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JTATM
Journal of Textile and Apparel, Technology and Management

Special Issue 1: ITMA, 2023

Fiber-to-Fiber Textile Recycling: Innovations and other Drivers for a Circular Economy

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A version of this article is published in Textile World Magazine.

Introduction:

ITMA 2023, Transforming the World of Textiles, provided insight into current and future issues facing the Global Textile Complex. There were opportunities to learn about new and innovative technologies being developed and implemented to address these issues. There was a notable focus on Sustainability and Circularity throughout all sectors of the supply chain including new fiber development, processing, yarn production, fabric production, finishing, cut and sew operations and recycling. In addition to numerous exhibitors showcasing their products, there were ITMAlive sessions, Innovator Xchange panels and presentations, and ITMA Innovation Awards related to Sustainability and Circularity. During ITMA, a two-day session, Planet Textiles 2023, sponsored by the Sustainable Apparel Coalition explored trends and the latest thinking on circularity, sustainability, and identified drivers that will shape the industry of the future. ITMA 2023, with over 111,000 visitors and over 1,700 exhibitors, provided opportunities to network with diverse stakeholders and gain insights into technologies and trends shaping the future of textile recycling (Fiber2Fashion, 2023). This paper focuses on fiber-to-fiber recycling, highlighting new technology innovations and other drivers moving this sector of the industry forward.

Recycling and Environmental Sustainability in the Global Textile Complex

Reclaiming and reusing post-industrial waste has been a common practice throughout many textile industry sectors for decades. Post-consumer recycling is an emerging area of interest that has unique challenges requiring the development and use of innovative technologies to achieve the goal. In this report, the focus is on the drivers, challenges and solutions to post-consumer waste collection, separation, and recycling, many of which were highlighted at ITMA 2023. There were numerous new technologies introduced as well as innovative uses of existing technology that allow for the steps in textile recycling to be mechanized, automated and combined. Legislation, both in development and soon to be implemented, was reviewed, and noted as a driver in moving toward fiber-to-fiber recycling and circularity in the global textile value chain. It is also noted that numerous partnerships among companies in various sectors of the supply chain have been formed and are contributing to the transformation of the industry.

The production of textile products, from fibers to consumer products, are resource intensive requiring large amounts of water, energy and chemicals depleting the world of natural resources. These processes can pollute the air, water, are known to produce greenhouse gas (GHG) emissions and impact the biodiversity of the environment. Recycling textile products at the end of life can reduce this depletion of natural resources, reduce pollution and help reduced the strain on the planet's environment. In this report, recycling includes breaking the product down to the fiber level or its base molecules/monomers in support of the circular economy and closed loop manufacturing is the interest and the focus. This level of recycling is completed using chemical or mechanical processes depending on the raw material being recycled and intended future use. Recycling will provide raw materials from which new products can be manufactured. There is an overabundance of post-consumer textile waste. Chun (2023) noted that according to McKinsey, roughly 97% of all clothing eventually ends up in a landfill and within 12 months of its manufacturing date, 60% of clothing is in the landfill. Reference needed Media Pressure, consumer demand, regulations and technology are driving forces behind the move toward fiber-to-fiber circularity.

Textile Waste: Pre and Post Consumer

Waste can be categorized as pre- or post-consumer. Pre-consumer waste is from the manufacturer and never makes it to the consumer or retailer. It can also be classified as post-industrial waste. Cutting room floor scraps, rejects, trimmings, threading, or end of process waste are examples of this. For years companies have found ways to reuse or sell this waste diverting it from landfills and sometimes it is used in other products. An advantage of pre-consumer versus post-consumer waste when considering reuse and recycling is there is a better understanding of the raw materials in the waste stream.

Post consumer waste includes items that have been used by the consumer, disposed of, and diverted from the landfill. Post-consumer waste contains mixed material is difficult to recycle. Although not truly post-consumer, 30% of garments produced are not sold and are commonly landfilled or burned are also potential raw materials for fiber-to-fiber recycling. (Rudenko, 2018)

Fiber-to-Fiber recycling of post-consumer textile waste

Numerous challenges have been identified regarding textile/apparel recycling in general and specifically related to post-consumer waste. Some critical for effective fiber-to-fiber recycling are garment disassembly and fiber identification. As apparel and other textile products are commonly made of multiple components from various materials, a frequently identified challenge is the use of mixed materials within the products. These can include various fasteners and embellishments as well as various fabrics of different fibers within the garment. In many cases the fabrics are made from unknown fiber blends, which is problematic in the recycling process. Remembering that the different materials are recycled differently, the presence of mixed materials has previously limited effective fiber-to-fiber recycling.

When post-consumer waste is collected, the first step is sorting. Sorting is most commonly a manual process and there are numerous criteria, sometimes up to 60 sorting categories are used. Initially those products of 'high value', identified as designer goods vintage items, are removed for high end resale. Then items suitable for resale through thrift shops are identified and removed. The remaining products may be identified as suitable to sell to rag dealers, and fiber content is of importance in determining how functional they will be in this use. (Englund, et al. 2017)

To move the remaining goods to recycling so the fibers and/or raw materials can be reused, resulting in effective closed loop manufacturing, it is important to accurately identify the raw materials. This is critical in

determining appropriate recycling techniques (chemical or mechanically) and potential end-uses.

Fiber Content: Polyester, in 2021, had a market share if 54% of total fiber global fiber production, followed by cotton and other natural cellulosic fibers with about 28% market share, man-made cellulosics about 6.4% and nylon accounting for approximately 5% market share (Textile Exchange, 2022). In the clothing industry, over 68% of the fibers used in apparel are synthetic fibers, primarily polyester (Chen, et al., 2021), followed by cotton. Blends of cotton-polyester, 65/35 and 50/50, are commonly used in apparel products (Kronberga, 2022).

The majority of products contain multiple fibers that have been intimately blended and therefore it is difficult to separate the fibers. For fiber-to-fiber recycling to be successful, and the most effectively method of recycling selected, it is critical that the material is identified to be appropriately recycled. Historically determining the materials within the product was cumbersome and has been achieved using a specially trained workforce that can identify fiber content by touch or others who examine the labels for this information. Next, the products need to be disassembled to remove non-textile products as this would interfere with the recycling process. As these processes are completed manually, they are time consuming and create a bottleneck in the recycling process.

Fiber Content Determination: Technology was presented at ITMA 2023 that aids in the identification of fibers using near infrared (NIR) spectroscopy. NIR uses the unique signature based on the chemical composition of the fiber for sorting and completed in milliseconds (Reference). Several companies at ITMA were promoting this technology including **Valvan** and **Andritz**, among others. These two leaders have also combined various technologies and partnering with others to provide sorting and recycling systems.

Valvan, located in Belgium, has developed a library of fiber signatures and when the NIR signature from the fiber is compared with those in the library, the fiber is identified in milliseconds. The identification system, Fibersort™, uses Artificial Intelligence (AI) to predict the concentration of fibers. Fibersort™ can also separate by colors using an RGB camera. The quick identification allows this technology to aid in fast automatic sorting of the product. Valvan has stated that there is 99% accuracy on single fiber materials and 95% accuracy on blends.

Andritz, headquartered in Sweden, recently announced a partnership with Pellenc ST and Synergies TLC to establish the first combined industrial scale automatic textile sorting line in France. Technologies in Pellenc ST's Mistrial machines use NIR, visible spectrometry, induction, and X-Rays with NIR suitable for fiber identification. (Pellenc ST, 2023).

Product Disassembly and Separation of fibrous and non-fibrous components: Products must be disassembled by removing fasteners, such as buttons or zippers, and embellishments including leather patches and sequins, before moving to fiber recycling. The garment pieces are cut and innovative technology capable of identifying and removing the non-fibrous materials from the waste stream was demonstrated. The technology pulls any garment components containing non-fibrous materials such button or zippers and removes them from the product stream while only fabric pieces move forward to the next step, shredding.

Both **Valvan** and **Andritz** demonstrated technology at ITMA that effectively separated non textile components from the base fabrics that are found in post-consumer textile waste. This includes fasteners such as buttons, zippers, and snaps, and embellishments like leather patches, studs, sequins. Both companies have combined new technology to develop systems that have the potential to transform the textile waste

industry and move towards a circular economy.

Valvan demonstrated that after the fiber content was determined, and the garment was clipped into smaller pieces fed into the Trimclean™, a highly effective system which removes zippers, buttons, labels, and other non-textile raw materials (Figure 1). The undesirable components ae pneumatically separated from the textile. This increases the purity of the feedstock resulting in both quality and reliable feedstock for fiber-to-fiber recycling. Valvan creates solutions for all steps in the recycling process including supply systems, bailing systems, and sorting.

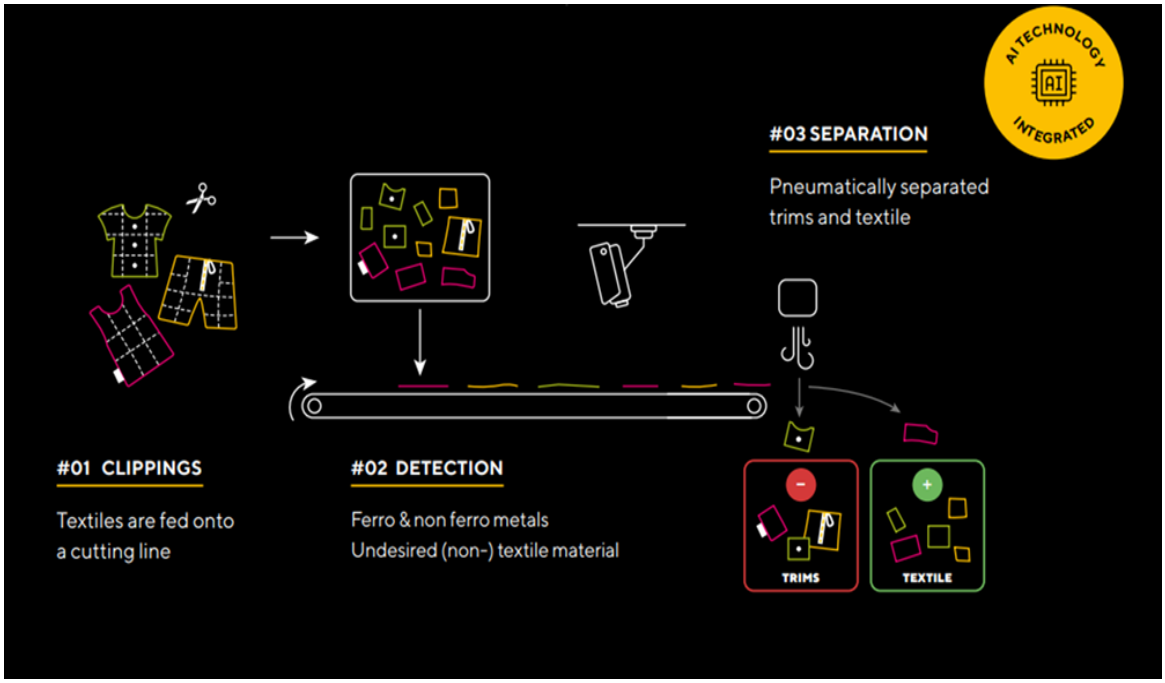

Figure 1. Schematic of Trimclean™ process, Valvan Trimclean™ Leaflet https://www.valvan.com/uploads/general/VALVAN_trimclean_leaflet-A4_08_lowres.pdf?v=

Andritz also demonstrated technology which successfully separates non textile components from the fabrics. Like Valvan, the Andritz system covers several segments in the textile industry from sorting, shredding and mechanical recycling. The equipment will shred the fabric while simultaneously removing heavy and metal parts including buttons, zippers, rivets and other embellishments commonly found in apparel. Andritz moves forward into both chemically and mechanical recycling through collaborations with international partners.

Fiber Separation and Regeneration:
Technology that can instantly identify fiber content in the sorting process and then removal of non-textile components from post-consumer textile waste has been described. However, until recently, it has not been possible to separate fibers in multifiber blended fabrics and therefore fiber-to-fiber recycling has been limited to those products of a single fiber. As the push for recycling continues, technology to separate garments containing blends of fibers is critical Through various panels, presentations and various networking events, companies pioneering fiber separation from mixed textile materials were present. Representatives from **Circ®**, **Ambercycle**, and **Renewcell** shared information about their technology that successfully separates the different fibers in fabric blends and the production of new fibers from the recycled raw materials.

Circ: Circ has flexible technology that is capable of separating synthetic fibers from cellulosic content; capturing the majority of the raw materials so it can be remade into high quality fibers to be used in future clothing. Circ, headquartered in Danville Virginia, USA, initially focused on biofuel production but is not applying a technical solution to blended textile fabrics (Pilkington, 2022). Peter Majeranowski, Circ CEO, stated "A key step in a fully circular fashion system is creating technology to break down textile waste and create new fibers from it [and then] creating garments that are using fibers made from recycled textile waste" in an interview with Elle (Chong, 2023) Circ uses a hydrothermal processing technology to treat and separate the fibers. (https://circ.earth/)

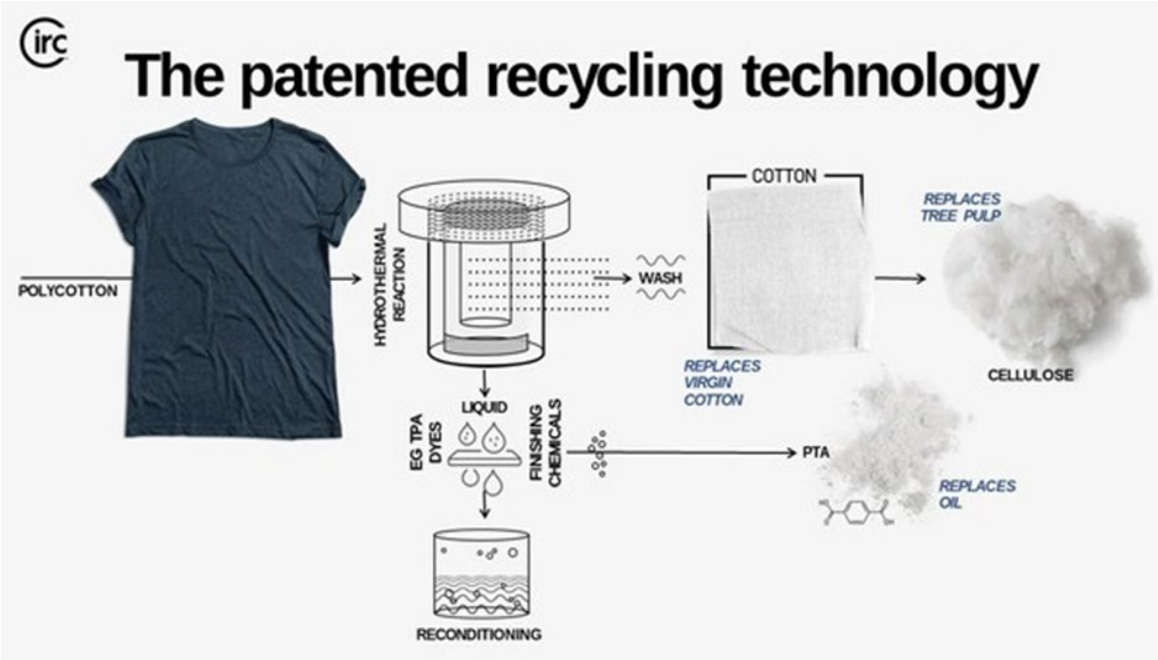

Figure 2. Circ patented recycling technology. Circ, 2022.

Ambercycle: Aksay Sethi and Moby Ahmed founded Ambercycle in 2015 as they developed a breakthrough technology using a biological recycling process that enables the molecular separation of different fibers, such as cotton and polyester. This process, known as Ambercycling, produces regenerated materials from post-consumer waste that has be separated and purified at the molecular level. In their process, a whole T-shirt goes into a reactor, and through their patented process, they recover the polyester and reform it into a yarn. These newly regenerated materials can then be produced into fabrics and new garments can be made (Patel, 2021). This not only reduces garments from going into landfills but also reduces the need to use new resources. Ambercycle introduced Cycora® which has been designed to serve as a direct replacement for polyester used in apparel. Cycora® is a closed loop circular yarn created by regenerated textile waste. Ambercycle collaborated with Avery Dennison to create a unique scannable QR code label, a form of digital tagging. This tagging allows for full traceability, transparency, and authenticity (Redgrave and Bosi, 2023)

Renewcell was formed in Sweden in 2017 and its technology transforms cellulose waste into pulp and allows for the efficient reuse of chemicals. Renewcell's goal is to recycle more than 1.4 billion t-shirts every year by 2030. The process still has limitations when recycling blends however Renewcell's

technology can recycle clothes that are made of cotton and up to 5% non-cotton material like polyester (Renewcell) https://www.renewcell.com/en/

Legislation driving textile recycling:
There are numerous drivers moving industry and consumers to a circular economy. Increased awareness of the environmental impact of the global textile complex through scientific reporting, social awareness, and ease of access to information is one of these. Another of these is legislation related to textile waste, both pre-and post-consumer waste and in some cases the implementation of Extended Producer Responsibilities. Specifically, the EU's Waste Directive Framework requires countries to separate all textile waste by 2025 and the Circular Economy Action Plan ensures that circular economy principles are applied to all textile manufacturing products. These actions have pushed forward the technologies discussed here and support their implementation so companies throughout the supply chain will be in compliance.

The Planet Textiles event at ITMA2023, June 12 and 13, organized by the Sustainable Apparel Collation, highlighted the upcoming legislation during the panel presentation "The Global Legislative Landscape: What to expect for Fashion, Sport and Footwear" moderated by Baptiste Carriere-Pradal with speakers Ilishio Lovejoy and Maxine Bédat. Current and future legislation is expected to impact all sectors of the value chain.

Baptisite Carriere-Pradal began the session with an overview and noted that although 10 years ago it was thought that consumers would be the drivers of a change to more environmentally and socially sustainable goods, and the brands would change things to meet this demand by ensuring the choices they provide to consumers are made with a 'fairly minimum impact'. However, Carriere-Paradal noted that it is now the citizens that are requiring this which has resulted in an increase in legislation addressing the way products are designed, sourced, manufactured, marketed and what happens at end of life. Chun (2023) noted that regulatory trends are also a factor influencing the landscape of sustainability within the global textile complex and most will factor into future innovation development and implementation. Many of the legislative acts mentioned during Planet Textiles relate to transparency and traceability of the product. Increased transparency will allow more accurate and easily accessible information regarding product raw material content and processing and will aid in the recyclability of post-consumer textile waste. Following are the pieces of legislation discussed and or mentioned during the session. It is expected these will drive the development and implementation of innovative technologies leading to a more sustainable industry.

The **Fashion Sustainability and Social Accountability Act**, also known as the **New York Fashion Act,** was a bill introduced in the New York Assembly in 2022, however it did not move forward due to lack of support. A 2023 version of the bill was reintroduced, and it stalled in the last session**.** The Act has the four key elements of supply chain mapping, due diligence, adverse impact disclosures, and targeted impact reduction (Lupo, 2023). During the panel presentation, Maxine Bédat noted that this bill includes due diligence language incorporating what has otherwise been voluntary. The approach requires the fashion seller and/or brand to set and achieve science-based targets. Bédat stated, "the idea is not to put the information on the consumer and have the consumer decide and decipher any labeling." (Planet Textiles, 2023) The brand will set the goals and decide how they will structure their business to meet these. There is language within the New York Fashion Act, of not only what the fashion seller/brand has to do, but also regulators must provide information and be available to prevent lack of clarity about what is the responsibility of the supply chain and seller.

The aim of the **Corporate Sustainability Due Diligence Directive** (CSDDD) adopted by the European Commission in February 2022 is to "foster sustainable and responsible corporate behaviour throughout global supply chains... requiring companies to identify, and where necessary, prevent, end or mitigate adverse impacts of their activities on…. the environment for example pollution and biodiversity loss." (and to anchor human rights and environmental consideration in companies' operation and corporate governance" (European Commission, 2022).

According to Carriere-Pradal, when referring to the CSCDD stated "…even if this obligation will be for the people putting the product on the market, it'll have definitely ripple effect for everybody in the value chain" so there will be changes throughout the industry". (Planet Textile, 2023)

The **Corporate Sustainability Reporting Directive** (DSRD), adopted by the European Parliament in November 2022, strengthens, and expands sustainability reporting to move to a green and sustainable economy. This framework will be introduced in phases beginning in 2024. It includes reporting on Environmental and Social aspects and required how related issues impact their business and how their operation affect people and the planet. Items related to environmental areas include science-based targets, EU Taxonomy, and climate risk related reporting. (Crabbendam, 2022)

On March 30, 2022, the proposal for a new **Ecodesign for Sustainable Products Regulation** (ESPR) was published by the European Commission and will improve product circularity, energy performance and other environmental sustainability aspects. It will allow for the setting of performance and information requirements of most categories of physical goods placed on the EU market. The requirements cover a board range including product durability, reusability, and reparability, recycled content, carbon, and environmental footprints and including Digital Product Passport (DPP). The ESPR proposal will apply to all products placed on the EU market whether they are produced inside or outside of the EU.

Conclusion:

ITMA 2023 provided the opportunity to learn about the trends impacting sustainability and circularity within the global textile complex. With increased media attention and consumer awareness on the environmental impacts of textile industry, technology, and legislation, there is a transformational change in future. Innovations that allow for the mechanization and automation of textile sorting, fiber identification, and the creation of new fibers from textile pre- and post-consumer waste are being developed and implemented as the industry moves to meet this change. Start-ups and well-established companies are taking leadership roles through all sectors of the textile and apparel supply chain in meeting the new criteria of the industry. Increased collaboration among NGO's, industry and academia are tackling the complex issues facing the industry. New collaborations, innovative technologies, increased consumer awareness and legislation are driving this transformative change.

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