

Opinion: Fibre mechanical and chemical textile recycling are synergistic technologies

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Introduction

Fibre mechanical and chemical textile recycling both have their own benefits. At the same time, we have to admit they are not universal technologies, nor overlapping, but merrily completing each other. Fibre mechanical recycling is currently the most mature, widely used textile recycling route, while chemical solutions are still emerging alternatives. However, together they form foundation for transitioning the textile sector toward a sustainable, circular model.

Fibre mechanical recycling is called environmentally friendly technology, because it avoids the use of chemicals and especially large quantities of water. This makes the impact of fibre mechanical recycling, typically open carding, markedly lower compared with chemical recycling.¹ Mechanical systems are stated to be more affordable to invest in and that their operational costs are lower, more accessible and widely adopted on a commercial scale.²

Mechanical systems are well-established and mature technology for more robust for various types of raw materials from post-industrial waste (spinning waste to cut-offs) to different post-consumer materials.³ Severe mechanical processing shortens fibres, whereas refined mechanical techniques enable the production of longer fibres suitable for spinning into new yarns. However, material losses are inevitable, and open carding speeds may need to be limited, while the quality of recycled fibre can be improved by pretreatments. But still, the average fibre length is reduced, and the number of fines is pronounced, especially with the finest fibres.

Contrary to fibre mechanical recycling, the chemical recycling technologies, either through dissolving and recrystallisation or depolymerisation followed by repolymerisation, allow textiles to be recycled repeatedly without major quality loss.⁴ Unlike mechanical fibre recycling, chemical methods typically require pretreatment of textiles containing dyes, finishes, elastane, and other additives. Especially, these purity issues have caused challenges in chemical recycling up-scaling. Chemical polyester recycling generates far lower CO₂ emissions than manufacturing virgin polyester, largely because it avoids the energy-intensive processing of petroleum feedstocks. By reclaiming existing synthetic fibres, it also keeps polyester out of landfills and incinerators, reducing soil, water, and air pollution. Importantly, recycling eases pressure on diminishing crude-oil resources, which are essential for producing virgin polyester, helping address both resource scarcity and environmental impacts across the textile industry.

Although mixed textile compositions (i.e., polyester with cotton; polyester with viscose; certainly, there are tertiary mixtures of fibres like cotton, polyester with elastane) still pose challenges when sorting is not carefully controlled, integrating chemical recycling technologies within modern industrial hubs enables more efficient identification, separation, and preparation of standardised feedstock streams. High precision textile sorting is essential for achieving

consistent, high-quality recycling outcomes, both mechanical and chemical. Strengthening sorting infrastructure is therefore a critical step toward building a scalable, circular textile economy capable of recovering more materials and reducing environmental impacts. Recycling technologies within modern industrial hubs enable more efficient identification, separation, and preparation of standardised feedstock streams.

Traditional manual textile sorting is slow, prone to human error, and difficult to scale for large waste streams. Automated sorting systems using spectroscopy such as Near-Infrared (NIR) and hyperspectral imaging combined with artificial intelligence/machine learning (AI/ML) classification greatly improve waste identification accuracy and processing speed. However, machine based sorting is still affected by several factors, including fabric thickness, multilayered structures, blended materials, coatings, and -based sorting is still affected by several factors, including fabric thickness, multilayered structures, blended materials, coatings, and dark dyed-dyed textiles, all of which can reduce signal quality and hinder precise material recognition.⁵ Visible and infrared spectroscopy (including hyperspectral) combined with machine learning allows rapid composition detection and quality grading.⁶ In the future, utilising information from the textiles Digital Product Passport (DPP) will support textile sorting and improve the matching of waste textiles to recyclers' input specifications.⁷

Removing dyes from mixed textile waste is a critical preprocessing step before chemical recycling, regeneration, or re-dyeing. Mixed waste is challenging because it contains different fibres (cotton, polyester, nylon, elastane) and heterogeneous dye types, each responding differently to decolourisation.⁸ For example, alkaline processing conditions required for effective removal of dyes from cotton could be detrimental to polyester, causing hydrolysis and significant material loss if not carefully selected.⁹ Removing dyes, finishes, metals, and additives that interfere with dissolution, depolymerisation, glycolysis, and hydrolysis processes improves yield and the purity of reproduced polymers and textile fibres.¹⁰

To support a holistic understanding of textile recycling methods, the following Table 1. Compares fibre mechanical recycling and chemical recycling across key criteria relevant to industry professionals and researchers. The aspects covered include advantages, limitations, technology readiness, market acceptance, and broader impacts, providing a structured overview grounded in the preceding discussion.

Table 1 Comparison of fibre mechanical and chemical recycling in different aspects

Aspect	Fibre mechanical recycling	Chemical recycling
Technology readiness level (TRL)	High and commercially mature and established (TRL is 9). ¹¹	Medium (TRL6-7) to high, but less mature and still scaling industrial adoption. ¹²
Customer acceptance	Customer acceptance is generally lower for products derived from post-consumer textile waste, particularly when the recycled fibres are of mixed colours, as this reduces their commercial appeal. However, products manufactured from colour-sorted post-industrial textile waste are more readily accepted by customers due to their more consistent appearance and perceived higher quality.	Growing interest as awareness of circularity increases; acceptance depends on demonstrated quality and economics.
Environmental benefits	Low water and chemical usage; reduces landfill and incineration; lower energy footprint.	Significantly reduces CO ₂ emissions for synthetic textile origin as compared to their virgin sources; enables recycling of challenging waste streams; lowers resource pressure. ¹³
Economic benefits	Lower operational costs; affordable investment (easy to convert the conventional yarn spinning machines); rapid returns; scalable for various waste streams.	Potential for high-value output; enables recovery from complex blends; long-term savings through resource efficiency.
Challenges	Fibre quality loss and shortening (i.e., post-consumer textile waste); limited to compatible textile types, like elastane; material losses; require effective pretreatment like sterilisation.	Preprocessing is required to remove various contamination (dye/finish/additive, elastane removal); complexity of mixed waste; higher initial costs; scaling technology and infrastructure.
Strengths	Established, reliable, and efficient; low environmental impact; accessible for diverse operators.	High-quality recycled output; versatility for complex and coloured textiles; aligns with circular economy principles.
Weakness	Fibre shortening and material losses; limited to not able to process for elastane or its blends.	Emerging technology with higher investment costs; complex preprocessing required (dye/finish removal); require more energy and chemicals.
Opportunities	Integration with chemical recycling for cascading processes; improvements in sorting and pretreatment; expanding feedstock diversity.	Advanced sorting and pre-treatment technologies; Utilisation of DPP; processing of previously unrecyclable blends; driving innovation in circular textiles.
Threats	Competition from emerging chemical processes; limitations for blended/fancy textiles; market saturation.	Regulatory uncertainty, market acceptance, and technical bottlenecks in scaling and feedstock standardisation.

Conclusion

Fibre mechanical recycling provides a quick and affordable solution for retrieving value, whereas chemical recycling ensures that even damaged or blended textiles are effectively reused. This drastically improves overall recovery yields. One of the most promising ways to create a scalable, cost-effective circular textile system is by combining mechanical and chemical recycling in a cascading process. Certain early ecosystem building may be influenced by the fact that feasible chemical recycling should be some 5 to 10 times larger than the typical mechanical recycling and balancing these takes of its own time. As well as time required to open value added market and supportive low-end application is another issue especially in current economic instability.

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Conflicts of interest

The authors declare no conflict of interest.

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