AltMat	Biobased Textiles and Fibers
6. Amphico	Biobased Textiles and Fibers
7. AMSilk	Biobased Textiles and Fibers
8. Ananas Anam	Biobased Textiles and Fibers
9. Arda Biomaterials	Biobased Textiles and Fibers
10. Azolla	Biobased Textiles and Fibers
11. Baimai New Materials	Biobased Textiles and Fibers
12. Banaweave	Biobased Textiles and Fibers
13. Bast Fibre Technologies	Biobased Textiles and Fibers
14. BastCore	Biobased Textiles and Fibers
15. Bear Fiber	Biobased Textiles and Fibers
16. Bfiber Enterprise	Biobased Textiles and Fibers
17. Bio2Materials	Biobased Textiles and Fibers
18. Biofluff	Biobased Textiles and Fibers
19. Biolin Research	Biobased Textiles and Fibers
20. BPREG	Biobased Textiles and Fibers

21. Canvaloop	Biobased Textiles and Fibers
22. Circular Systems	Biobased Textiles and Fibers
23. ClarosTech	Biobased Textiles and Fibers
24. Climatex	Biobased Textiles and Fibers
25. CompPair	Biobased Textiles and Fibers
26. CRAiLAR Fiber Technologies	Biobased Textiles and Fibers
27. Culture In	Biobased Textiles and Fibers
28. Daphne Textiles	Biobased Textiles and Fibers
29. Dimpora	Biobased Textiles and Fibers
30. Doppelhaus	Biobased Textiles and Fibers
31. Dropel Fabrics	Biobased Textiles and Fibers
32. Erthe	Biobased Textiles and Fibers
33. Evolvision	Biobased Textiles and Fibers
34. Fibe (Plant Textiles)	Biobased Textiles and Fibers
35. Fiberly	Biobased Textiles and Fibers
36. Flocus	Biobased Textiles and Fibers
37. Fluff Stuff	Biobased Textiles and Fibers
38. GALY	Biobased Textiles and Fibers
39. Geochanvre	Biobased Textiles and Fibers
40. Gozen	Biobased Textiles and Fibers
41. Green Continue	Biobased Textiles and Fibers
42. Green Whisper	Biobased Textiles and Fibers
43. GreenCore Composites	Biobased Textiles and Fibers

44. Greensapio	Biobased Textiles and Fibers
45. HeiQ AeoniQ	Biobased Textiles and Fibers
46. Himalayan Wild Fibers	Biobased Textiles and Fibers
47. Keel.Labs	Biobased Textiles and Fibers
48. Kintra Fibers	Biobased Textiles and Fibers
49. Kuura (Plant Textiles)	Biobased Textiles and Fibers
50. Lignolix	Biobased Textiles and Fibers
51. Linal	Biobased Textiles and Fibers
52. MABE Bio	Biobased Textiles and Fibers
53. Mango Materials	Biobased Textiles and Fibers
54. Modern Synthesis	Biobased Textiles and Fibers
55. MycoWorks	Biobased Textiles and Fibers
56. Mylium	Biobased Textiles and Fibers
57. Nanoloom	Biobased Textiles and Fibers
58. Nanoweave	Biobased Textiles and Fibers
59. Newlight (Huntington Beach)	Biobased Textiles and Fibers
60. NFW	Biobased Textiles and Fibers
61. Nicelle Technologies	Biobased Textiles and Fibers
62. Nobrak	Biobased Textiles and Fibers
63. NOOSA (Plant Textiles)	Biobased Textiles and Fibers
64. OceanSafe	Biobased Textiles and Fibers
65. Orange Fiber	Biobased Textiles and Fibers
66. Polybion	Biobased Textiles and Fibers

67. Ponda	Biobased Textiles and Fibers
68. Pureyarns	Biobased Textiles and Fibers
69. Pyratex	Biobased Textiles and Fibers
70. Qmilk	Biobased Textiles and Fibers
71. Re-Bello	Biobased Textiles and Fibers
72. Renaissance Fiber	Biobased Textiles and Fibers
73. Revoltech	Biobased Textiles and Fibers
74. Rheom Materials	Biobased Textiles and Fibers
75. Rubi	Biobased Textiles and Fibers
76. Sahifab	Biobased Textiles and Fibers
77. Samatoa Lotus Textiles	Biobased Textiles and Fibers
78. Simplifyber	Biobased Textiles and Fibers
79. Smobya	Biobased Textiles and Fibers
80. Solena Materials	Biobased Textiles and Fibers
81. Spinnova (HEL: SPINN)	Biobased Textiles and Fibers
82. Spintex	Biobased Textiles and Fibers
83. StexFibers	Biobased Textiles and Fibers
84. Tandem Repeat	Biobased Textiles and Fibers
85. Tera Mira	Biobased Textiles and Fibers
86. Tômtex	Biobased Textiles and Fibers
87. TreeToTextile	Biobased Textiles and Fibers
88. Vegea	Biobased Textiles and Fibers
89. Verdant Innovatives	Biobased Textiles and Fibers

90. Viaex Technologies	Biobased Textiles and Fibers
91. Vollebak	Biobased Textiles and Fibers
92. Werewool	Biobased Textiles and Fibers
93. Woolchemy	Biobased Textiles and Fibers
94. Xefco	Biobased Textiles and Fibers
95. Baleena	Microplastic and Microfiber Filtration
96. Cora Ball	Microplastic and Microfiber Filtration
97. Ecofario	Microplastic and Microfiber Filtration
98. Matter.	Microplastic and Microfiber Filtration
99. PlanetCare	Microplastic and Microfiber Filtration
100. PolyGone	Microplastic and Microfiber Filtration
101. Xeros Technology (Hydrofinity US commercial laundry customer portfolio)	Microplastic and Microfiber Filtration
102. Ambercycle	Recycling
103. BlockTexx	Recycling
104. CDC_STUDIO	Recycling
105. Cellucircle	Recycling
106. Circ	Recycling
107. Evrnu	Recycling
108. GAMA Recycle	Recycling
109. Gr3n	Recycling
110. Huminly	Recycling
111. Hybridworks Chemical	Recycling
112. Infinited Fiber	Recycling
113. Intrinsic Advanced Materials	Recycling
114. Neotextile	Recycling
115. Poliverde	Recycling
116. RE&UP	Recycling
117. Re:NewCell	Recycling
118. Recover	Recycling
119. Refiberd	Recycling
120. Reju	Recycling

121.	Samsara Eco	Recycling
122.	Sixone	Recycling
123.	Spiber	Recycling
124.	Syntetica	Recycling
125.	Syre (Synthetic Textiles)	Recycling
126.	Waste2Wear	Recycling
127.	Worn Again Technologies	Recycling

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