

Mapping Circular and Sustainable Fashion, Textiles and Technology Innovation

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A photograph of a woman with long dark hair, wearing a denim shirt, smiling while looking at a laptop. She is in a cafe or office setting with shelves of coffee cups in the background. The image is overlaid with a blue gradient.

Dash & Miller
Credit: Alys Tomlinson

1 Executive summary

1 Executive summary

Global pressures, including environmental challenges and the increasing complexity of value chains, are accelerating the need for circular and sustainable innovation across the fashion, wider apparel and textiles industry. Understanding both historical developments and contemporary practices is essential to address environmental, social and economic impacts while creating opportunities for systemic transformation, moving towards a resilient, equitable and sustainable future.

The industry is a vast, global, multi-material discipline, linking everything from clothing to interiors. A hub of innovation, it is at the forefront of the shift towards circular and sustainable practices. At the same time, the sector generates significant environmental challenges: high volumes of solid waste, microplastic pollution and toxic chemical discharges, with only a small fraction of materials recycled and the remainder sent to landfill.

The EU COST Action 628 marked a key intervention, introducing life-cycle assessment, eco-efficiency indicators and cleaner production methods. However in the UK, a successful textile manufacturing industry and parallel technical education began to decline from the late 1980s due to emergent low-cost production practices, and increasing competition from abroad. Consequently, in the UK, research publications in technical textiles also fell after 2012.

Early circular innovation focused predominantly on sustainable dyeing, bioprocessing and life-cycle assessment. Post-2011 work in this field began to expand across material design, sourcing, recycling and circular business models.

This research identifies 4 thematic areas: circular innovation in material design; circular innovation in material sourcing; circular innovation in recycling; and circular innovation in business models. **Circular innovation in material design** explores waste-derived, bioderived and biosourced materials, alongside biotechnology and regenerative cultivation, offering alternatives to conventional oil-based fibres. **Circular innovation in material sourcing** incorporates regenerative agriculture, responsible fibre standards, traceability platforms and supplier management, embedding environmental, social and animal-welfare considerations at the raw-material stage. **Circular innovation in recycling** demonstrates advances in mechanical and chemical processes, fibre-to-fibre recycling and closed-loop systems, and also highlights that scaling is constrained by material complexity, inconsistent feedstock, insufficient collection infrastructure and limited economic incentives. **Circular innovation in business models** — including repair, reuse, rental, resale and on-demand production — integrates sustainability into commercial practice, but requires consumer engagement, cultural shifts and supportive policies to succeed.

1 Executive summary

Systemic circularity demands coordinated action across industry, policymakers, designers, scientists, and consumers. Key enablers include robust policy frameworks, extended producer responsibility, targeted investment, shared standards, digital traceability and workforce development. Collaborative training integrating design, STEM, materials science, sustainability and social responsibility is essential. Investing in digital infrastructures to create shared databases will allow suppliers to leverage data sets, AI and statistical analysis for material evaluation, life-cycle assessment and improved demand forecasting, traceability and supply-chain collaboration.

This report draws on a mixed-methods study, including academic and grey literature, 34 semi-structured interviews with higher education institutions (HEIs), industry stakeholders, and circular innovation companies, and a matrix of 135 circular and sustainable innovations. Case studies illustrate barriers, scaling potential, and the skills and policy interventions needed to embed circular practices across the sector. In addition, a specially commissioned workshop was held, to test emerging research against actual operational conditions. The workshop gathered industry-generated evidence on the feasibility, scalability and limitations of current common approaches to circularity, with the overall aim of facilitating future research and policy prioritisation. The workshop findings are presented as a standalone insert alongside the main body of the report.

1.1 Methodology

Research aim: To assess the developmental progress of current and emerging circular/sustainable technologies, innovations and solutions in fashion and textiles (F&T).

Research objectives:

- To review emerging and future capabilities in circular and sustainable F&T innovation, including feasibility, scalability and limitations of current common approaches to circularity.
- To make recommendations to support future circular/sustainable innovation practices, based on industry and higher education best practices spanning fashion, wider apparel and textile contexts.

A mixed-methods study was conducted in which academic and grey literature were reviewed, and primary data collected. The data was analysed using a thematic analysis, and recommendations for innovation quality assessment methods were made.

Interviews

Thirty-four semi-structured interviews were conducted between October 2024 and November 2025 with participants recruited from HEIs, industry and circular innovation companies identified as key players in the global value chain of fashion, apparel and textiles. The interviews centred on the participants' views on: historic circular innovation of significance; current innovation activities to be part of emerging future capability in F&T; barriers and limitations to the uptake of these; what policy conditions are required for success; where circular innovations should be focused and how these could be funded; what cultural values need to be in place for these innovations to be sustainably maintained; and what skills, particularly interdisciplinary, are needed that the industry finds challenging to recruit and where these may best be evolved. Responses from the participants informed the core thematic foci of the report, in particular Section 3: Circular innovation in the fashion, wider apparel and textiles industry (page 50).

A specially commissioned workshop was held, to test emerging research against actual operational conditions — and in general industry perception of circular practices. The workshop gathered industry-generated evidence on the feasibility, scalability and limitations of current common approaches to circularity, with the overall aim of facilitating future research and policy prioritisation (page 90).

During the same period 15 international and UK-based conferences and events were attended (page 45), which also informed the research approach.

Matrix of Circular Innovation Industry Practices

A matrix (page 158) of 135 circular/sustainable fashion, wider apparel and textiles innovations to date was divided into the following categories: material design (76), material sourcing (10), recycling (33) and business models (16).

Post Carbon Lab climate-positive
microbial colours
Credit: Alys Tomlinson



2 Literature review

2 Literature review, landscape mapping and review of sustainable textiles and fashion innovation

The textile industry is a vast, global, multi-material discipline that interfaces with everything around us, from clothing to interiors. It is this industry that provides the hub and baseline position for most innovation to date — and the industry that is primarily addressing the need to shift to circular/sustainable innovation.

The textile industry produces huge quantities of solid waste that needs disposal. Textile materials shed microplastics, which relatively recent evidence shows are pervasive in our environment and, when degraded, also release various toxic dyes and chemicals applied during manufacturing to enhance functional properties. When these materials are disposed of, only a fraction is recycled; the rest goes to landfill.

Research into achieving textile sustainability at its earliest point, post the influence of oil and other chemical processes on rapid textile “innovation”, mainly focuses on replacing toxic chemicals, such as carcinogenic dyes (e.g. those that produce benzidine). In the 1990s, few dyes were listed as carcinogens by the US Environmental Protection Agency. By 2000, most established dye manufacturers stopped producing this type of dye, and textile manufacturers phased out their application.

In pursuit of “innovation”, many other problematic chemicals have found their way into textiles for clothing, including, for example, formaldehyde, which was used to produce wrinkle-resistant cotton fabrics. As formaldehyde is used across multiple industries, it is difficult to attribute specific health effects to any single source, which potentially obscures links between textile-related exposure and long-term toxicity. Most wrinkle-resistant textiles were treated with a crosslinking resin containing methylol groups, such as dimethylol dihydroxyethylene urea (DMDHEU). These react with the hydroxyl groups of cellulose, reducing their moisture regain, improving rigidity and reducing their hydrogen-bond-formation ability — and improving the wrinkle-recovery properties of the treated fabrics. Reid et al. first discovered that cotton fabrics treated with wrinkle-resisting resins liberate formaldehyde during their use and storage [1]. In the 1980s, Professor Kazuhide Yamamoto of Daido-Maruta Finishing Co in Japan began developing non-formaldehyde-based crease-recovery treatments for cotton fabrics [2]. Various methods were also developed at this time to measure the

1 Reid, J.D., Arceneaux, R.L., Reinhardt, R.M., Harris, J.A., 1960. Studies of wrinkle resistance finishes for cotton textiles, I-Release of formaldehyde vapours on storage of wrinkle-resistant cotton fabrics. *American Dyestuff Reporter*, 49, 490-495.

2 Yamamoto, K., 1982. Crease-resistance treatments of cotton fabrics with non-formaldehyde crosslinking agents. *Textile Research Journal*, 52, 357-362.

2 Literature review

formaldehyde release from treated fabrics [3,4]. Unfortunately, there are many examples of material innovation that, while good for profit, have ultimately been harmful for people or planet.

The research identifies the EU COST Action 628 (2001–05) as a significant intervention that supported an important European research collaboration focused on the life-cycle assessment (LCA) of textiles. It aimed to create environmental data, eco-efficiency indicators and best available technologies for the textile industry to support more sustainable competitiveness and cleaner production by assessing impacts from fibre to product. This research built a critical database and an ISO Type III Environmental Product Declaration, which helped provide the European textile industry with the scientific tools and data needed to become more environmentally responsible and economically resilient.

Traditionally a major textile and garment manufacturer, the UK has experienced a significant decline in these industries since the 1980s due to competition from emerging, low-cost textile-manufacturing countries, such as China, Bangladesh, Pakistan and Vietnam. This transition has subsequently seen the decline of textile technology education in the UK, with fewer postgraduates studying textile technology at UK universities [5]. During this time China has increasingly focused on building more sustainable manufacturing provision.

At the same time, there has been an uptake in fashion and textile design-related education in the UK, which has become appealing to students beguiled by brand awareness, the link to celebrity, brand presence on the high street and the consumer experience, with consequently unprecedented growth in scale and related economy. The increasing production, consumption and environmental impact of apparel and textiles begins to become more evident globally, in addition to a convergence of technology-related factors including the emergence of online shopping, fast fashion, lower quality of textiles and apparel products, and higher profit margins sought by brands. Global apparel and textile supply chains, and the wider business ecosystem, have consequently become extremely complex.

3 Roberts, E.C., Rossano Jr., A.J., 1984. Formaldehyde release from cotton fabric. *Textile Chemist and Colorist*, 16, 67-72.

4 Andrews, B.A.K., Reinhardt, R.M., 1984. Formaldehyde release from durable press cotton fabric. *Textile Chemist and Colorist*, 16, 100-105.

5 Bunyan, C., Rainton, S., Connor-Crabb, A., Harris, J., Russell, S., 2025. *Toward Achieving National Capability: Ensuring a Circular and Sustainable UK Fashion and Textile Industry*. University of the Arts London and University of Leeds.

2 Literature review

Goldsworthy et al. assessed environmental science research needs across the fashion, textile and technology value chain with an emphasis on circular economy principles, sustainable production, design, materials and recycling technologies [6]. However, the literature review finds that from 2012 there seems to be a period of evident decline in UK-led research publications in the field of technical textiles. The theoretical review therefore maps academic research spanning circular and sustainable apparel/textiles innovation pre-2012 and post-2011.

A theoretical literature review is complemented by a **Matrix of Circular Innovation Industry Practices** (ref.pp 158), included with this report, and primary research including interviews with industry and HEI leaders and stakeholders spanning the following 4 themes (ref.pp 158):

- Circular innovation in **material design**.
- Circular innovation in **material sourcing**.
- Circular innovation in **recycling**.
- Circular innovation in **business models**.



Anam PALF®, textile-grade fibre made from waste pineapple leaves by Ananas Anam
Credit: Ananas Anam

6 Goldsworthy, K., Harris, J., Hassan, M., Solomon, L., 2022. Catalyst Report on Circular Fashion and Textiles. University of the Arts London.

2.1 Circular/sustainable textile and fashion innovation pre-2012

Research conducted in the UK

With no published report on the circular economy or circular design in the public domain prior to 2012, the concept of circular and/or sustainable apparel and textiles was still in its infancy. Research mainly focused on closed-loop production — for example, to minimise effluent production, as the colour of effluent and the presence of various endocrine disruptors, such as nonyl-phenol ethoxylate, drew the attention of UK environmental agencies.

Sustainable dyeing and finishing	Research led by the University of Manchester and the University of Leeds focused on more sustainable dyeing and finishing methods, and the extraction of natural dyes and their application for the colouration of various textile fibres [7], spent-dyebath recycle and reuse [8,9,10], dyehouse effluent treatment [11,12,13,14,15], dyeing with disperse dyes in the presence of a free-radical initiator [16,17,18], and reduction of environmental impacts of dyeing and finishing [19]. It was found that spent dyebath decolourised with ozone can be reused for dyeing and bleaching of textiles up to 3 times [17], considerably reducing effluent production.
Bioprocessing	Professor Jinsong Shen's group at De Montfort University carried out research into bioprocessing textiles, including the enzymatic shrink-proofing treatment of wool [20,21] in collaboration with EU partners. During laundering, wool-fibre garments undergo felting,

7 Badri, B.M., Burkinshaw, S.M., 1993. Dyeing of wool and nylon 6.6 with Henna and Lawsone. *Dyes and Pigments*, 22, 15-25.

8 Hassan, M.M., Hawkyard, C.J., 2007. Decolorisation of effluent with ozone and re-use of spent dyebath. *Environmental Aspects of Textile Dyeing*, 149-190.

9 Hassan, M.M., Hawkyard, C.J., 2002. Reuse of spent dyebath following decolorisation with ozone. *Coloration Technology*, 118, 104-111.

10 Burkinshaw, S.M., Graham, C., 1995. Recycling of exhausted reactive dyebaths. *Dyes and Pigments*, 28, 193-206.

11 Hassan, M.M., Hawkyard, C.J., Barratt, P.A., 2006. Decolourisation of dyes and dyehouse effluent in a bubble-column reactor by ozonation in the presence of H₂O₂, KMnO₄ or Ferral. *Journal of Chemical Technology and Biotechnology*, 81, 158-166.

12 Hassan, M.M., Hawkyard, C.J., 2006. Decolourisation of dyes and dyehouse effluent in a bubble-column reactor by heterogeneous catalytic ozonation. *Journal of Chemical Technology and Biotechnology*, 81, 201-207.

13 Hassan, M.M., Hawkyard, C.J., 2002. Decolourisation of aqueous dyes by sequential oxidation treatment with ozone and Fenton's reagent. *Journal of Chemical Technology and Biotechnology*, 77, 834-841.

14 Hassan, M.M., Hawkyard, C.J., 2002. Ferral-catalyzed ozonation of aqueous dyes in a bubble-column reactor. *Catalysis Communications*, 3, 281-286.

15 Hassan, M.M., Hawkyard, C.J., 2002. Ozonation of aqueous dyes and dyehouse effluent in a bubble-column reactor. *Journal of Environmental Science and Health, Part A: Toxic/Hazardous Substances and Environmental Engineering*, 37, 1,563-1,579.

16 Burkinshaw, S.M., Lu, J.G., 1994. Dyeing in the presence of free radical initiators, part 7: The dyeing of silk fibres. *Dyes and Pigments*, 26, 1-13.

17 Burkinshaw, S.M., Lu, J.G., 1994. Dyeing in the presence of free radical initiators, part 6: The dyeing of wool with disperse dyes. *Dyes and Pigments*, 25, 205-227.

18 Burkinshaw, S.M., Lu, J.G., 1994. Dyeing in the presence of free radical initiators, part 5: The effects of radical initiators on nylon 6.6. *Dyes and Pigments*, 24, 59-73.

19 Blackburn, R.S., Burkinshaw, S.M., 2002. A greener approach to cotton dyeings with excellent wash fastness. *Green Chemistry*, 4, 47-52.

20 Lenting, H.B.M., Broekman, H., Guebitz, G.M., Kokol, V., Shen, J., 2009. Industrial production of enzyme-modified wool fibres for machine-washable bed coverings. *Biotechnology Journal*, 4, 1,441-1,449.

21 Smith, E., Zhang, Q., Shen, J., Schroeder, M., Silva, C., 2008. Modification of Esperase® by covalent bonding to Eudragit® polymers L 100 and S 100 for wool fibre surface treatment. *Biocatalysis and Biotransformation*, 26, 391-398.

which causes them to shrink, affecting their appearance. It was found that enzymatic shrink-proofing treatment produced uneven effects, which limited its industrial application, and a further polymeric coating of fibre was needed to make wool fibres shrink-proof, affecting the sustainability of the developed process.

Research conducted in the EU

Life-cycle assessment (LCA)

Research on end-of-life environmental impacts and the effect of fashion and textiles on climate change started in the new millennium. The EU COST Action 628 was established to produce industrial environmental data on textiles in Europe and suggest tools for comparisons of conventional technologies with modern clean technologies, including economic sustainability [22]. LCA is an environmental indicator and a tool for sustainable textile product design [23]. Güngör et al. calculated the LCA of a cotton bathrobe [24], which showed that cotton fibre — the most commonly consumed natural fibre in bath towels — is not an environmentally friendly fibre as previously assumed. The LCA of flax and hemp production showed that bioretting had higher impacts than the reference scenario for climate change and energy usage, and lower energy usage was needed to reduce the environmental impacts of hemp [25]. The LCA was used to assess the environmental impact of polyester/cotton-blend fabrics used in hotels and their laundry services [26]. The inventory calculations proved that cotton-fibre production consumes about 40% less energy than polyester-fibre production, but growing cotton requires huge amounts of water (7 to 29 tons per kg of raw cotton fibres). Pesticides and fertilisers used in traditional cotton cultivation have ecotoxic effects in contrast to organic cotton cultivation.

The use of recycled process effluent appears a technically feasible solution to tackle the issue of water shortage in different parts of the world and LCA can be used for water management in the textile industry [27]. The LCA shows that regenerated cellulose fibres produced in Europe (Tencel, Modal, Viscose) have the lowest overall impact among all fibres studied, and also have lower environmental impacts than viscose fibre produced in Asia (comparable to the environmental impacts of polyester) [28]. Cotton is identified as the least preferred choice due to its high ecotoxicity, eutrophication, and water and land use. The LCA of polyester-bottle recycling by mechanical recycling, semi-mechanical recycling, back-to-oligomer recycling and back-to-monomer recycling shows that mechanical recycling had the lowest environmental impacts — much lower compared to those of virgin polyester [29].

For an accurate assessment of the hazard levels of chemicals during their life cycle, LCA developers tried to include the fate of chemicals in the life-cycle impact assessment (LCIA).

22 Nieminen, E., Linke, M., Tobler, M., Beke, B.V., 2007. EU COST Action 628: Life cycle assessment (LCA) of textile products, eco-efficiency and definition of best available technology (BAT) of textile processing. *Journal of Cleaner Production*, 15, 1,259-1,270.

23 Nieminen, E., 2006. Definition of the environmental indicators for textiles and a tool for sustainable product design. *Revista de Quimica Textil*, 179, 43-46.

24 Güngör, A., Palamutçu, S., Ikiz, Y., 2009. Cotton textiles and the environment: Life cycle assessment of a bathrobe. *Tekstil ve Konfeksiyon*, 19, 197-205.

25 van der Werf, H.M.G., Turunen, L., 2008. The environmental impacts of the production of hemp and flax textile yarn. *Industrial Crops and Products*, 27, 1-10.

26 Kalliala, E.M., Nousiainen, P., 1999. Life Cycle Assessment environmental profile of cotton and polyester-cotton fabrics. *Autex Research Journal*, 1, 8-20.

27 Tarantini, M., Scalbi, S., Misceo, M., Verità, S., 2004. Life cycle assessment as a tool for water management optimisation in textile finishing industry. *Proceedings of SPIE: The International Society for Optical Engineering*, 5,583, part. no. 17, 163-170.

28 Shen, L., Worrell, E., Patel, M.K., 2010. Environmental impact assessment of man-made cellulose fibres. *Resources, Conservation and Recycling*, 55, 260-274.

29 Shen, L., Worrell, E., Patel, M.K., 2010. Open-loop recycling: A LCA case study of PET bottle-to-fibre recycling. *Resources, Conservation and Recycling*, 55, 34-52.

Beck et al. compared the Uniform System for the Evaluation of Substances adapted for LCA and a simple river model (box approach) to measure the LCIA of textile chemicals [30] considering their practicability and the value added to the assessment results. They found that emissions and use of energy still dominated the LCIA results even if ecotoxicity is assessed with a rather complex fate model such as USES-LCA.

Bioprocessing

In the EU in the 2010s, sustainable textile innovation mainly focused on bioprocessing textiles using various enzymes. The selection of bacterial strain and culture conditions greatly affects the productivity and quality of bacterial nanocellulose [31]. It is possible to enhance bacterial nanocellulose production and improve its properties when scaling up submerged cultivation in stirred tank reactors [32]. As well as bacterial cellulose production, other areas of study included enzymatic modification of wool textiles, reduction of vat dyes and colouration of textiles. Coating wool fabric with nordihydroguaiaretic acid by oxidation with laccase made it shrink- and wrinkle-resistant, and provided high antioxidant activity [33]. Coating wool fabric with lauryl gallate using laccase enzyme enhanced its antioxidant, antibacterial and water-repellent properties [34,35]. As protease treatment is uneven and damages wool fibre through penetration, the microbially produced functionalised high molecular weight protease provided controlled enzymatic hydrolysis of the wool surface [36]. Laccases are blue multicopper oxidases widespread in fungi, plants and bacteria that catalyse the oxidation of various aromatic compounds, particularly phenols, using molecular oxygen, which is reduced to water.

Vat dyes are insoluble in water but must be dissolved to dye textiles in aqueous conditions — usually using a strong reducing agent such as sodium dithionite, which is toxic. Enzymatic reduction of vat dyes for different fibres made the dyeing process eco-friendly [37,38]. Azoreductase was also found to reduce vat dyes such as Indigoid [39]. The laccase-catalysed oxidative coupling of the colourless 2,5-diaminobenzenesulfonic acid (2,5-DABSA) and 1-hydroxyphenol (catechol) to cotton fabric produced a brown colour shade [40,41]. Enzymatic scouring of cotton with pectinases was found ecologically and

30 Beck, A., Scheringer, M., Hungerbühler, K., 2000. Fate modelling within LCA: The case of textile chemicals. *International Journal of Life Cycle Assessment*, 5, 335-344.

31 Chen, G., Wu, G., Chen, L., Wang, W., Hong, F.F., Jönsson, L.J., 2019. Performance of nanocellulose-producing bacterial strains in static and agitated cultures with different starting pH. *Carbohydrate Polymers*, 215, 280-288.

32 Chen, G., Wu, G., Alriksson, B., Chen, L., Wang, W., Jönsson, L.J., Hong, F.F., 2018. Scale-up of production of bacterial nanocellulose using submerged cultivation. *Journal of Chemical Technology and Biotechnology*, 93, 3,418-3,427.

33 Hossain, K.M.G., González, M.D., Juan, A.R., Tzanov, T., 2010. A single step enzymatic modification of wool textile to improve its various properties. *American Association of Textile Chemists and Colorists International Conference 2010*, 126-130.

34 Hossain, K.M.G., González, M.D., Lozano, G.R., Tzanov, T., 2009. Multifunctional modification of wool using an enzymatic process in aqueous-organic media. *Journal of Biotechnology*, 141, 58-63.

35 Hossain, K.M.G., González, M.D., Lozano, G.R., Tzanov, T., 2009. Multifunctional modification of wool using an enzymatic process in aqueous-organic media. *Journal of Biotechnology*, 141, 58-63.

36 Araújo, R., Silva, C., Machado, R., Casal, M., Cunha, A.M., Rodríguez-Cabello, J.C., Cavaco-Paulo, A., 2009. Proteolytic enzyme engineering: A tool for wool. *Biomacromolecules*, 10, 1,655-1,661.

37 Božič, M., Díaz-González, M., Tzanov, T., Guebitz, G.M., Kokol, V., 2009. Voltametric monitoring of enzyme-mediated indigo reduction in the presence of various fibre materials. *Enzyme and Microbial Technology*, 45, 317-323.

38 Božič, M., Kokol, V., Guebitz, G.M., 2009. Indigo dyeing of polyamide using enzymes for dye reduction. *Textile Research Journal*, 79, 895-907.

39 Pricelius, S., Held, C., Murkovic, M., Božic, M., Kokol, V., Cavaco-Paulo, A., Guebitz, G.M., 2007. Enzymatic reduction of azo and indigoid compounds. *Applied Microbiology and Biotechnology*, 77, 321-327.

40 Calafell, M., Díaz, C., Hadzhiyska, H., Gibert, J.M., Dagà, J.M., Tzanov, T., 2007. Bio-catalyzed coloration of cellulose fibres. *Biocatalysis and Biotransformation*, 25, 336-340.

41 Hadzhiyska, H., Calafell, M., Gibert, J.M., Dagà, J.M., Tzanov, T., 2006. Laccase-assisted dyeing of cotton. *Biotechnology Letters*, 28, 755-759.

2.1 Circular/sustainable textile and fashion innovation pre-2012

economically favourable compared with traditional NaOH scouring [42,43]. Bioscouring of wool fibres with lipolytic enzymatic products was found to be efficient in terms of the scouring effect and wool fibre protection during scouring, and wastewater pollution indicators [44]. Enzymes were also extensively studied for processing bast fibrous plants, such as flax, hemp, jute and ramie [45,46]. Alkaline pectinase (BioPrep 3000L) was found as an alternative to alkaline boiling for scouring cotton fabrics with a considerable reduction in energy usage and effluent generated [47]. Sono-biochemical scouring of cotton with cutinase and pectate lyase showed that scouring time could be dramatically reduced compared to conventional alkaline scouring [48]. Cutinase is effective in the degradation of cotton waxes at low temperatures, permitting the design and introduction of a competitive innovative enzymatic scouring process [49]. The combined use of α -amylase and hemicellulose or pectinase in the pre-treatment of cotton enables the desizing, scouring and bleaching of cotton fabric in a 1-step treatment [50]. Pretreatment of cotton with the fungus *T. hirsuta* laccase resulted in a whiteness increase of 8.5%, causing biobleaching of cotton fabrics [51]. Peroxidase enzymes were also studied for biobleaching cotton fabrics, and increased their whiteness from 55 to 66 on the Berger scale [52]. Enzymes, especially proteolytic enzymes, have been extensively studied for shrink-proofing wool. For example, serine protease secreted by the Gram-positive bacterium *Bacillus subtilis* was found to effectively remove cuticles from wool fibre surfaces to make the fabric shrink-proof [53]. However, protease absorbed into wool fibre damages the fibre. Therefore, to restrict the enzymatic action to the cuticle surface, protease was modified with polyethylene glycol [54]. The combined protease and transglutaminase enzymatic treatment of wool fibres made the wool garments machine-washable [55].

The laccase-immobilised polyamide can be used to decolourise dyehouse effluent

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- 42 Grancarić, A.M., Pušić, T., Tarbuk, A., 2006. Enzymatic scouring for better textile properties of knitted cotton fabrics. *Journal of Natural Fibres*, 3, 189-197.
- 43 Grancarić, A.M., Ujević, D., Tarbuk, A., Šajatović, B.B., 2009. Enzymatic scouring of cotton knitted fabric with neutral pectinases: The influence to sewability. *Tekstil*, 58, 529-545.
- 44 Popescu, A., Grigoriu, A., 2010. Biotechnologies for textile materials made of protein fibres. Enzymatic scouring of raw wool. *Industria Textila*, 61, 291-296.
- 45 Kozłowski, R., Batog, J., Konczewicz, W., Mackiewicz-Talarczyk, M., Muzyczek, M., Sedelnik, N., Tanska, B., 2006. Enzymes in bast fibrous plant processing. *Biotechnology Letters*, 28, 761-765.
- 46 Batog, J., Konczewicz, W., Kozłowski, R., Muzyczek, M., Sedelnik, N., Tanska, B., 2006. Survey and recent report on enzymatic processing of bast fibres. *Journal of Natural Fibres*, 3, 113 – 129.
- 47 Popescu, A., Grigoriu, A., Zaharia, C., Mureșan, R., Mureșan, A., 2010. Mathematical modelling and the technological process optimization for the bio-scouring of the cotton textile materials. *Industria Textila*, 61, 70-80.
- 48 Agrawal, P.B., Nierstrasz, V.A., Warmoeskerken, M.M.C.G., 2010. Ultrasound-boosted enzymatic cotton scouring process with cutinase and pectate lyase. *Biocatalysis and Biotransformation*, 28, 320-328.
- 49 Agrawal, P.B., Nierstrasz, V.A., Bouwhuis, G.H., Warmoeskerken, M.M.C.G., 2008. Cutinase and pectinase in cotton bioscouring: An innovative and fast bioscouring process. *Biocatalysis and Biotransformation*, 26, 412-421.
- 50 Opwis, K., Knittel, D., Schollmeyer, E., Dörfler, C., Bachus, H., Köppe, A., Köppe, U., 2006. Combined use of enzymes in the pretreatment of cotton. *Melliand International*, 12, 130-135.
- 51 Pereira, L., Bastos, C., Tzanov, T., Cavaco-Paulo, A., Guebitz, G.M., 2005. Environmentally friendly bleaching of cotton using laccases. *Environmental Chemistry Letters*, 3, 66-69.
- 52 Opwis, K., Knittel, D., Schollmeyer, E., Hoferichter, P., Cordes, A., 2008. Simultaneous application of glucose oxidases and peroxidases in bleaching processes. *Engineering in Life Sciences*, 8, 175-178.
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[56]. Cellulase enzymes were studied to decrease pilling in cotton textiles [57], through enzymatic hydrolysis of cellulose [58,59]. Enzymes, such as laccase and Mn-peroxidase, enabled decolourisation of textile dyes [60]. Catalase enzyme modified with allyl glycidyl ether was bonded to polyester fibres for the destruction of peroxide [61,62]. Polyester fibres were modified enzymatically with lipase and esterase to increase their hydrophilicity [63]. Enzymatic coating of cellulose surfaces with polyphenols increased the antimicrobial activity of the treated fabric [64], recycling of starch-based desizing liquor [65] and hydrolysis of cellulose [66]. This introduced antioxidant capacity to cellulosic materials by enzymatic modifications [67], delignification of cellulosic fibres [68], grafting polyphenols onto flax fibres [69], decolourisation of textile dyes [70] and application of enzyme in textile printing.

Textile-waste recycling

Before 2012, very little research on recycling post- and pre-consumer textile waste was carried out by academic researchers, although the textile industry started using pre-consumer textile waste from an early stage. Several Bangladeshi textile manufacturers were already using apparel-manufacturing waste fabrics to develop new products before the new millennium. The consideration of textile-waste recycling came to the fore at this time, with key areas of research including electronic textiles, textile wastewater and reusing reclaimed fibres. The textile dyeing and finishing industries are major industrial water polluters, and biological- and membrane-based wastewater treatment technologies may play a significant role in cleaning and reusing dyehouse effluent. It is also necessary to evaluate the negative environmental impact of the emerging generation of electronic textiles and smart materials, with a recent article outlining possible end-of-life implications.

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- 64 Schroeder, M., Aichernig, N., Guebitz, G.M., Kokol, V., 2007. Enzymatic coating of lignocellulosic surfaces with polyphenols. *Biotechnology Journal*, 2, 334-341.
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In addition, several studies [71] reported [72] the performance of recycled fibres in the preparatory stages of spinning, as post-consumer fibres may be weakened due to degradation their lifetime.

Research conducted in the rest of the world

Circular design/economy

Evidence confirms that while the theoretical foundations of the circular economy existed earlier, there was very little, if any, focused academic or industrial research regarding the circular design of textiles before 2012. Research interest, along with the adoption of the term “circular economy” as a business model for textiles, significantly increased only after 2012. Du et al. outlined the basic concept of the Rapid-Response Eco-Supply Chain in China according to the basic theory and operation principle of the circular economy. They devised circular-economy principles for the Rapid-Response Circular Supply Chain to support the sustainable development of China’s textile industry and overcome “green” trade barriers by incorporating circular supply chains aligned with circular economy and green manufacturing practices [73,74].

Sustainable dyeing and finishing

A published article reported that a durable water-repellent plasma coating on polyester/cotton-blend fabric with fluorocarbon monomers (e.g. 1,1,2,2-tetrahydroperfluorodecyl acrylate and 1,1,2,2-tetrahydroperfluorododecyl acrylate) and a further treatment with a quaternary ammonium compound made the fabric antibacterial [75,76]. Studies also examined novel solvent development for the dissolution of cellulose to manufacture rayon-like fibres [77]. Cotton fabrics have poor wrinkle-recovery properties and easily form creases, especially during laundering, and the common anti-crease finished fabric releases formaldehyde, a possible carcinogen. Therefore, research was undertaken into making an anti-crease finishing treatment for cotton fabric ecofriendly. Coating cotton fabric with an amino-based silicone microemulsion considerably increased the wrinkle recovery of the treated fabric [78]. Treating cotton fabrics with copolymers of hydrophobic N-alkyl and benzophenone-containing polyethylenimines provided durable antimicrobial properties [79]. Similarly, dyeing silk fabric with natural dyes provided antibacterial properties [80]. Reducing indigo dyes with borohydride for cotton fabrics was a more eco-friendly, sustainable process compared to the traditional dithionite-based reduction process [81].

71 Elsasser, N., Maetschke, O., Wulfhorst, B., 1998. Processing performance of reclaimed fibres in the preparatory stages of spinning. *Melliand Textilberichte*, 79, 813-816 and E216.

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Dyeing wool fabric with the extracts of a mixture of *Terminalia arjuna* fruits and madder produced shades from mustard brown to reddish brown [82]. Sonochemical scouring and bleaching of flax fabric with a combined laccase enzyme and hydrogen peroxide enhanced the colourfastness to washing of fabric further dyed with reactive dyes [83]. Wool fabric dyed with reactive dyes microencapsulated with a phospholipid mixture of commercial soybean lecithin-based liposomes provided good colour strength and uniform dyeing [84]. Natural dyes extracted from various biomasses, such as *Hibiscus rosa sinensis* flowers [85], *Emblica officinalis* G. fruit [86], *Illicium griffithii* [87], turmeric, madder, catechu, Indian rhubarb and henna [88], *Allium cepa* [89], various leaves [90] and *Maba angustifolia* [91], were studied for dyeing fabrics made with a range of fibres. A rapid and improved approach to indigoid and anthraquinoid dyes was developed using microwave irradiation [92]. The colourfastness to washing of reactive dyed ramie fabric can be improved by after-treatment with chitosan biguanide hydrochloride in combination with silicon sol and a fixing agent [93]. Supercritical fluid, especially supercritical CO₂-based dyeing, was widely explored to replace aqueous-based effluent-producing dyeing methods [94,95]. Sericin treatment of polyester fabric was studied for the surface modification of polyester fabric to enhance its dyeability [96]. Studies also covered applying keratin hydrolysate to enhance reactive dye exhaustion into cotton fabric [97]. Enzymatic treatment was studied as a method to modify the surface of polyester fabric and enhance its dyeability [98]. Enzymatic bioscouring considerably

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Bioprocessing enhanced treated cotton fabric's handle properties [99]. The application of biodegradable plant leaf enzymes can replace detergents used in textile processing [100]. Enzymatic modification of polyamide fabrics with pepsin and trypsin enzymes failed to enhance the dyeability of the treated fabrics with natural dyes [101]. Scouring cotton fabric with pectin hydrolase combined with the Fenton system ($\text{Fe}^{2+}/\text{H}_2\text{O}_2$) considerably increased the wettability and wicking properties of the fabric [102]. The enzymatic scouring of cotton fabric with cellulase and pectinase enzymes increased the hydrophilicity of the treated fabric [103]. Biofuel cells with enzyme-modified conductive textiles were prepared by modifying carbon nanotube-decorated stretchable textiles with fructose dehydrogenase and bilirubin oxidase [104]. As well as being used to modify [105,106]. Papain and hydrolase [107] in combination with cyclamate, were studied for shrink-proofing wool fibres. A novel and effective method based on Esperase and papain enzymes was developed to make wool fibres anti-felting and anti-pilling, and to enhance their dyeing properties. Lysozyme from chicken egg white immobilised onto wool fibres, using tris(hydroxymethyl)-phosphine as a cross-linker for the immobilization of lysozyme, made the antibacterial [108]. Wool fabric was modified with chitosan through disulfide bond breaking and reforming [109] enhancing its antibacterial activity. The laccase-mediated dye-free colouration of wool fabric based on laccase-mediated radical-coupling of amino acids onto wool fibre produced [110], which could be a sustainable alternative to traditional dyeing with acid and reactive dyes.

This field of practice may include enzymatic modification of flax fabric, biopolishing of viscose rayon fabric, oxidoreductases for modification of linen fibres, biobleaching of cotton fabric with glucose oxidase and enzymatic modification of cellulosic fibres. Research found that treatment with cellulase and pectinase softened linen fabric, making the alternative softening treatment with silicone softener redundant [111]. Cellulase was also found to effectively decrease the pilling tendency of viscose fabric by breaking down

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specific glycosidic bonds in cellulose macromolecules [112]. Glucose oxidase, laccase and their combinations were found effective for the bleaching of cotton and linen fabrics [113,114]. Radhakrishnaiah et al. found that the enzymatic treatment altered the properties of a ring-spun, random-blended polyester-cotton yarn more than it altered the properties of a corresponding sheath-core yarn [115].

Textile-waste recycling	Very few articles were published on post-consumer textile-waste recycling before 2012, but research in this area gained momentum from this time. Shukla et al. reviewed the chemical recycling of polyester waste into hydrophobic textile dyestuffs [116] and recycling of waste PET into useful textile auxiliaries [117].
Sustainable regenerated fibres	Various sustainable cellosolves have been developed but the cellulosic fibres regenerated from them behave differently. Diao et al. reported on the stretch-induced crystallisation behaviour and the formation of cellulose II hydrate in the case of cellulose fibres regenerated from ionic liquid (IL) [118]. In the case of cellulosic fibre regenerated from ILs, the coagulation bath composition had a significant impact on the structure and characteristics of regenerated cellulose fibres [119]. Quercetin fibre regenerated from [Emim] Ac IL underwent a structural transformation and obtained an increased water solubility, while quercetin regenerated from [Emim]DEP IL remained unchanged [120]. Silk fibre regenerated from N-methylmorpholine-N-oxide (NMMO) exhibited poor tensile properties and a brittle behaviour, but the mechanical properties improved after post-spinning drawing [121]. In the regenerated silk fibre treated in methanol, the structure changed from random-coil or silk I conformation to silk II conformation and the breaking intensity also improved [122]. The dissolution of silk fibroin in 1-butyl-3-methylimidazolium chloride IL increased with an increase in temperature [123]. Tussah silk/cellulose-blend fibre regenerated from ILs exhibited a break strength of 1.4124cN/dtex and an elongation at break of 9.8% [124]. The silk fibroin fibres regenerated from NMMO exhibited better tensile

112 Bahtiyari, M.I., Duran, K., Körlü, A.E., Perincek, S., 2010. Usage of commercial cellulases in biopolishing of viscose fabrics. *Tekstil ve Konfeksiyon*, 20, 57-64.

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124 Zengge, G., Bowen, C., Jun, S., Lei, G., Fei, L., Yi, L., Study on spinning and structure properties of regenerated tussah silk/cellulose blend fibres using ionic liquids. *Advanced Materials Research*, 236-238, 1,156-1,159.

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properties comparable to other regenerated fibres, and strain at breaking comparable to natural *Bombyx mori* silk fibre [125]. The swelling and dissolution mechanisms of dry, never-dried and re-wetted lyocell fibres studied in NMMO/water with various water contents showed radial dissolution starting from the outer layers [126]. Jiang et al. prepared 50/50 bagasse cellulose and wood cellulose blend regenerated fibre using 1-butyl-3-methylimidazolium chloride IL as a solvent, and the crystallinity of the fibre increased with an increase in drawing speed [127]. The regenerated fibre produced from bagasse using NMMO/water exhibited a tensile strength (530 MPa) and Young's modulus (33 GPa) comparable to commercial lyocell fibre [128]. The bacterial cellulose fibre regenerated from NMMO/water exhibited a cellulose II crystalline structure, lower degree of crystallinity, smaller crystallite sizes and better thermal stability than virgin bacterial cellulose [129]. Silk fibroin fibre regenerated into an ammonium sulphate coagulation bath exhibited improved mechanical properties and degree of crystallinity when the draw ratio was increased from 4 to 6 [130]. The hair keratin/cellulose composite fibre regenerated from 1-ethyl-3-methylimidazolium diethyl phosphate IL had a tensile strength of 277 MPa and an elongation at break of up to 27% [131]. The cellulose fibres regenerated from wood pulp dissolved in 1-ethyl-3-methylimidazolium diethyl phosphate IL showed high strength comparable to viscose rayon [132]. The regenerated zein and zein/soy protein fibre showed poor strength, which only slightly improved after crosslinking treatment with glutaraldehyde [133]. The electroconductive multiwalled carbon nanotubes/reduced graphene oxide/cellulose composite fibre regenerated from 1-ethyl-3-methylimidazolium diethyl phosphate showed an electrical conductivity of 1,195 S/m, specific capacitance of 597 mF/cm², and specific surface area of 91 m²/g [134].

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Dr John G Parkinson has offered recycling services to the industry for over 35 years, starting linouio in 2019, with Camira Group recently becoming linouio's parent company

Credit: Alys Tomlinson

2.2 Circular/sustainable textile innovation in the UK post-2011

Research conducted in the UK

Circular and sustainable innovation in textiles and fashion is mainly carried out around circular economy and circular design, bioprocessing, sustainable dyeing and finishing, sustainable production of regenerated cellulose, textile-waste recycling and life-cycle analysis. Aside from circular economy and circular design, other research into sustainable textile innovation is mainly conducted by textile technology researchers. While only a handful of UK universities are working in these areas, more are involved in circular-fashion and circular-economy research. Increasingly, interdisciplinary researchers from design, STEM, business, economics, law, humanities and marketing are collaborating to address significant industry challenges and opportunities.

Rainton et al. showed how collaborative R&D funding supports industry-academic partnerships to drive innovation, sustainability and circularity in the industry, while highlighting barriers for SMEs and recommending ways to make future funding more accessible and impactful [1]. Connor-Crabb et al. identified that, while some progress is being made, the industry requires systemic change, stronger regulation, better infrastructure and coordinated collaboration across the supply chain to make meaningful progress [2]. Hemingray et al. highlighted the impact of COVID-19 and Brexit on the industry, including ongoing issues faced by SMEs and micro-businesses in particular, as well as the industry's resilience and adaptability when faced with these challenges [3].

Circular design/circular economy	Within this field, the issue of using recyclable or biodegradable fibres in materials selection for production gained great momentum, reflecting contemporary UK circular-manufacturing practices [4]. This was predominantly studied by the arts and design departments of some UK universities. Areas of study included denim circularity using 100%-recycled post-consumer content and sustainable dyeing methods [5], a design-led framework for fast and slow circular-fashion life cycles that produced guidelines for designers to better design circular-fashion products [6], and the current state and future possibilities for circular polyester-based fashion textiles [7].
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In addition to good circular design, the fashion supply chain needs to be optimised to

1 Rainton, S., Harris, J., Russell, S. J., 2025. Innovation Funding for UK Fashion and Textiles: An Overview of R&D Mechanisms to Support Collaborative, Industry-Led Academic Research. University of the Arts London and University of Leeds.

2 Connor-Crabb, A., Bonetti, F., Bulman, S., Bunyan, C., Guo, Y., Hulme, A., Rainton, S., Solomon, L., Toms, S., Vecchi, A., 2025. Sustainable and Circular Practices in the UK Fashion and Textile Industry. University of The Arts London and University of Leeds.

3 Hemingray, C.S., Vecchi, A., Bonetti, F., Toms, S., Bulman, S.E.L., Connor-Crabb, A., Guo, Y., Silva, E.S., Solomon, L., 2023. Impact of Brexit and COVID-19 on the UK Fashion, Textiles and Technology Ecosystem. University of the Arts London and University of Leeds.

4 Junestrand, L., Singh, S., Hounslea, T., 2025. Circular Manufacturing Report: Circular Fashion Innovation Network. UKFT, Positive Fashion and Circular Concept Lab.

5 Black, S., 2023. MUD Jeans: Denim with circularity. *Accelerating Sustainability in Fashion, Clothing and Textiles*, 173-179.

6 Goldsworthy, K., 2017. The Speedcycle: a design-led framework for fast and slow circular fashion lifecycles. *Design Journal*, 20, S1960-S1970.

7 Hornbuckle, R., Goldsworthy, K., Knight, L., 2023. A systemic material innovation study of the current state and future possibilities for circular polyester. *Sustainability (Switzerland)*, 15, 9,843.

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improve sustainability across the whole fashion-product value chain [8,9,10,11] by adopting closed-loop bio [12,13,14] and by strengthening domestic manufacturing to reduce transport impacts and improve supply-chain resilience [15].

UK fashion and textile design explored how open design could contribute to the circular economy and make the industry more sustainable [16]. In the 2010s, there was growing concern among consumers about the social and environmental impact of their purchases, and fashion businesses began to understand the benefits and untapped economic potential of using waste textiles efficiently [17]. Saha et al. opined that institutional factors, consumer behaviours, sustainability-orientated innovation and transition challenges were critical for circular economy, and suggested that future areas of research for the clothing industry should be the disruptive and rebound effect of the circular economy, institutional isomorphism and innovation capability [18].

Simane et al. studied circular-economy knowledge, attitudes and practices among senior managers in the Ethiopian textile industry, and, interestingly, found that their participation in environmental-management training and their managerial status negatively affected their willingness to adopt circular practices [19]. Studies also examined the role of nanotechnology in sustainable textiles [20], and many fashion textiles entering the consumer market were treated with toxic nanoparticles, such as copper and silver, which are not durable during laundering and ultimately end up in laundry effluent. Moreover, evidence that textiles release microplastics during laundering also encouraged fashion designers to use more natural materials over synthetic textiles.

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- 8 Fares, N., Lloret, J., Kumar, V., de Leeuw, S., Barnes, L., 2024. Optimisation of multi-tier supply chain distribution networks with corporate social responsibility concerns in fast-fashion retail. *Corporate Social Responsibility and Environmental Management*, 31, 311-330.
 - 9 Barnes, L., Lea-Greenwood, G., 2010. Fast fashion in the retail store environment. *International Journal of Retail and Distribution Management*, 38, 760-772.
 - 10 Burkitt, A., Dakin, L., 2025. Responsible UK Fashion and Textile Supply Chains: Building a Sustainable Future. UKFT and Positive Fashion.
 - 11 James, A.M., Reitsma, L., Aftab, M., 2019. Bridging the double-gap in circularity. Addressing the intention-behaviour disparity in fashion. *Design Journal*, 22, 901-914.
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 - 13 Millward-Hopkins, J., Purnell, P., Baurley, S., 2023. A material flow analysis of the UK clothing economy. *Journal of Cleaner Production*, 407, 137158.
 - 14 Igoe, E., Noble, S., Torres, L., Cunningham, J., 2021. Commoning situated knowledge: Co-teaching-and-learning the 'design-led upcycling' of waste clothing. *Lecture Notes in Production Engineering*, Part F1159, 79-85.
 - 15 UKFT, Positive Fashion, British Fashion Council, 2025. Reshoring for Real: The future of UK domestic manufacturing.
 - 16 Smith, P., Baille, J., McHattie, L.-S., 2017. Sustainable Design Futures: An open design vision for the circular economy in fashion and textiles. *Design Journal*, 20 (sup1), S1938-S1947.
 - 17 Moorhouse, D., Moorhouse, D., 2017. Sustainable design: Circular economy in fashion and textiles. *Design Journal*, 20 (sup1), S1948-S1959.
 - 18 Saha, K., Dey, P.K., Kumar, V., 2024. A comprehensive review of circular economy research in the textile and clothing industry. *Journal of Cleaner Production*, 444, 141252.
 - 19 Simane, B., Malcolm, R., O'Meara, N., Oremo, F., Geleta, Y., Ahmedin, A., 2024. Knowledge, attitudes, and practices on circular economy among senior managers of Ethiopian textiles and agro-food processing companies. *Circular Economy and Sustainability*, 4, 3,093-3,117.
 - 20 Black, S., 2009. The role of nanotechnology in sustainable textiles. *Sustainable Textiles: Life Cycle and Environmental Impact*, 302-328.

Life-cycle analysis (LCA)	LCA is a tool for assessing the sustainability of textile products and measures the environmental impacts of products and processes, e.g. water and energy usage, and CO ₂ production. LCA is particularly complex and limited LCA studies relating to fashion and textiles have been carried out in the UK. Relevant research in this area may include the LCA of wool face masks [21], recycled wool-blend sweaters [22] and wool-producing sheep-production systems [23].
Bioprocessing	Replacing toxic chemicals used in textile chemical processing with enzymes was envisaged as environmentally friendly and safe. Although nature-derived, some of the enzymes developed for the textile industry could be toxic and their effluent needed proper treatment before discharging into the environment. Most of the enzymes are readily biodegradable and therefore the effluent produced by textile processing becomes harmless. Studies included enzymatic colouration of wool fabrics [24], which enabled colouration of textiles at almost room temperature (30°C), producing a diverse colour palette and achieving good to excellent colourfastness to washing, rubbing and light. It was found that cotton fabric treated with a biofilm protein from <i>Bacillus subtilis</i> as a fire retardant passed the BS standard test [25]. Enzymes were studied for scouring and bleaching treatment of jute fibres, which have considerably higher lignin content compared to other natural fibres. Hassan and Saifullah found that enzymatic scouring and bleaching combined treatment, with a 50/50 mixture of Alcalase and cellulase, provided the best performance in terms of improvement in whiteness index, hydrophilicity, wettability, dyeability and enzymatic scouring of textile fibres [26]. BslA, a <i>Bacillus subtilis</i> biofilm protein, was produced recombinantly with and without a cellulose-binding module, and the cell-free extract was used to treat bacterial cellulose either ex-situ, through drip coating, or in-situ [27]. The produced bacterial cellulose exhibited increased hydrophobicity and water contact angle.
Sustainable dyeing and finishing	Textile chemical processing has a high environmental impact as its toxic dyes and chemicals produce effluent that needs tertiary treatments before discharging to watercourses. Areas of study include natural dyes such as sulphonated lignin [28,29] and

21 Angelis-Dimakos, A., Whitehouse, A., Vyrkou, A., Hebden, A., Rana, S., Goswami, P., 2022. Life cycle environmental impact and economic assessment of British Wool face masks. *Cleaner Environmental Systems*, 6, 100084.

22 Wiedemann, S.G., Biggs, L., Clarke, S.J., Russell, S.J., 2022. Reducing the Environmental Impacts of Garments through Industrially Scalable Closed-Loop Recycling: Life Cycle Assessment of a Recycled Wool Blend Sweater. *Sustainability* (Switzerland), 14, 1,081.

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28 Hassan, M.M., 2024. Valorisation of sulphonated lignin as a dye for the sustainable colouration of wool fabric using sustainable mordanting agents: enhanced colour yield, colourfastness, and functional properties. *RSC Sustainability*, 2, 676-685.

29 Hassan, M.M., 2023. Valorisation of sulfonated kraft lignin as a natural dye for the sustainable dyeing of wool fabrics: Effect of peroxide oxidation. *ACS Sustainable Chemistry and Engineering*, 11, 13,787-13,797.

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extracts of blackcurrant fruits or anthocyanin [30,31,32], aerial parts of Argy wormwood [33], sumac gall nut [34] and herbs [35]. Natural dyes were also studied for screen printing [36] and inkjet printing [37,38].

Studies examined reducing energy and water usage to make textile dyeing with synthetic dyes more sustainable. Techniques included low-liquor ratio dyeing [39,40] and low-temperature oxidation polymerisation-based dyeing [41,42], along with lowering the load of pollutants in generated effluent. Effluent treatment is costly, so studies also covered effluent-free dyeing processes, such as waterless dyeing in silicone solvent [43,44], palm oil [45] and liquid ammonia [46]. Sustainable dyed textiles showed slightly lower colourfastness to washing, as the diffusion of dyes into fibres was less efficient compared to traditional aqueous-based dyeing. Other studies included zero-effluent antibacterial treatments [47],

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- 31 Houghton, J.A., Tidder, A., Stenton, M., Blackburn, R.S., 2024. Coloration in flow: The potential of in situ coloration of casein fibres to mitigate environmental impact of traditional dyeing methods. *ACS Sustainable Chemistry and Engineering*, 12, 2,130-2,134.
- 32 Farooque, S., Rose, P.M., Benohoud, M., Blackburn, R.S., Rayner, C.M., 2018. Enhancing the potential exploitation of food waste: Extraction, purification, and characterization of renewable specialty chemicals from blackcurrants (*Ribes nigrum* L.). *Journal of Agricultural and Food Chemistry*, 66, 12,265-12,273.
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- 35 Thakker, A.M., Sun, D., 2022. Sustainable application of novel herbs on cotton fabrics as biomordants and colourants. *Environmental Science and Pollution Research*, 29, 47,598-47,616.
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- 38 Thakker, A.M., Sun, D., 2022. Engineering sustainable inks from natural biomaterials for digital printing. *Sustainability and Climate Change*, 15, 272-278.
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- 43 Hossain, M.Y., Liang, Y., Pervez, M.N., Ye, X., Dong, X., Hassan, M.M., Cai, Y., 2021. Effluent-free deep dyeing of cotton fabric with cacao husk extracts using the Taguchi optimization method. *Cellulose*, 28, 517-532.
- 44 Cai, Y., Huang, X., Ehsan, M.N., Riza, M., Jiang, T., Pervez, M.N., Han, S., Hassan, M.M., Naddeo, V., 2024. Broadening color shade of dyed wool fibre with binary and ternary natural plant dye combinations. *Journal of Natural Fibres*, 21, 2340065.
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- 46 Gao, B., Huang, X., Jiang, T., Pervez, M.N., Zhu, W., Hassan, M.M., Cai, Y., Naddeo, V., 2022. Sustainable dyeing of ramie fibre with ternary reactive dye mixtures in liquid ammonia. *RSC Advances*, 12 (30), 19,253-19,264.
- 47 Hassan, M.M., 2023. Wash-durability, surface, and antibacterial properties of wool fabric treated with nature-derived thymol and totarol under subcritical CO₂, aqueous, and ethanol media. *Process Safety and Environmental Protection*, 177, 355-365.

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sustainable fire-retardant treatments [48,49,50] and insect-resist treatment [51] in sub-critical CO₂ and improving the wash-off process of reactive dyed cotton using sustainable chemistry [52]. The insect-resist and antibacterial treatment carried out in sub-critical CO₂ exhibited better wash durability compared to the aqueous treatments. Junestrand et al. surveyed global innovations in textile and apparel dyeing technologies and practices — including cleaner production methods, dye recycling and circularity — to inspire industry collaboration that can reduce environmental impacts across supply chains [53].

Sustainable production of regenerated cellulose fibre	Regenerated cellulose fibres are made from various cellulose feedstocks, such as wood pulp and bamboo pulp. The traditional method uses carbon disulphide for the xanthation process to ease the dissolution of cellulose in an alkaline solution, but carbon disulphide is a possible carcinogen and highly toxic. Eco-friendly solvents such as n-methyl morpholine N-oxide [54,55] and ionic liquids [56,57] were studied as solvents for dissolving and regenerating cellulose.
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Research conducted in the EU

Circular economy/circular design	Sustainable products and circular economy are gaining momentum in scientific, economic and policy fields. Research is mainly undertaken by multidisciplinary researchers spanning areas such as fashion design, fashion business, marketing and law. Dagilienė et al. prepared a circular product design framework and self-assessment tool [58]. The use of 3D-printed TPU elements was studied to join clothing parts made from low-elasticity chiffon fabrics and improve their wearing comfort [59]. In 2023, a survey study involving 56 German textile manufacturing companies examined the extent of circularity already embedded in the countries industry [60]. It found that many companies were not prepared
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48 Kandola, B.K., Pornwannachai, W., Ebdon, J.R., 2024. Flame retardance of a bio-based furan resin: Effects of added flame retardants. *Polymer Degradation and Stability*, 220, 110637.

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52 Amin, M.N., Blackburn, R.S., 2015. Sustainable chemistry method to improve the wash-off process of reactive dyes on cotton. *ACS Sustainable Chemistry and Engineering*, 3, 725-732.

53 Junestrand, L., Singh, S., Hounslea, T., 2025. Innovations in Textile and Apparel Dyeing: Technology and Colour. UKFT.

54 Haule, L.V., Carr, C.M., Rigout, M., 2016. Investigation into the supramolecular properties of fibres regenerated from cotton based waste garments. *Carbohydrate Polymers*, 144, 131-139.

55 Haule, L.V., Carr, C.M., Rigout, M., 2016. Preparation and physical properties of regenerated cellulose fibres from cotton waste garments. *Journal of Cleaner Production*, 112, 4,445-4,451.

56 Kuzmina, O., Bhardwaj, J., Vincent, S.R., Wanasekara, N.D., Kalossaka, L.M., Griffith, J., Potthast, A., Rahatekar, S., Eichhorn, S.J., Welton, T., 2017. Superbase ionic liquids for effective cellulose processing from dissolution to carbonisation. *Green Chemistry*, 19, 5,949-5,957.

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58 Dagilienė, L., Čeičytė-Pranskūnė, J., Telešienė, A., Valušytė, R., Varžinskas, V., 2024. Developing a circular design framework: Co-creation and validation of a circular product and service design tool. *Journal of Industrial Ecology*, 28, 783-799.

59 Lekeckas, K., Stirbe, J., Ancutiene, K., Valusyte, R., 2023. Testing of 3D printing on textile fabrics for garments application within circular design. *International Journal of Clothing Science and Technology*, 35, 627-647.

60 Arnold, M.G., Pfaff, C., Pfaff, T., 2023. Circular business model strategies progressing sustainability in the German textile manufacturing industry. *Sustainability (Switzerland)*, 15, 4595.

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for a circular transformation and that the EU Strategy for Sustainable and Circular Textiles was insufficiently known. Niinimäki et al. proposed a set of design and manufacturing strategies for the textile and clothing industry to reduce the environmental impact of textile and clothing production and consumption [61].

Beyond environmental and economic concerns, social sustainability is increasingly recognised as integral to corporate sustainability, especially in textile value chains facing uncertainty and vulnerability [62]. A 2013 report outlined integrating key social-sustainability concepts and topics into existing textile, clothing and fashion business model innovations [63]. A 2023 article reported effective ongoing strategies (mini-loops) leading to incremental changes towards a circular economy in sustainable fashion design [64]. Coppola et al. developed a framework of dynamic capabilities needed for circular transition in the Italian clothing industry using the theoretical lenses of natural-resource-based views [65]. Another 2023 article outlined the industry's approach to the core sustainability concept and circular economy in the German fashion and textile industry [66]. Several articles reported the danger of fast fashion in solid waste formation and its effect on the environment, as fast-fashion items are discarded more frequently than high-value items [67,68]. A 2018 article discussed new value creation through social manufacturing, specifically facilitated by do-it-yourself, do-it-together and participatory design strategies [69]. A 2023 article explored the Dutch circular textile mission's transition processes, comparing how technical and non-technological solutions, produced by engaged actor constellations, developed and interacted, to assess key factors driving or blocking its overall fulfilment [70]. Another article outlined a linear economy strategy for resource utilisation — a surprisingly wasteful model of value creation, leading to a decline in prosperity and concomitant global influence [71]. A 2017 article outlined institutional analyses and sustainability by identifying and comparing 2 pathways towards the circular economy, and explaining how their organisational arrangements differed [72]. A 2023 article proposed a circular supply chain adaptation approach to understand responses to circular economy adoption barriers in the textile and

61 Niinimäki, K., Hassi, L., 2011. Emerging design strategies in sustainable production and consumption of textiles and clothing. *Journal of Cleaner Production*, 19, 1,876-1,883.

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65 Coppola, C., Vollero, A., Siano, A., 2023. Developing dynamic capabilities for the circular economy in the textile and clothing industry in Italy: A natural-resource-based view. *Business Strategy and the Environment*, 32, 4,798-4,820.

66 Wiegand, T., Wynn, M., 2023. Sustainability, the circular economy and digitalisation in the German textile and clothing industry. *Sustainability (Switzerland)*, 15, 9111.

67 De Oliveira, L.G., Miranda, F.G., de Paula Dias, M.A., 2022. Sustainable practices in slow and fast fashion stores: What does the customer perceive? *Cleaner Engineering and Technology*, 6, 100413.

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72 Fischer, A., Pascucci, S., 2017. Institutional incentives in circular economy transition: The case of material use in the Dutch textile industry. *Journal of Cleaner Production*, 155, 17-32.

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fashion industries [73]. Bressanelli et al. published a case study on the Italian Prato district's centuries-old woollen industry based on recycled wool [74].

A key challenge to adopting a circular economy is that it uses the linear economy model (take-make-waste), and Koszewska opined that the transition requires significant changes to production and consumption models [75]. Niinimäki et al. highlighted the environmental price of fast fashion [76]. Indrie et al. proposed an algorithm that reuses upholstery-production textile waste to create interior decoration parts [77]. A method was developed to measure the drape characteristics of used textiles to reuse them in manufacturing curtains, tablecloths, napkins and fashion accessories [78]. Elnashar et al. collected, preserved and protected knowledge of old patterns and weaving techniques used in selected regions of Romania [79]. Tripa et al. identified the main sources of textile waste in Romania and proposed manufacturing customised cloth textile waste to rethink, reuse or recycle waste in the production stage [80]. Pera and Ferrulli showed how consumers' engagement in the post-consumer textile-disposal practices of reuse, repair, donate and resell can implement a circular economy [81]. Wjunow et al. reported on the suitability of cactus leather to develop sustainable textiles [82]. Furferi et al. prepared a circular economy guideline for textile industries transitioning from traditional production processes to a systemic approach considering the circular economy [83].

After post-consumer textile waste has been collected, the main challenge is sorting and separating it based on fibre types. Bonifazi et al. developed a short-wave infrared (1,000–2,500 nm) spectroscopic technique to extract information regarding textile products' fabric composition [84,85]. Reznichenko and Harlin showed using bioderived feedstocks or electro-cracking in existing fossil-based "grey" olefin manufacturing processes can considerably improve the sustainability of polyolefin fibre production [86]. Hinkka et al. built a cost model based on empirical and secondary data to estimate and compare the costs of different

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74 Bressanelli, G., Nesi, C., Saccani, N., Visintin, F., 2022. Circular economy in the textile industry: Evidence from the Prato district. *Sustainable Production, Life Cycle Engineering and Management*, 123-131.

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alternatives for the end-of-life textile supply chain [87]. Consumer attitudes towards circular fashion in Poland and Canada, with the countries' different cultures, levels of economic development and approaches to environmental and social issues, show that Polish consumers perceived the need for environmental labels to a greater extent, while Canadians were more willing to choose sustainable clothing and reduce consumption [88]. The choice of purchasing clothing is affected by many factors. A Polish study on fashion consumption and age/gender effects on clothing choice shows that consumers would not purchase a sustainable or green product if it did not provide enough aesthetic, functional and financial benefits to satisfy their needs and aspirations [89].

To implement a circular economy, communication is necessary between designers, sorters and recyclers [90]. By using a system dynamics computer simulation model, Franco showed the relationship between design considerations at the beginning of a product's life and their implications for the product's take-back stage when a new manufacturing cycle begins [91]. By using case studies of cradle-to-cradle certified textile manufacturing companies in Europe, Franco provided a dynamic understanding of how certain collaborative supplier-buyer innovation factors, coupled with complex aspects in product design, combine to determine the output speed and quantity of circular products to be sold, taken back and, ultimately, regenerated [92]. Hrouga and Michel developed a new supply-chain manager dashboard to identify circular economy barriers and constraints in implementing the circular economy concept, such as a lack of sustainability performance, regulation and mandatory responsibilities of supply-chain actors [93]. Designing circular economy policies and planning approaches in urban areas is an emerging research field. Working with 2 Danish municipalities, Christensen analysed how urban municipalities can support and facilitate the circular economy through multiple modes of governance including the use of their assets, ownership of utilities and waste companies, legislation and/or economic regulation, and through facilitating, coordinating and collaborating [94].

Many synthetic polymer-made single-use devices and materials are used in healthcare+ facilities, especially surgical departments, for their convenience and sterility. Their design does not consider end-of-life, making sorting and recycling options impossible [95].

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Sustainable dyeing and finishing

Textile chemical processing has a high environmental impact as its toxic dyes and chemicals produce effluent that needs tertiary treatments before discharging to watercourses. Research focused on natural dyes [96,97,98,99], biofunctionalisation [100,101,102], biopolymer-modified silica and metallic oxide sols coatings [103,104,105,106], antimicrobial finishing with chitosan [107], glycerol-assisted dyeing [108], dyeing under supercritical CO₂ [109], functionalisation of textiles with curcumin [110] and salt-free dyeing of cotton with reactive dyes [111]. Natural dyes are expensive and produce dull colours with poor light and wash fastness. The functionalisation of cotton textiles with L-Cysteine considerably enhanced their antimicrobial properties [112]. Cotton fabrics dyed with different tea extracts exhibited high UV protection [97]. Zhou et al. reported on the fabrication of antibacterial and antioxidant polyamide, silk and wool fabrics by inkjet printing with tannin and curcumin, which produced yellow shades along with high antibacterial and antioxidant activities. The functionalisation of cellulosic fabrics treated with microencapsulated salvia and thyme oils provided antibacterial properties along with an increase in tensile strength [98]. The hydrophilic properties of the fabrics were significantly decreased when cotton fabrics were coated with chitosan-incorporated silica sol. Grafting of wool with alginate biopolymer and Ag nanoparticles increased the treated fabric's antimicrobial and antioxidant properties

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[¹⁰¹]. The radical UV-curing of chitosan on cotton and silk conferred antimicrobial properties [¹⁰²]. Ferrero et al. studied ethanol and glycerol as additives in traditional aqueous dyeing, which replaced levelling and retarding agents [¹⁰³]. Abate et al. studied simultaneous dyeing and antimicrobial finishing with disperse dyes and chitosan derivatives, respectively, under supercritical CO₂, which produced excellent colour yield with good colourfastness to washing [¹⁰⁵].

Sustainable production of regenerated fibre

Natural cotton fibre and traditional regenerated cellulose fibre production have high environmental impacts, so studies include alternative solvents for dissolving cellulose to make spinning dope for the production of regenerated cellulose from wood pulp. Studied processes include cellulose carbamate [^{113,114}], N-methylmorpholine N-oxide/water [¹¹⁵], ionic liquid [^{116,117,118,119,120,121,122}] and dimethyl sulfoxide/diethylenetriamine/1,5-diazabicyclo [4.3.0]non-5-ene ternary solvent [¹²³]. However, ion liquid-mediated regenerated fibres showed poor tensile strength, especially in wet conditions. Adding chitosan to cellulose spinning dope produced regenerated fibres with good antimicrobial properties [¹²⁴]. Mixed cellulose and chitosan regenerated fibres were used as a feedstock to generate carbon fibres, which increased their carbon yield and structural properties [¹²⁵].

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- 115 Protz, R., Lehmann, A., Ganster, J., Fink, H.-P., 2021. Solubility and spinnability of cellulose-lignin blends in aqueous NMMO. *Carbohydrate Polymers*, 251, 117027.
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Bioprocessing	This area of research mainly emphasised enzymatic shrink-proofing of wool fibres [126], antimicrobial coating of fibres by binding catechol by laccase [127], enzymatic modification of the surface of polyamide fibres [128], hydrophobic modification of jute fibres [129], bioscouring of hemp fibres [130], enzymatic modification of polyester [131], modification of flax fibre [132] and modification of flax/PLA non-woven fabric [133]. However, enzymatic shrink-proofing of wool was found unfeasible industrially, as it was very un-uniform. Cotton and polyester fabrics coated with catechol and p-phenylenediamine by in-situ polymerisation by laccase enzyme made them antibacterial [134]. The hydrophobicity of polyamide hinders the comfort and processing of fabrics. The laccase-catalysed TEMPO oxidation grafted trehalose onto polyamide, considerably enhancing the hydrophilicity of polyamide fabrics [124]. Similarly, enzymatic modification of polyester fabrics enhanced their surface hydrophilicity, allowing inkjet printing with disperse dyes [127]. On the other hand, horseradish peroxidase (HRP)/H₂O₂-catalysed binding of dodecyl gallate onto jute fibres considerably increased their hydrophobicity, allowing compatibilisation with polypropylene in composites manufacturing. Enzymatic modification of flax fibres caused a decrease in fibre roughness and pronounced fibrillation, while the tensile and flexural strength increased by 5%–45% and 10%–35%, respectively [129]. Enzymatic modification of PLA/ flax nonwoven fabrics with cellobiohydrolases and endoglucanases increased adhesion between PLA and flax fibres.
Textile-waste recycling	This decade emphasised recycling and reusing/repurposing post-consumer textile waste. Both mechanical and chemical recycling were explored. Recycling mono-fibre textiles is relatively easy compared to textiles made with blended fibres. Chemical and mechanical recycling methods are both used to recycle post-consumer textiles based on fibre types used in manufacturing. Schlapp-Hackl et al. developed a technique for chemically recycling used cotton towels, dissolving them in an ionic liquid and dry spinning to produce regenerated cellulosic fibres [135]. However, due to the cellulose dissolution, the colour of the cellulosic fibres turned to magenta from blue because of the leaching of 1 dye component or more into the spin bath. Similarly, cashmere-fibre-based used textiles were chemically recycled by dissolving keratin textiles in an ionic liquid and dry spinning [136],

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and waste-cotton textiles [137] and hemp-fibre-based textile waste [138] were recycled to produce regenerated cellulosic fibres. When chemically recycling post-consumer cotton/polyester-blend textiles, the polyester fraction was recovered through a dissolution of cellulose fraction in an ionic liquid to produce regenerated cellulose and polyester fibre by melt spinning [139]. Bågenholm-Ruuth et al. chemically recycled used cotton waste to regenerate cellulose through dissolution in a hydrated zinc chloride [140] and acid hydrolysis [141]. Costa et al. prepared long chain ester from waste textiles, which was used as a superhydrophobic coating [142]. They also chemically recycled waste cotton textiles through degrading cellulose by acid hydrolysis and converting it into carboxymethyl cellulose and cellulose acetate [143]. Haslinger et al. studied the ionic-liquid-based chemical recycling of vat and reactive dyed cotton fibres to coloured regenerated fibres [144] but found that a reactive dyed (Remazol Black B) cotton textile did not dissolve well in the ionic liquid. All ionic-liquid-based chemical recycling recycled the dyed textiles rather than decolourising the dyes, so may not achieve the desired specific colour. Jamshaid et al. studied recycling yarn and rag paper waste to produce yarns, and found that yarn waste had better fibre length, uniformity, and floating fibre compared to rag waste [145].

Several published literatures reported on recycling post-consumer polyester textile waste and converting it into terephthalic acid and ethylene glycol by using various catalysts [146,147,148]. Reports show that 50% of the collected clothing could be reused after simple mending, and that fibres recovered from waste textiles could be reused in fibre-reinforced composites manufacturing [149,150]. For example, recycled polyester could be reused in manufacturing reinforced concrete by mixing concrete with molten polyester waste [151].

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Recycling textiles made from blended fibres is problematic. Various techniques have been studied, such as chemo-enzymatic separation and recycling polyester/cotton, polyester/elastane, and polyamide/elastane blend waste [152,153,154], as well as the challenges of recycling mixed synthetic textile waste [155]. Bio-upcycling viscose/polyamide and polyester/cotton textile blends [156,157] was also studied. Mamun et al. reported on enzymatic depolymerisation for recycling polyester textiles to recover monomers, to manufacture new polyester fibre [158].

When post-consumer textiles are collected at kerbside, the different fibre types are mixed, and separating them correctly is very challenging. Becker et al. developed a near infra-red-based textile sorter for sorting polyester-containing textile waste [159], and the technology can identify the polyester content in polycotton and polyester blended with elastane, viscose, acrylic or wool. Another area of study was sustainable entrepreneurship in reusing textile waste in Portugal [160]. Broega et al. opined that sustainable creative business models for reusing discarded fabrics need to be adopted by the textile industry to make it more sustainable [161].

LCA of textile products

Roos et al. prepared an inventory framework using nomenclature for textile-related chemicals, which was used to build up a generic chemical product inventory for including textile chemicals in LCAs [162]. The impacts of water and land use are often ignored or treated in an over-simplified manner in LCAs, which may provide insufficient foundation for LCA-based decision-making [163]. Sandin et al. prepared an LCA tool for measuring the environmental impacts of wood-based fibre production considering these aspects [164]. The impact of land use was assessed by considering changes in the vascular plant species richness and the vulnerability of the surrounding ecosystem to measure the impact on

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- 162 Roos, S., Jönsson, C., Posner, S., Arvidsson, R., Svanström, M., 2019. An inventory framework for inclusion of textile chemicals in life cycle assessment. *International Journal of Life Cycle Assessment*, 24, 838-847.
- 163 Roos, S., Zamani, B., Sandin, G., Peters, G.M., Svanström, M., 2016. A life cycle assessment (LCA)-based approach to guiding an industry sector towards sustainability: the case of the Swedish apparel sector. *Journal of Cleaner Production*, 133, 691-700.
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biodiversity. A novel consequential approach was applied in the inventory analysis of water use, to capture the system-scale effects considering how forestry and cotton farming influence the hydrological cycle. Zamani et al. reported on the LCA of textile recycling in Sweden [165]. They found that the material reuse process showed the best performance of the studied systems, with savings of 8 tonnes of carbon dioxide equivalents (CO₂-eq) and 164 gigajoules (GJ) of primary energy per tonne of textile waste. Bianco et al. reported on the LCA of a single woollen undershirt [166], showing that its production produced 11.7 kg CO₂-eq but the energy used in the wool transformation process had a relatively low impact (11%). Álvarez et al. reported on the LCA of decolourising textile effluent by combined electrochemical and ultraviolet radiation, and reusing textile saline effluents [167]. They found that the consumption of Na₂CO₃ and NaCl in the dyeing process is the largest contributor to the environmental impact. The LCA results showed that reusing residual salts and water of the electrochemical-UV decolourised textile effluent has clear environmental advantages [168]. Van der Velden and Vogtländer proposed a social LCA method for benchmarking textile supply chains and found that the hotspots were Indian cotton fields and Bangladesh garment factories [169]. Van der Velden et al. reported on the LCA of e-textiles and opined that it is necessary to select materials based on their environmental impacts [170]. They reported the LCA only using 1 iteration of the eco-design process. They prepared updated inventory data for textiles made of cotton, polyester, nylon, acryl, and elastane based on published literature, life cycle assessment (LCA) databases, the emission registration database of the Dutch government, and personal communication with textiles and production-machinery manufacturing companies [171]. Broeren et al. carried out an LCA of sisal fibre and its environmental impacts depending on location and local practices, including residue disposal, fertiliser use, and transportation distances [172]. Hammar et al. carried out an LCA of textile fibre-to-fibre recycling using cellulose carbamate technology, which showed potential to reduce the environmental impacts of lyocell production [173]. To accurately assess toxic effects, it is essential to study the fate of textile chemicals released in processing effluent as well as from disposed textiles. The LCA calculations dominate CO₂ production and energy usage but their ecotoxicity is mostly ignored [174]. Nørup et al. reported on the material flow analysis and life cycle inventory carried out at a textile sorting centre in Lithuania [175]. They stated that the majority of textiles received and sorted

165 Zamani, B., Svanström, M., Peters, G., Rydberg, T., 2015. A carbon footprint of textile recycling: A case study in Sweden. *Journal of Industrial Ecology*, 19, 676-687.

166 Bianco, I., De Bona, A., Zanetti, M., Panepinto, D., 2023. Environmental Impacts in the textile sector: A life cycle assessment case study of a woollen undershirt. *Sustainability (Switzerland)*, 15, 1166.

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169 Van der Velden, N.M., Vogtländer, J.G., 2017. Monetisation of external socio-economic costs of industrial production: A social-LCA-based case of clothing production. *Journal of Cleaner Production*, 153, 320-330.

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174 Beck, A., Scheringer, M., Hungerbühler, K., 2000. Fate modelling within LCA: The case of textile chemicals. *International Journal of Life Cycle Assessment*, 5, 335-344.

175 Nørup, N., Pihl, K., Damgaard, A., Scheutz, C., 2019. Evaluation of a European textile sorting centre: Material flow analysis and life cycle inventory, *Resources, Conservation and Recycling*, 143, 310-319.

were reusable but decreased from 79.8% to 74.9% between 2015 and 2017; the quantity of recyclable textiles increased over this period, from 12.9% to 17.3%; while the amount of waste increased from 5.4% to 6.4%.

Research conducted in the rest of the world

Sustainable dyeing and finishing The topics studied in this area of research include zero-effluent waterless reverse-micellar dyeing of textiles [176,177,178], dyeing in silicone oil [179,180], liquid paraffin oil [181,182], plant oil [183,184,185], ethanol [186,187], deep eutectic solvents [188] and supercritical CO₂ [189,190,191]. Other topics include dyeing wool fabrics with sorghum extracts [192], non-toxic crosslinking of protein materials [193], enzymatic colouration of wool fabrics with phenols [194], dyeing

- 176 Tang, Y.L.A., Lee, C.H., Wang, Y., Kan, C.-W., 2023. Comparison of water-based dyeing system and alkyl polyglucoside (APG) surfactant-based reverse micellar dyeing system with reactive dyes for cotton. *Cellulose*, 30, 4,011-4,023.
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synthetic textiles with polyphenols [195], green antimicrobials for textiles [196,197], dyeing cotton with folic acid [198], dyeing cellulose with orange-peel extracts [199], dyeing cotton with cationic curcumin [200], nonaqueous dyeing of cotton with reactive dyes [201], dyeing textiles with structural colours [202,203], salt-free dyeing viscose rayon and cotton fabrics with reactive dyes [204,205], dyeing silk and cotton with natural dyes [206,207,208,209,210], fire-retarding cotton fabric with graphene-based intumescent [211], dyeing cotton fabric with waste-derived dyes and mordants [212], sono-chemical processing of textiles [213,214], dyeing cotton with indigo carmine [215], dyeing polyester with disperse dyes using an environmentally

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friendly dye carrier ^[216], dyeing textiles with olive mill wastewater ^[217], indigo reduction by α -hydroxycarbonyls for dyeing cotton fabrics ^[218], antibacterial textiles with natural bioactive agents ^[219,220], shrink-proofing wool with sericin in a combination with UV radiation ^[221], sericin-based bioactive coating of polyester ^[222], enhancing photo-protection of wool and cotton fabric with spent coffee-extract ^[223], sustainable colouration of textiles with natural dyes ^[224,225,226,227], extraction, dyeing, and antibacterial finishing of textiles with natural dyes in supercritical CO₂ ^[228,229], dyeing textiles with nanocellulose and indigo ^[230,231], dyeing cotton in ionic liquids ^[232], salt-free dyeing of cotton fabric with acid dyes ^[233], reusing fashion waste as a flame retardant ^[234] and chemical-free degumming of silk ^[235].

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Life-cycle analysis

As in the UK and Europe, LCA of textile fibres and products was the major concern in this decade. Studied areas included the distribution of microplastics in rivers associated with surrounding textile industries [236], perfluorinated compounds in textile wastewater in Southeast China [237], strategies to reduce environmental impacts of textiles [238], use of LCA and circularity indicators to measure the sustainability of textiles [239], LCA associated with production, use, and end-of-life of wool garments [240], analysis of green certification standards related to recycled textiles based on life cycle thinking [241], LCA of dyeing and dye degradation by advanced oxidation processes [242,243], LCA of wool textiles [244], inclusion of microplastics in the LCA of apparel and home textiles [245], use of LCA to decide the applicability of recycled cotton over virgin cotton yarns [246], LCA of melange yarns [247], LCA of polyester/wool blends [248], LCA of diapers [249,250], analysis of social subcategories throughout LCA approach for the textile industry [251], assessment of the impact of organic cotton use and consumer habits in the sustainability of jean production

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using the LCA approach [252], LCA of alternatives for industrial textile recycling [253,254] and LCA of denim using recycled cotton fibres [255].

Circular design	Also outlined was a smart textile waste management system; to create a sustainable circular economy [256], strategies to mitigate barriers to supply chain sustainability [257] and the use of circular economy indicators for measuring social innovation in the Brazilian textile and fashion industry [258]. The system also outlined how local production in Brazil may strengthen a circular fashion system [259], using blockchain technology to implement traceability [260], investments for a creative and innovative transition to a circular economy [261], incremental change to support cleaner circular production practices [262], implementation of biorefineries for cleaner waste-textile management [263] and use of the circular-economy concept to reduce the environmental impact of COVID-19 face-mask waste [264].
Textile-waste recycling	Gholamzad et al. reported on chemically recycling waste polyester-cotton, where cellulose was degraded enzymatically, then converted into ethanol, and polyester was recovered [265]. The process enabled 98% recovery of the polyester portion of the fabrics. Recycled polystyrene in combination with silica was applied to textiles by dip-coating, which made the fabric superhydrophobic and also showed excellent chemical and acid resistance [266]. In the chemical recycling of nylon 6-based textiles, nylon 6 fibres were converted

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into their monomer, caprolactum, by hydrolysis [267]. A published article reported on the recovery of nylon 6 from its waste and blends with other fibres through dissolution in CaCl₂/ethanol/water without any degradation [268]. Acrylic fibres are always mixed with other textile fibres to enhance their functional properties, which makes it very difficult to recycle them mechanically. Dyes were separated from dyed acrylic textiles by dissolving in dimethyl sulfoxide and butanediol, and the regenerated acrylic fibres showed properties similar to those made from virgin acrylic resin [269]. Mu et al. reported on chemically recycling nylon fibres from nylon-based carpet wastes and separating dyes through dissolution in butanediol [270]. Mu et al. also reported on a clean technology to completely recycle all reactive dyes from dyed cotton and regenerate cellulosic fibre via controlled dye hydrolysis, fibre swelling, and dissolution in NMMO/water [271], and recycling waste wool textiles into protein fibres [272]. Wool fibres from post-consumer waste garments are recovered through mechanical recycling, which creates short fibres with poor properties. A published article reported on chemical recycling and regeneration of protein fibres from waste wool, with 80% of waste wool recycled [273]. Similarly, other reports covered recycling disperse dyes, acid dyes and direct dyes from polyethylene terephthalate, nylon and cotton fibres, respectively, through dissolution in appropriate solvents [274]. Weber et al. reported on recycling and reusing textile waste in Ontario, Canada [275]. Textiles made up 4.4% of the residential waste stream, and 65% of this waste could be reused and 21% recycled. To separate polyester from waste polyester/cotton textiles, cotton was dissolved in 1-allyl-3-methylimidazolium chloride ionic liquid and the polyester fraction was recovered intact [276,277].

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2.3 National/international conferences: mapping circular innovation interests

The research sought a wider perspective through attending conferences and events held in the UK, Europe and the US, which provided insights from emergent and established industry positions. Recurring themes linked challenges across circularity, sustainability and innovation, highlighting global concerns including issues related to policy and legislation; overproduction and overconsumption; textile waste and resource issues; social-welfare concerns for workers; skills development; scaling up investment; and support for start-ups and innovation companies.



Exhibition stalls at Materials Research Exchange 2026
Credit: Fashion, Textiles and Technology Institute

Event	Details
Sustainable Apparel and Textiles Conference, Amsterdam (April 2025)	The focus of this 2-day event was to address how supply chains can be transformed, how to develop net-zero strategies, drive positive social impact, engage consumers, address how circularity can be scaled, incoming legislation and increased stakeholder expectation. Primary themes were responsible sourcing and ethical trade, which included responsible procurement and ethical supply-chain implementation. The theme of <i>nature positive production</i> was concerned with biodiversity and regenerative agriculture. Best practices were discussed in implementing circularity, using low-impact materials and scaling closed-loop design. Communicating sustainability efforts to consumers with transparency was also debated. Topics included: co-creation in climate action; regenerating nature; microfibre pollution; extended producer responsibility; digital product passports; forced labour; living wages; alternative business models; and data stability.

The **OR Foundation** led a poignant panel discussion about the effects of overproduction resulting in textile waste and the impact it has on communities in Ghana.

2.3 National/international conferences

The conference was attended by industries and organisations such as Adidas, Burberry, WRAP, the OR Foundation and start-up Sequinova.

Key takeaways:

- The devastating effects of overproduction and the associated challenges.
- Scaling circular design innovations.
- Challenges of communicating to consumers.

Autex World Conference, Dresden (June 2025)

The Autex conference was organised by the Institute of Textile Machinery and High-Performance Material Technology at TU Dresden. The 3-day event covered a wide range of themes; attendees included academics, researchers, technological centres and companies, with presentations predominantly from academics and research students, all with an in-depth focus on their specialised topic.

Primary themes were concerned with textiles recycling, life-cycle analysis, sustainability and circularity.

Topics included: supply-chain management; robotics and automation in textile and clothing production; design; textile economy; fibre science and engineering; biopolymers; nanofibres and technologies; textile processing; structures; properties and machine development; coating; dyeing technologies and systems; industrial, technical, medical and protective textiles; testing; smart textiles; and artificial intelligence (AI) in textile and clothing science.

Key takeaways:

- Challenges in scaling up pilot recycling circular initiatives due to lack of consistent availability of material and variability in the material content (particularly recovered marine waste).
- Challenges in scaling bioderived circular material innovations for textile/fibre applications such as from freshwater algae and agro-industrial waste (peach pulp from the food industry).

Sustainable Apparel and Textiles Conference USA (June 2025)

The focus of this 3-day event held in New York was largely on brands and how they will adapt to regulatory changes, build resilience and collectively scale circular systems, through industry-led panel discussions.

A poll was conducted to determine what attendees were hoping to gain from their attendance. Responses included: **“To understand the true barriers to circularity, innovation, business, current challenges, perspectives on policy and tangible solutions.”**

Primary themes were resilience in action and the adaptation of strategies amid global political and environmental challenges for sustainable long-term growth.

Topics included: climate accountability; rethinking material choices while navigating the increased reliance on fossil-based synthetics and integrating next-gen materials; eradicating “forever chemicals” to reach phase-out targets for 2025; innovation in finance to drive sustainable transformation; whether strict regulations on green claims are hindering genuine progress and overcoming overproduction; and ways to prevent waste, boost efficiency and optimise supply chains.

The impact of tariffs was explored, including how they are reshaping procurement decisions with US apparel and textile industries moving away from China towards new global hubs and reshoring. Tariffs are dominating, disrupting and creating uncertainty, which is affecting sustainability. Additionally, tariffs are affecting sourcing strategies, which is impacting suppliers and their supply chains.

The conference was attended by both industry and academic representatives including

2.3 National/international conferences

Bank & Vogue, Ralph Lauren, Foot Locker, Levi Strauss & Co, Cotopaxi, NYU Stern Center for Sustainable Business, SUAY and Cascale.

Key takeaways:

- The impact of tariffs as the biggest disruptor to circular and sustainable developments.
- Challenges of agricultural fibre crop production due to climate unpredictability across the US.

UKFT Sustainability Conference, London (September 2025)

The prominent theme of this 1-day event was circular innovation in action across the fashion and textile supply chain. The opening address from Adam Mansell, Director of UKFT, outlined the UKFT Sustainability Survey 2025 and the key legislative challenges: digital product passports and extended producer responsibility. The barriers were identified as cost, skills, data and the burden of administration. Innovation knowledge gaps were identified as recycling (mechanical, thermo-mechanical, chemical and biological), low-impact dyes and processes, next-generation (biobased) materials, transparency and traceability (blockchain, digital tools).

Topics included: real-world developments in next-generation materials, dyes, colours, manufacturing processes and recycling technologies.

Presentations from UK innovators about their next-generation materials explored the challenges in supply-chain integration, scaling beyond pilot projects and meeting technical and commercial requirements. Key enablers for market adoption were identified as collaboration, regulatory support, and rigorous R&D. These were delivered by Solena, Ponda (BioPuff®), Modern Synthesis, Materra, Rheon Labs and Positive Materials. Next-generation colours and dyes were represented by Amphico, DyeRecycle, Post Carbon Lab, SwitchDye and Alchemie Technology. Next-generation manufacturing featuring MannyAI, Fashion Enter, Sudbury Silk Mills and LaundRe. The session on next-generation recycling consisted of presentations by Coleo, Epoch Biodesign, Matoha and Beyond Retro x Seasalt.

In addition to the companies listed who gave presentations or participated in a panel discussion, other UK industry attendees included ASOS, Barbour, Burberry, DAKS, Pentland Brands, Stella McCartney, Camira and John Smedley.

Key takeaways:

- Challenges of scaling circular/sustainable material innovations, implementation within existing manufacturing capabilities and retaining innovations within the UK.
- Reduction in fashion consumption with an opportunity for regulators and policy-makers to incentivise brands to transition to circularity at scale with financial support.

Textile Institute World Conference, Porto (October 2025)

Jorge Faria, Managing Partner of chemical company Aquitex and Conference Chairman, introduced the 4-day conference **Fibre to Future: Transforming Fashion and Textiles through Sustainability and Digitalisation**, emphasising the importance of collaboration between academia and industry in textile research, development, innovation, applied science and the alignment of scientific innovation with industry reality.

The opening address by Charles Wood, Textile Institute World President, stated that the primary theme of the conference was **“recognition of synergies — when design and sustainable technologies are effectively integrated to produce commercial solutions for better aesthetics and functionality”**. The future of the apparel and textile industry was discussed by Mário Jorge Machado, President of Euratex (European Apparel and Textile Confederation), with key priorities being industrial policy, effective research, innovation and skills development, and sustainable supply chains.

Topics included: the EU textiles strategy concerning the transition from vision to regulation, including ecodesign, and digital product passports; green public procurement; Carbon Border Adjustment Mechanism; Waste Framework Directive, including Extended

2.3 National/international conferences

Producer Responsibility; textile labelling regulation; sustainable finance (taxonomy); Forced Labour Regulation; waste shipment; corporate sustainability due diligence; microplastics; REACH revision (Registration, Evaluation, Authorisation and Restriction of Chemicals); PFAs and other chemicals; PEM convention on rules of origin; green claims including PEF; and the Corporate Sustainability Reporting Directive.

The core question raised was whether Europe will shape the change or be shaped by it in relation to waste reduction, overproduction and reskilling workers.

The challenges for a successful transition were identified as a need to connect with policy-makers to achieve the right policies for the industry, brands taking responsibility for their supply chains, consumer understanding of the situation and a need to change markets, regulation and technology.

The conference was attended by several representatives from academia who presented papers, including from the University of Leeds, Manchester Metropolitan University, Northumbria University, University of Coimbra, Kyoto Institute of Technology and The Hong Kong University of Science and Technology.

Key takeaways:

- Education can accelerate the fashion industry towards sustainable practices with digitisation and tools in design.
- Skills challenges include a shortage in technical and specialist skills, an ageing workforce and a misalignment between education and industry requirements.
- There is a lack of investment in new technologies.

Circular innovation meetings

Impact+ research seminar, London
(November 2024)

- Primary focus included presentations from academics across the Impact+ network concerning environmental index measures promoting assessment and circular transparency in fashion.
- Themes focused on air, land and aquatic environments included geography and environment — natural textile fibres, terrestrial environmental science, textile fibre degradation, forensic science — fibres and microfibres.
- The network's aims are to communicate; assemble critical knowledge; build a world-leading multi-stakeholder network; improve collation, analysis and assessment; and inform, educate and generate engagement with academics and industry.

Textile Institute, Eco-Luxe and Savile Row, London
(November 2024)

- Primary focus included a pilot project to create a zero-waste, circular initiative, processing wool waste from bespoke tailoring companies.
- Collaborative working with bespoke tailors, linouio wool recyclers and UK weavers for collection, sorting, transportation, garneting, carding, yarn production and weaving to create new textiles.

Network+ Programme Co-ordination Team Meeting, Exeter
(January 2025)

- Primary focus included environmental impact, standards and baselines, interdisciplinary collaborations, knowledge and behaviours, and stakeholder communication.
- It also explored the funding landscape with UKRI, NERC and AHRC in supporting early-career researchers.
- There were 3 objectives: how design and environmental science can be aligned; embedding the circular economy; and the next collaborations.
- Panel discussions covered eco labels — regulations and standards, interdisciplinary collaborations, collaborative approach — value, policy, business, people, knowledge and behaviours, and stakeholder communication.

2.3 National/international conferences

Innovate UK Materials and Manufacturing Showcase, London (February 2025)	• Primary focus included circularity and materials through advancing innovation, circular manufacturing processes, systems and biobased solutions for net-zero goals, sustainable industries and resource efficiency. • Advanced technologies such as AI, IoT and robotics are changing the sector by enhancing efficiency, production and product quality. • Being the backbone of innovation research is how supply chains can transform to achieve net-zero goals, and build resilience and adaptability. • <i>Assets and Infrastructure</i> explored how new physical assets and intangible capabilities are driving the scale-up of sustainable technologies and the challenges in associated new infrastructure to develop physical assets for sustainable industries, building the skills and knowledge to support innovation and help them to scale. • The future workshop sessions explored the future of the UK manufacturing workforce through elevating skills in general and for future manufacturing.
John Smedley factory visit, Matlock (March 2025)	• Primary focus included understanding the company ethos to design and manufacture for longevity and durability. • Key initiatives supporting a transition to circular/sustainable goals included a change in consumer behaviour towards less consumption and investment in higher-quality products, policies to support circular/sustainable initiatives, correct recycling, technical education, social awareness and collaboration across industry and academia at every level. • With 275 employees, the company utilises 1,300kg of yarn each week to create its knitwear collections. • It has invested in new, more sustainable production methods, including state-of-the-art in-house dye facilities, which will significantly reduce energy and water usage.
Retail Supply Chain Sustainability Conference: Segura, London (March 2025)	• There were 3 innovation insights featuring SMEs, supported by FTTI presenting innovative solutions for the fashion and textiles industry from Ananas Anam, linouiiio and Project Plan B. • The audience included retailers, brands and supply chain partners.
Conquering the textile waste mountain with Camira, Clerkenwell Design Week, London (May 2025)	• Presentations spanned the interiors industry, discussing how circular design can play a critical role in the challenge of textile waste. • They also included World Circular Textiles Day's 2050 vision with sub-themes of materials, products and people, as well as how researchers and businesses have made a circular future more possible. • Collaboration was seen as being key to supporting designers and decision-makers to embrace design as a force for good environmental change.
Future Fibres Network+, The Design Museum, London (June 2025)	• Future Fibres Network+ is part of the UKRI circular fashion and textile programme NetworkPlus, a collaboration between the University of Huddersfield, University of Leeds, University of the Arts London, University of Plymouth and the UK Fashion and Textile Association led by the University of Exeter. • The Network aims to bring environmental science into the heart of the UK fashion, apparel and textile sectors. • Presentations from the network's funded projects included <i>All cellulose composites; Unlocking the potential of post-consumer textiles; Neoprene recycling; Coloration in flow; Increasing textile circularity; and Biotic textiles as an enabler of improved circularity.</i>
Materials Research Exchange (February 2026)	• Materials Research Exchange (MRE 2026) is Innovate UK's flagship event showcasing the UK's advanced materials research and innovation. • The event brought together researchers, manufacturers, designers, and investors through seminars, panel discussions, and the Advanced Materials for the Future conference, covering areas including biomaterials, textiles, polymers and composites.

A hand is shown holding a large quantity of small, light blue, spherical beads. The hand is positioned in the center of the frame, with the fingers slightly curled to hold the beads. The background is a solid, vibrant blue with a subtle, fine-grained texture. The overall composition is clean and modern, with a focus on the tactile quality of the beads and the gesture of holding them.

3 Circular innovation in the fashion, wider apparel and textiles industry

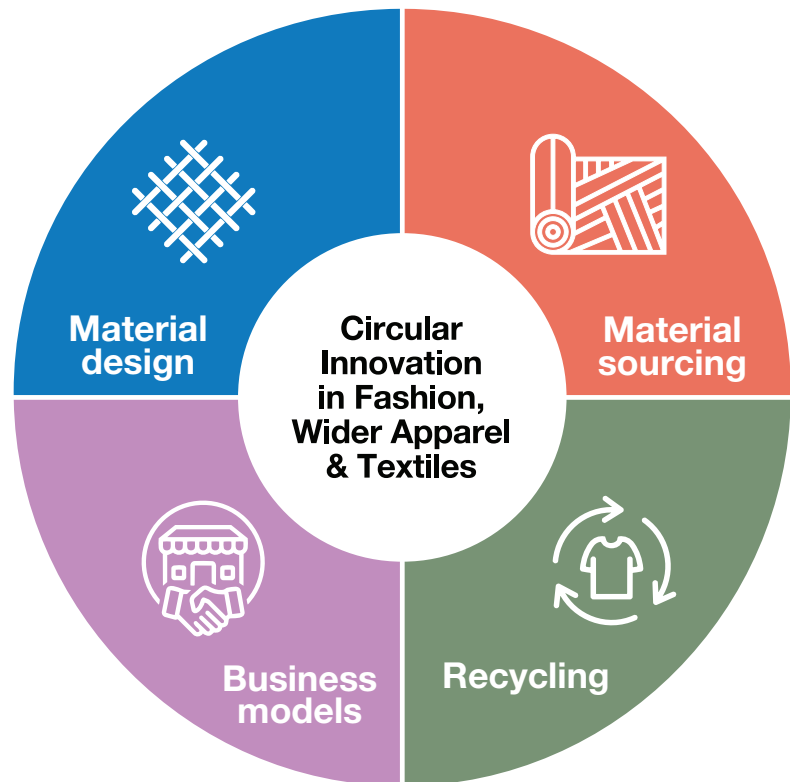


Fig. 1
Illustration showing 4 key types of circular innovation in fashion, wider apparel and textiles

The research identifies 4 thematic areas: circular innovation in material design; circular innovation in material sourcing; circular innovation in recycling; and circular innovation in business models. **Circular innovation in material design** explores waste-derived, bioderived and biosourced materials, alongside biotechnology and regenerative cultivation, offering alternatives to conventional oil-based fibres. **Circular innovation in material sourcing** incorporates regenerative agriculture, responsible fibre standards, traceability platforms and supplier management, embedding environmental, social and animal-welfare considerations at the raw-material stage. **Circular innovation in recycling** demonstrates advances in mechanical and chemical processes, fibre-to-fibre recycling and closed-loop systems, and also highlights that scaling is constrained by material complexity, inconsistent feedstock, insufficient collection infrastructure and limited economic incentives. **Circular innovation in business models** — including repair, reuse, rental, resale and on-demand production — integrates sustainability into commercial practice, but requires consumer engagement, cultural shifts and supportive policies to succeed.

The following four sections each provide a summary overview of relevant innovations, selected short case studies and a conclusion for each of the 4 thematic areas.

3.1 Circular innovation in material design

Summary

The scope of this research, mapping **circular innovation in material design** to date, is demonstrated through examples, drawing from the Matrix of Circular Innovation Industry Practices (ref.pp 158) spanning: biosourced/bioderived materials, biotech, waste feedstock, agricultural and food-industry waste, and the use of enzymes to break down textile post-industrial waste, in addition to important innovation in more traditional material contexts such as wool and cotton production.

The Matrix of Circular Innovation Industry Practices (ref.pp 158) identifies 135 circular/sustainable apparel and textile innovations, which include **76** examples of **circular innovation in material design**. The following examples briefly outline a sample of the range of innovation.

Amphico's Amphitex is a 100% recyclable and PFC-free waterproof and breathable textile for use in outdoor apparel. The Amphidry™ yarn used in the textile is inherently superhydrophobic and the fabric's construction means it needs no additional water-repellent chemical coating. **Aeropowder** is an engineered biomaterial made using chicken feathers, a waste product from the poultry industry, to create an insulation material. **Bananatex®** by Qwstion is a biodegradable fabric from the Abacá banana plant, cultivated without pesticides or fertilisers and grown within a regenerative permaculture environment. Its cultivation provides stable livelihoods for small-scale farmers. The company focuses on making bags from plants, and the fabric is a result of its material research. **BioBlack TX™** is a water-based dispersion featuring a proprietary black pigment from FSC-certified wood waste. **SQIM** is a mycelium-based fabrication for materials in fashion. **Mirum®** is a plastic-free leather-alternative material made from natural rubber, plant oils, waxes, natural pigments and minerals. **Planet of the Grapes** is a leather alternative made from grape marc, a waste product from wine manufacturing. **TômTex** is a materials innovation company creating biomaterials from chitosan (found in the hard exoskeletons of shellfish and crustaceans) and mushrooms. Its formulations can replicate any leather texture, colour or new material looks. **Ingeo™** by NatureWorks transforms sequestered CO₂ from plants such as corn, cassava, sugar cane or beets into long-chain sugar molecules, which are fermented to create lactic acid — the building block of the company's materials range. **Deap** creates seaweed-based fibres produced using the Lyocell process. **Aerseeds** are aerodynamic seed pods made from food waste, which are carried by the wind over large areas and difficult terrains to deliver nutrients and a variety of seeds, to rehabilitate depleted soils and accelerate natural regeneration.

3.1 Circular innovation in material design

For the purposes of this research, the following 5 **case studies** briefly evidence different aspects of circular innovation in **material design** for the fashion, wider apparel and textiles industry, which have gone through a significant level of development.

Case studies

Orange Fiber (food) is the world's first brand to produce sustainable viscose fabrics from citrus-juice by-products. Viscose has the same molecular structure as cellulose and is a semi-synthetic fibre made from natural sources of regenerated cellulose, derived, for example, from relevant agricultural products and wood. There are many types and grades of existing rayon fibres and films. In 2014, Orange Fiber established its cellulose extraction licence and trademark, and patented its innovative process, which is now used in countries all over the world that produce citrus juice. Its production sites are mainly established in Italy. The registered trademark identifies products containing its yarns and fabrics, and guarantees traceability and accountability for its products and supply chain.

Pastazzo — waste that remains after juice production — accounts for 60% of the weight of fresh fruit. Disposing of the citrus-pulp waste has a significant economic and environmental cost, so its use as a resource has positive benefits. Orange Fiber collects the waste and creates cellulose from the citrus pulp. Through a partnership with the Lenzing Group, this is then processed into fibre, and made into yarns and Tencel™ Limited Edition x Orange Fiber fabrics.

Orange Fiber's primary concept is to reuse production waste as a resource and consequently reduce the use of virgin raw materials. The first phase involved process design and laboratory testing in collaboration with the University of Milan. The company's process for extracting cellulose from citrus waste from the food industry, suitable for spinning yarn, was patented first in Italy and then in other countries that produce citrus juice. Partnering with the Lenzing Group in 2021 allowed Orange Fiber to consolidate an industrial process in which part of the wood pulp used in viscose production is replaced by pulp-derived cellulose.

3.1 Circular innovation in material design

The cellulose extracted from the citrus pulp becomes a cotton-like fibre suitable for spinning and then transforming into fabrics. The fabric can be made from 100% of this material but blends are designed to give specific characteristics based on customer preferences.

Orange Fiber continues to evaluate its water consumption, processing efficiency, the impact of what would otherwise be unused waste and overall carbon footprint, so that it can maximise and generate the value of each resource at every stage of the process.

Ananas Anam's business model is based on environmental, social and sustainability values. Its **Piñatex**, **Piñayarn** and **Piñafelt** products are derived from agricultural plant waste from pineapple farming in the Philippines, which would otherwise be left to rot or be burned, releasing CO₂. Using the waste leaves of the fruit harvest provides positive social impact by generating an additional and diversified stream for the pineapple farmers, while creating jobs in rural communities. In developing these materials, the company has optimised material design and manufacture to improve the quality of the products.

The fibres are extracted from the leaves, washed with water and dried in the sun — or, in the rainy season, in drying ovens. The company uses a proprietary method to process the leaf fibre to a premium textile grade with no bleaching, pulping or dyeing. An enzymatic wash removes impurities without using harmful chemicals, while the rest of the process is mechanical.



Drying pineapple leaf fibre indoors
Credit: Ananas Anam

3.1 Circular innovation in material design

Anam PALF, the key ingredient for Piñatex, Piñayarn and Piñafelt, is traceable from plant to product and comes with a certificate of origin. It is strong and durable, and its composition is mostly cellulose, so it is easy to dye with natural or conventional dyes. It is recyclable, compostable, has no harmful chemicals and is water and energy efficient.

Piñafelt is created through a mechanical process. The fluff-like pineapple leaf fibre (PALF), 80%, is mixed with a corn-based polylactic acid, 20%, to make a non-woven mesh. The rolls of Piñafelt are shipped by boat to Spain for finishing into Piñatex, a leather alternative. The process involves colouring the Piñafelt using GOTS-certified pigments, with a top coating applied to give additional strength, durability and water-resistance, followed by a high solid PU transfer coating to create Piñatex Performance.



Ananas Anam swatch card
Credit: Ananas Anam

Piñayarn is created in a closed-loop production ensuring zero waste. The dry spinning technology used to produce it needs no water or chemicals, resulting in a low-environmental-impact, breathable and biodegradable yarn. Through waste valorisation, Piñayarn reduces the amount of pineapple leaves being burned, which saves the equivalent of up to 6kg of CO₂ emissions from being released into the atmosphere per kilogramme of yarn produced. Piñayarn is recyclable, compostable and biodegradable at the end of life.

3.1 Circular innovation in material design

Piñatex, however, presents the following challenge, as Dr Raquel Prado, former Head of Research, outlines:

“It cannot be recycled currently because it still contains a small amount of PU (about 5–7%) at the end of its life. However, because the material is mostly cellulosic, it could potentially be chemically recycled as a textile if shredded. Most of the material can also be composted. About 89% in laboratory tests. While the coating does not break down, it does not interfere with the composting process. Tests carried out with BLC confirmed that composting does not release harmful substances and that the resulting soil is safe. The main challenge is that there are currently no composting facilities that accept textiles, as they require specific nutrient balances.”

**- Dr Raquel Prado,
former Head of Research, Ananas Anam**

Colorifix has developed a biological process that replaces the use of harmful chemicals to create colour and dye textiles. The process reduces harm to the environment while keeping industry standards and Colorifix is scaling its business. The process is more ecofriendly than conventional textile dyeing. It combines pigment production and dyeing in a single process, using plant-based renewable feedstocks and lower usage of water and other resources, and virtually eliminates the use of toxic chemicals.

The process begins with engineering biology; after identifying a colour produced by specific organisms, the company searches public databases to find the instructions for making the colour in its DNA code. Then it engineers a safe microbe with that DNA code to convert it into a microscopic colour factory. After the colour has been initially tested, Colorifix sends a vial of freeze-dried colour-producing microbes to its customers, who can then grow hundreds to thousands of litres of colour-producing microbes using precise fermentation. These engineered microbes are grown in bioreactors, in the same way beer is brewed, and grow on non-hazardous ingredients such as agricultural by-products, which are rich in sugars, peptides and salts. Everything in the fermenter — microbes, water and media — is then pumped into standard dye machines with the yarn, fabric or garment to be dyed.

3.1 Circular innovation in material design

The Colorifix process is similar to that of conventional dyeing, starting with half bleaching, fixing the pigment to a material (dyeing) and washing to fix the dye. The difference is that the pigments are created through fermentation, and they use microorganisms to bind to the textiles through their natural concentration of metal salts such as magnesium.

CFX is Colorifix's subsidiary company, which sells its patent-pending CE-certified bioreactors. The technology uses a genetically modified (GM) process but is not a GM product. Its dyes carry the OEKO-TEX Eco Passport, pioneering the first dye safety testing programme, which incorporates biocompatibility tests with skin allergies and irritations.

Pigment 001, Botanic Cyan and Azure Drift, comes from the fermented leaves of a plant. Although linked to the colour blue and used for denim, it can also yield a closely related pink pigment.

Pigment 002, Blushing Rose and Solar Glow, harnesses the DNA of underwater bacterium, then engineers their microbes and adjusts the pH of the fermentation process to create 4 distinct colours.

Pigment 003, Sunlit Sand, is a pigment from bacteria that thrives in soil and deep-sea sediments. It is lightfast and retains its vibrant colour under the strongest sunlight. When this pigment-producing bacteria is created on a plate, the colour spills across the entire surface, escaping the confines of the bacterial colonies, driven by the pigment's unique chemical structure, which enables it to diffuse and transport beyond the cell's boundaries.

Ponda Ltd's BioPuff® biomaterial design is a lightweight, warm, water-repellent textile insulation material. It is created by extracting fibres from bulrush plants that aid wetland regeneration, reducing reliance on feathers and synthetic fillers, and is traceable from plant to product.

Rewetting wetlands and peatlands represents a resilient and sustainable landscape for social, economic and environmental interests that protect and enhance biodiversity. Natural wetland environments sequester and store large amounts of carbon and BioPuff® stores more than it emits. Paludiculture, or marsh farming, is the practice of farming on wetlands such as rewetted peatlands, bogs and fens. Ponda partners with farmers and conservation groups to regenerate carbon-emitting wetlands by cultivating *Typha latifolia*, a native, shallow-water, rhizomatous perennial plant that thrives in freshwater or slightly brackish marshes (bulrushes or cattails). It is a low-maintenance crop that grows quickly (sequestering carbon), creates habitats (increasing biodiversity) and provides a high-quality fibre for textile production. This guarantees to customers that the company is not sourcing from controversial sources.

3.1 Circular innovation in material design



Ponda

Credit: University of Leeds

The company is composed of a community of scientists, designers, growers and partners. Its facilities include fibre processing and prototyping capabilities that allow the company to meet industry quality standards. It has partnered with leading apparel brands to test BioPuff® in real-world conditions, and its product has additional potential in upholstery and homeware.

In November 2025 Ponda raised \$2.4 million in seed funding to grow BioPuff® and expand its wetland farming network across Europe. This will help the company move BioPuff® from pilot scale to commercial scale and strengthen its network of wetland growers who are regenerating peatland through paludiculture.

PACT designs biomaterials from collagen, herbal extracts, oils and minerals. It starts with a material made with a rich natural protein, collagen, and aims, in part, to replace plastic. Collagen, a structural protein, is a major building block of skin and plentiful in the human body. The process begins with transforming cosmetic-grade recovered collagen into collagen skins called Oval, which are enriched with natural materials. This roll-to-roll patented biomaterial has been rigorously tested, and the collagen base allows for flexibility and customisation, from precise colour to intricate embellishments. It is traceable by design and is fully compatible with existing supply chains. Oval is a supple, versatile and elegant leather alternative with the potential for new design aesthetics as it can be printed, embossed or coloured in many ways, offering a potentially viable alternative to plastic-coated materials.

3.1 Circular innovation in material design

The multidisciplinary PACT team includes engineers, designers, biologists and material scientists — while all these disciplines come under the umbrella of science, each has its own terminology, methods and technologies. The designers and brands the company works with have a tacit language when they are specifying, a range of skills they have developed over years, and knowledge through touch to understand how a material works. Communication between these disciplines and between design, commercial and scientific teams requires developing a shared language to understand and solve problems.

At the end of October 2025, PACT received Series A funding of over \$20 million to accelerate the commercial scale-up of Oval with financing by Forbion and HV Capital, with support from other investors. It will also use the funding to expand its portfolio through a newly commissioned state-of-the-art lab and pilot line production at the company's Cambridge headquarters. In scaling up, it will be able to meet demand from luxury apparel and lifestyle brands, and intends to develop new markets in interiors, footwear and automotive applications. The pilot line will allow PACT to scale and deliver commercial volumes of Oval as well as develop new material solutions.

Dr Yudi Ding, founder and CEO, said that the real challenge is not developing materials in the lab, but industrialising and scaling them to meet the exacting standards of the textile industry, and to make materials innovation succeed.

“I think material science is at the crux of it. The way that bacteriologists have created a bacterium that can eat plastic, that has to be the direction we need to be developing — something that's biodegradable and won't be there forever. Planet of the Grapes uses waste from the grapes grown for the wine industry to make a leather substitute. People are using enzymes and/or organisms — for instance, Post Carbon Lab is using photosynthesis on clothes. The challenge is it's all small scale and there is no investment.”

- **Jane Shepherdson, Industry Consultant and Chair, My Wardrobe HQ (previously CEO, Whistles)**

Conclusion

The use of bioderived/biosourced materials was prevalent pre-oil due to limited material resources. Henry Ford experimented with agricultural waste, with a laboratory that explored the use of soybean oil to develop a plastic that was used for materials in automobiles, viscose derived from soy and the use of orange peel. A precursor for some of the developments occurring today, he wanted to find a use for waste materials from agricultural sources for industrial applications.

“The answer is around materials. It’s about the ability to be able to do something with waste that was going to be thrown away, along with more alternative fibres in the mix, and the capability to be able to utilise these materials in the industry. There are fibre innovations, alternative materials that are considerably more sustainable than the conventional ones we currently use. Fibres like flax, hemp and banana waste are going to be available to reduce the overall impact, then alongside the best cotton alternatives like regenerative cotton, because even organic cotton is thirsty, and we are too reliant on it.”

- Simon Platts, Responsible Sourcing and ESG Consultant and founder of SP&KO

One of the barriers identified to the uptake of these types of innovation is scaling up. The technology may exist, but it is difficult to scale. It has been suggested through the wide range of people interviewed that funding, policy and legislation will be the impetus that drives change and encourages the uptake of these innovations to offer credible and economic viability. However, there needs to be a transparent framework, and the policies and legislation need to have a global impact to allow this transition.

3.1 Circular innovation in material design

Science is a route to finding answers though, ironically, it was science that discovered oil-derived materials. A combination of creativity and science can lead to innovation but the language between the disciplines needs to be aligned in order to ensure there is a consensus of understanding. Resources, technologies and circular production systems need to be aligned.

Pre-oil, this capability existed; post-oil, nearly all material innovation became focused towards this particularly financially and environmentally impactful field of practice, to the detriment of addressing how other innovations could scale up. Material designers have looked to bioderived materials, food waste, agricultural waste, et cetera, to see what they can achieve in a more circular and sustainable innovation context, while we look back, historically, to pre-oil and the circular innovation material opportunities that we could explore.

“You can design a shoe out of a single polymer that’s biosourced. The problem being that the technology is there, but no one’s doing it at scale yet. In addition, we want to think about using food waste to make into polymers for example out of crushed shells, rice husks or inedible corn, rather than displacing food crops.”

- **Professor James Busfield, Professor of Materials,
Queen Mary University of London**

3.2 Circular innovation in material sourcing

Summary

The scope of **circular innovation in material sourcing** examples identified through this research to date, drawing from the Matrix of Circular Innovation Industry Practices (ref.pp 158), encompasses sustainable supply chains, suppliers' management platforms, a library of sustainable suppliers, regenerative cotton/wool farming and production, as well as various certified standards that manufacturers can use to guarantee their products are either organic or traceable, or follow good welfare practices in farming and social areas. For manufacturers and producers, there is an increased responsibility and impending legislation, such as extended producer responsibility (EPR), to ensure traceability across global production supply chains. Manufacturers purchasing their raw materials from suppliers that have these globally recognised certifications can evidence good and fair practice in their responsibilities as producers, with the aim of achieving endorsement from the consumer. Circular innovation in material sourcing is critical in achieving sustainable objectives to ensure that all aspects of material procurement are considered, including water use, soil regeneration, supply-chain traceability and, importantly, social, human and animal welfare.

“Circular innovation is about the raw materials that we select in the first place — what we put into our products, as well as making sure our products are well made and made to last.”

- **Katharine Beacham, Head of Materials and Sustainability, Marks & Spencer**

The Matrix of Circular Innovation Industry Practices (ref.pp 158) identifies 135 circular/sustainable apparel and textile innovations, which include **10** examples of **circular innovation in material sourcing**. The following examples briefly outline a sample of the range of innovation.

The matrix includes the following globally recognised standards that endorse fibres as originating from good environmental and animal welfare practices: **Global Organic Textile Standard (GOTS)**, for sustainable production of garments and textile products made from natural fibres from organic farming, such as organic cotton or organic wool. The criteria include environmental and technical quality, as well as toxicity and social standards, which are guaranteed for the entire supply chain by this independent certification. Goods that can be certified include textile products, textile chemicals commonly implied in textile industry and manufacturing activities. **Nativa Precious Fibre (NPF)** guarantees the quality and traceability of wool fibres, from the

3.2 Circular innovation in material sourcing

farmer to the finished garments throughout the supply chain. Each certified contributor respects the principles and procedures in terms of corporate social responsibility, animal welfare, land management and industrial standards. **Community Clothing** makes clothes that aim to do good — for people, local communities, customers and the planet — with all its range made in the UK. It works with the highest quality, sustainably sourced wool, linen and cotton, which it believes offer the best wearability and overall environmental impact. **Laxtons** spins premium yarn products that promote quality and traceability. It reshored all of its manufacturing in late 2009. Sheepsoft yarn brand is 100% British wool, with the journey from fleece to finished yarn covering less than 50 miles. A combination of Bluefaced Leicester and Masham sheep breeds are used for durability, with full traceability and sustainability additionally supporting British farmers, UK manufacturing and high levels of animal welfare. Wooltrace is a fully traceable yarn (using the QR code on the batch) that supports fair pay for farmers, animal welfare and the sustainability of the British farming industry.

For the purposes of this research, the following **case studies** evidence in brief different aspects of **circular innovation in material sourcing** for the fashion, wider apparel and textiles industry. Each of these innovations has gone through a significant level of development.

Case studies

Segura is a tech company that specialises in supply-chain management solutions, and has developed an online sustainable supplier marketplace. It provides tools for retailers that map, monitor and report on their supply chains, from ordering and working with suppliers to meeting business, ESG and relevant legal standards. The tool helps retailers ensure that their chosen suppliers for all products — including fabrics, trims, fastenings and all other components — are adhered to within their supply chain and that no unauthorised third-party suppliers are involved at any stage of production. In turn, retailers can be confident and transparent about their supply chains with their customers.

Peter Needle, Founder and President of Segura, outlined that some of the ideals the business was founded on were established by delving deeply into examining what we make clothes from and how we make them, as well as considering the consequences for the planet and trying to examine every layer of all relevant ecosystems. Segura addresses commercial sensitivities, establishing methods of working with businesses that have seen suppliers becoming more open to sharing information as the world increasingly demands transparency.

Needle also works for 2 other companies that connect with Segura's work. Oii.ai is an algorithm used as a digital AI-optimisation tool for supply chains. Geodentify has developed a process of determining the geographic location of an object, device or data point, which is essentially materials traceability by locating samples. The innovative platform originated from the food industry and is now being used to

3.2 Circular innovation in material sourcing

Segura supply chain
transparency platform
Credit: Segura



SEGURA DIGITAL PRODUCT PASSPORT

1 Gather robust supply chain transparency data and evidence

2 Choose what information you want to display to your customers

3 Consumer scans item level QR code to view product credentials

Scan Me to find out more

segura
www.segura.co.uk

Helping retailers measure, manage and improve their supply chain's ESG performance through transparency and traceability.

The advertisement features a smartphone displaying the Segura app interface. The app shows a map of Turkey, a product image of a 'Relaxed Heavyweight T-Shirt', and a list of suppliers including 'Garment Manufacturer' and 'Fabric Mill'. A QR code is shown next to the text 'Scan Me to find out more'. The Segura logo and website URL are at the bottom.

track fibres in fashion. Combined with Segura, the 3 companies enable traceability across the supply chain. Geodentify identifies the physical product, and Oii optimises activity across the supply chain. The Oii solution creates a digital twin of the supply chain and, for brands looking to maintain their service to customers/clients, it will explain how much the inventory can be reduced without risking that service level. The calculation process is immediate, and extremely accurate.

Overproduction is one of the critical challenges currently, and drawing these 3 companies together provides an extremely efficient supply chain: inventory is reduced to a bare minimum; less safety stock is held; and items are therefore not being sold on the secondary market or recycled.

Kering's Material Innovation Lab (MIL), established in 2013, is dedicated to sourcing sustainable materials and fabrics for the group's Houses (comprising 13 companies, as of February 2026). It is both a library and a driver of change within a very complex supply chain. The primary materials focus is on sustainable cotton, silk, viscose and polyester, and it provides the group's key suppliers with resources, tools and new solutions to assist them in making more sustainable choices in their product development. This resource provides information from across the supply chain, from raw material sourcing to farming, spinning, weaving and sustainable dyeing, all relevant production processes. Material traceability is a major challenge, with complex supply chains; however, in 2021 Kering launched its circularity ambition

3.2 Circular innovation in material sourcing

to achieve full traceability in its key raw materials by 2025. MIL works with industry-leading start-ups to test innovations, which include dyeing and finishing solutions as well as new fibres created from biotech and agricultural waste.

Circularity begins with raw material extraction, ensuring that materials are cultivated in a way that replenishes and respects nature, and Kering is accelerating its transition to regenerative agriculture. The circular economy involves a mindset that focuses on innovation, creativity and responsibility, and the challenge is in increasing the longevity of products and reinventing the way we use and reuse materials. Kering's aims are to adopt a more holistic approach towards its overall business, promoting luxury that lasts, making production processes more efficient and ensuring collaboration across the entire industry.

Materra is a regenerative cotton and tech company working with and for smallholder farmers internationally. It builds custom regenerative cotton farming programmes and supply chains that are climate-resilient, traceable and equitable. Through AI-powered proprietary technology, it is digitising the base of the fashion supply chain, providing data to stay compliant with regulations and supply chain insurance against climate disruption. It has a multidisciplinary team of farmers, scientists, implementation experts and designers.

Regeneration is about restoring and enhancing life in a system, and regenerative agriculture is farming in a way that enhances the farm ecosystem and builds its capacity to evolve, renew and replenish the resources it needs to thrive. Materra's work with smallholder cotton farmers in India follows holistic consideration and the health of a whole system, maximising diversity, fostering relationships and trust, evolving



Materra regenerative cotton plant
Credit: Materra

3.2 Circular innovation in material sourcing

Regenerative cotton grown in India by farmers in collaboration with Mattered
Credit: Mattered



the capacity of all stakeholders, and respecting place-based and traditional knowledge while being innovative, forward-looking and open to change.

Mattered's focus on reducing resource use includes reducing carbon impact, improving water stewardship, reducing reliance on chemical inputs and implementing biological pest-management practices. Restoring biodiversity includes helping living ecosystems flourish with better soil management, crop diversity and the use of beneficial insects. Raising farmers' livelihoods includes co-designing with farmers, increasing farmer profits, incorporating local knowledge and building resilience in the field.

Cotton production accounts for a disproportionate volume of the world's insecticide, land and freshwater usage. As companies have sought more sustainable options, organic cotton has become increasingly popular — however, this requires substantially more land use and exponentially higher volumes of water, which creates serious challenges in managing the planet's natural resources.

Mattered's vision represents a new approach to cotton farming, offering higher yields to reduce the amount of land required to meet demand. The start-up's techniques also use up to 80% less water and emit up to 30% less carbon, with a fully transparent supply chain built on close relationships with farmers.

Responsible Animal Fiber (RAF) refers to a certification framework of standards that ensure animal fibres are produced ethically and sustainably, focusing on animal welfare, environmental impact and social responsibility. It has been developed by the Textile Exchange, which aims to promote responsible practices in the production of animal fibres with standards including: **Responsible Wool Standard (RWS)**, ensuring wool is sourced from farms that prioritise animal

3.2 Circular innovation in material sourcing

welfare and sustainable land-management practices; **Responsible Mohair Standard (RMS)**, focusing on the ethical treatment of goats and the environmental impact of mohair production; and **Responsible Alpaca Standard (RAS)**, addressing the welfare of alpacas and the sustainability of alpaca farming practices. The **Sustainable Fibre Alliance (SFA)** is a non-profit organisation providing an animal fibre standard that defines best practices for responsible cashmere and animal fibre production. Effective from 1 April 2025, its principles include improving the welfare of fibre-producing animals, safeguarding biodiversity and using land responsibly, preserving and enhancing fibre quality, and operating an effective management system to ensure traceability and sustainability throughout the supply chain.

The RAF framework aims to: promote animal welfare, ensuring that animals are raised in healthy environments and treated ethically throughout their lives; ensure environmental sustainability to minimise the ecological footprint of animal-fibre production through sustainable agricultural practices; and ensure social responsibility to guarantee fair and safe working conditions for all individuals involved in the production process. These are, however, independent, voluntary standards. On farms, the certification ensures that sheep, alpaca and goats are treated with respect to the Five Provisions, which recognise the interaction between the physical provisions of nutrition, living environment, health and behaviour, and their impact on the fifth mental provision, and also ensure best practices in the management and protection of the land.

British Wool is a natural fibre that is 100% renewable. It has performance properties including temperature regulation; is hypoallergenic with antibacterial properties; reduces dust and helps filter VOCs, which benefits people with allergies; is flame retardant; and absorbs moisture. It does not contribute to landfill or ocean pollution as it biodegrades in soil, adding nutrients to the earth. It has a crimp that gives it natural stretch, is wrinkle resistant, and has shape recovery and drape.

The UK Campaign for Wool aims to highlight wool's natural properties along with circular economy, regenerative farming and feed management in relation to reducing carbon and methane gas emissions.

The New Zealand Merino Company (NZM) offers ethical wool production with respect to transparency and animal welfare. ZQ is an on-farm certification programme established by NZM in 2007, which requires growers to meet strict standards regarding animal welfare, environmental integrity, social responsibility, fibre quality and traceability. ZQ sheep graze freely on open pastures in New Zealand, Australia and South Africa. The sheep producing the wool are fed well, humanely treated and mulesing free.

3.2 Circular innovation in material sourcing

linouiiio sources wool and luxury fibres such as cashmere from post-consumer and manufacturing waste resource, which it converts using heritage techniques into a range of high-quality materials and textiles, using responsible methods. The materials are colour sorted, then shredded and pulled back to fibre, which is compacted into bales. Each shade is created from the original colour, which eliminates further dyeing, and is then carded, spun and woven into textiles. linouiiio has installed state-of-the-art machinery at the Camira Yarns site in Huddersfield, and also partnered with the brand in 2022. The new machinery is being used to create linouiiio products and provides wool-recycling capability for UK retailers and textile manufacturers. Camira is also able to develop its range of quality recycled wool fabrics and claims to have the only textile recycling capability in the UK for such materials.

It offers a scalable recycling manufacturing service to brands and manufacturers to process larger quantities of their waste/resource streams. Clients can then choose to have their waste/resource returned in the form of recycled fibres or spun yarns (blended with virgin fibre) or developed into woven fabrics.

linouiiio works closely with **Eco-Luxe**, launched in 2023 with the support of **Savile Row** tailoring houses to collect their high-quality fabric cut-offs for recycling. The textile waste is then reprocessed into yarn by linouiiio, involving only wool and cashmere waste/resource, with any contaminants such as cotton threads removed prior to processing. The textile material is then broken down using a technique called garnetting, which opens the fibres — as these are shorter than the original raw material, they are blended with British natural yarn.

Filpucci's Re-Verso™ is a circular economy brand for wool, baby camel and cashmere that has been developed by Italian partners and represents an advanced, integrated, fully transparent, traceable and certified supply chain. **Green Line** is responsible for sourcing, sorting and sanitising post-consumer textiles in the second phase. **Nuova** is responsible for the rigorous hand-picked selection and the mechanical transformation process to create the raw Re-Verso™ material, with Filpucci responsible for the development of yarn.

It recovers, selects and processes post-consumer wool and cashmere articles left by customers in its global brand partners stores. This take-back system reduces textile waste — reusing and recycling wool and cashmere garments saves resources, allowing valuable materials to be reprocessed. There is community involvement in the take-back process, and the in-store collection is cost-effective. Additionally, Re-Verso™ involves pre-consumer off-cuts, wool trimmings and cashmere waste, which are transformed into regenerated yarns and fabrics.

Conclusion

With materials for textiles and apparel widely globally sourced, and traceability being a key component of EPR and evidence of circular/sustainable product material use, where materials come from and how they are produced needs to be transparent on multiple levels. Certifications offer manufacturers assurance of good practice in material procurement and production in their complex supply chains.

Circular procurement and sourcing are defined (ISO 59004: 2024) as emphasising solutions that enable product and resource circulation and prevent the creation of waste. These innovations are essential for creating a sustainable and equitable future, as they help businesses navigate resource constraints, and design products and supply chains for circularity.

“The goal is to develop better systems and infrastructure in all the main manufacturing countries, offering viable alternative supply chains that can compete with non-circular materials and supply chains.”

- **Laura Watson, Chief Creative Officer,
Seasalt Cornwall**

“We have transitioned from conventional material to organic or responsible material sources. We have also understood what proper traceability and due diligence are.”

- **Christian Jermyn, Director of ESG,
Seasalt Cornwall**

3.3 Circular innovation in recycling

Summary

The scope of **circular innovation in recycling** sourced through this research to date, drawing from the Matrix of Circular Innovation Industry Practices (included with this report), is demonstrated in the following ways: closed-loop recycling of pre-consumer and post-consumer polyester textiles waste, recycling polyester and nylon recovered from marine debris into yarn, recycling PET bottles into yarn, and mechanical shredding of pre-consumer textiles, including wool, cashmere and cotton, remade into yarn for textiles manufacturing.

“When mechanical recycling of post-consumer wool textiles began in the UK at scale in the early 1800s, it preceded the advent of man-made fibres, and a growing population necessitated resourceful use of existing materials. This meant organised collection of end-of-life textile waste to enable recycling, and an economic model that incentivised industrial-scale operations. Another example that goes back years and has stood the test of time in terms of organised end-of-life collection, recycling and incorporation of recycled content is paper..”

- **Professor Stephen J Russell, Professor of Textile Materials & Technology, University of Leeds**

The Matrix of Circular Innovation Industry Practices (ref.pp 158) identifies 135 circular/sustainable apparel and textile innovations, which include **33** examples of **circular/sustainable innovation in recycling**. The following examples briefly outline a sample of the range of innovation.

Antex recycles polyester using a thermo-mechanical process to turn post-industrial selvedge waste and post-consumer PET bottles into renewable polymer for industry. **Parley** produces fibres for sportswear, fashion, design and luxury industries from intercepted and upcycled marine plastic debris. **Patagonia** uses recycled polyester for its clothing. **Filati BeMiVa** creates regenerated polyester yarn recovered from PET bottles. **FibreLab's** textiles recycling uses mechanical shredding to turn pre-consumer and commercial textile waste into fibre. **linouiio** recycles textiles from consumer and manufacturers'

3.3 Circular innovation in recycling

waste, such as preloved wool and cashmere, for its range of fibres, yarns and fabrics. **John Lewis's** use of circular design centres around better material choices, from adding recycled content to ensuring products are recyclable and durable. It is moving towards innovations such as fibre-to-fibre recycling — however, the availability of materials is low. John Lewis has stringent net-zero targets. For products to meet circular-design criteria, they must be suitable for recycling based on recyclers' parameters. They must meet recycled-content standards, which the brand is setting, and the existing raw-material framework — set to change from “more sustainable” to “more sustainable and recycled”. **Marks & Spencer** (M&S) has established practices for developing fabrics for coats with a recycled-wool content in Prato, Italy. M&S made a coat from fabric from unwanted garments donated by customers through its Shwop initiative (2012). In partnership with Oxfam, M&S separated products with a high wool or cashmere content for mechanical recycling in Italy. The resulting high-quality fibre was made into yarn and woven into fabrics for the coat, ensuring a circular product. **linouio** (partly owned by Camira) uses post-consumer and manufacturers' waste resource — mainly wool and luxury fibres such as cashmere — to create a range of high-quality yarns and fabrics. This process originates from the traditional methods of “shoddy” (shredding old clothes into recycled fibres) and “mungo” (shredding old and new hard rags such as tailors' shreds, coats, caps and second-hand clothes, which may contain linen or cotton, with shredding teeth set closer for a finer ground material).

For the purposes of this research, the following **6 case studies** briefly evidence different aspects of **circular innovation in recycling** for the fashion, wider apparel and textiles industry, which have gone through a significant level of development:

Case studies

Project Plan B applies circular-design principles to repurpose polyester textile waste back into usable monofilament yarn. The garment design and manufacturing company specialises in workwear and school uniforms, predominantly using polyester materials. It manages the entire production process from design, sampling, yarn and fabric purchase through to garment manufacture and client delivery. Customers include workwear catalogue companies and those providing uniforms to large-scale employers (typically over 5,000 employees) such as supermarkets and healthcare businesses.

The company is strongly committed to tackling global environmental challenges faced by the textile industry and believes that by reimagining the way products are designed and manufactured right from the beginning, it can reduce the impact on the environment. Project Plan B has partnered with the Salvation Army Trading Company to facilitate the operational recycling of 100% polyester textiles, a closed-loop recycled polyester system. It has developed a range of circular clothing

3.3 Circular innovation in recycling



Project Plan B, unpacking polyester feedstock

Credit: Alys Tomlinson

principles that enable commonly used garments to be made from recycled and recyclable materials.

The system uses a heat extrusion process, reducing polyester textiles into rPET (recycled polyester) pellets. These pellets can then be turned into fibre to be spun back into polyester textiles or used for injection moulding. Its recycling system is the first in Europe designed for post-consumer polyester clothing and focused on trying to solve the problem of textile-to-textile clothing recycling. There are a set of parameters that need to be followed to enable recycling of used clothing to be fully circular, which make the choice of material, construction and embellishments critical at the design stage. Post-industrial textiles come with data sheets, and the materials are consistent. In post-consumer textiles there are wide variants such as place of origin,



Project Plan B

Credit: Alys Tomlinson

3.3 Circular innovation in recycling

different dyestuffs/chemicals used and the age of the garments.

Bank & Vogue was founded in 2000 and has 4 strands. It started with a contract from the Salvation Army of Canada to be the wholesaler of used clothes supplied by the charity, and now operates with 270 charities across the US, Canada and Europe, buying approximately 4 million garments a week. It finds homes for products that are donated



Clothing waste
Credit: Bank & Vogue

to thrift operators after they have sold what they can.

Approximately 15 years ago, it started upcycling old clothing that it couldn't resell or repair into products for its own stores and companies such as Topshop, and components of shoes for Converse and Nike. More recently, it has been working with US-based luxury accessories company Coach, making handbag components using existing materials instead of first-life-cycle materials. This equates to an 80% reduction in carbon, up to 98% reduction in water and up to 58% reduction in electricity, and demonstrates that "used" can contribute toward production of luxury products. Bank & Vogue also supplies mills for fibre-to-fibre recycling, in particular cotton, and sorts and grades the pre-processed cotton. In 2025, it supplied 22,000,000lbs of post-consumer textiles to cotton mills.

3.3 Circular innovation in recycling



Clothing waste bundles
Credit: Bank & Vogue

“We should have positive taxation, not negative taxation — in other words, a policy lever the government could have is no VAT on second-hand clothes. That would be an automatic win for encouraging circularity, because the most circular thing to do is to reuse.”

- **Steven Bethell, Founder, Bank & Vogue Ltd, BVH Services and Beyond Retro**

Circular Flow recycles neoprene, a synthetic rubber with chemical stability and flexibility over a broad range of temperatures, often used in wetsuits. It is a thermoset elastomer that cannot be melted down and re-processed to make new material as the quality would be low. Wetsuits are often discarded because of visual deterioration, but have found to degrade more slowly in terms of performance than previously thought. There is a growing demand for cold- and weather-resistant products such as wetsuits and marine products due to the growing number of people participating in water sports. This is in addition to regular professional use and demand in contexts such as the UK Navy, which purchases wetsuits annually, and equivalent international

3.3 Circular innovation in recycling

applications. Combined with the lack of sustainable collection and recycling systems for this type of material, this means they are a source of pollution as they end up in landfill or are incinerated.

Circular Flow collects wetsuits at the end of life from designated collection centres. These are consolidated and sent to its factory in Bulgaria where the neoprene waste is recycled. In collaboration with the brand partner, Circular Flow designs and develops a collection of products using the recycled neoprene waste. These have QR codes to enable customers to return the item to Circular Flow for recycling at the end of life. The technology to recycle neoprene into sheets, ready to be made into new products, has been in development for 6 years. It removes any disruptors, such as zips, buttons or other plastic and metal items, from the wetsuits, which are sent to partner facilities for recycling. The process does not involve burning or melting, and no toxic chemicals are emitted.

The Wetsuits from Wetsuits programme was launched in 2017 as an innovative closed-loop recycling scheme. In 2022 Finisterre collected over 1,000 used wetsuits to give them new life, and launched its first product made from recycled wetsuits in 2025 with its partner Circular Flow after much testing and development.

Globally, an estimated 8,380 tonnes of old wetsuits end up in landfill and incineration each year, producing huge amounts of carbon emissions. With their complex material structure, they have been almost impossible to recycle due to their material complexity — a single suit can contain up to 15 different types of neoprene and/or rubber composites combined with any fabric linings to add strength and durability. Circular Flow has developed new technology and manufacturing processes that bond the particles from the shredded wetsuits without removing the textile laminate, which enables them to process 100% of the neoprene to produce a stable and durable recycled material that can be used to manufacture a wide range of new products. Every component of the wetsuits is recycled, including zips and plastic elements, generating no waste.

Infinna™ is a virgin-quality circular fibre made from 100% cotton-rich textile waste, such as post-consumer garments that are destined for incineration or landfill, reducing reliance on virgin raw materials. It addresses the challenge of what to do with the mountains of textiles waste generated globally and the desire for new and more textiles.

It takes cotton-rich textile waste of all colours that are no longer fit for use, which may include synthetics in their construction — 88% of the total must be cotton. Non-fibrous materials such as buttons and zips are removed, and the textiles are mechanically shredded into fine pieces. The cleaning phase removes synthetic fibres and dyes, and recovers the cellulose from the garment, which is abundant in cotton. This is then broken down to the molecular level, activated with urea and dissolved to create a liquid cellulose, which is dried to a powder form. Infinna™'s scientific name is cellulose carbamate fibre. Whether

3.3 Circular innovation in recycling

the item is initially a T-shirt, cardboard or rice straw, the material turns it into the same powder and, from this point, material originating from the different feedstocks can be mixed.

The cellulose powder is turned into a honey-like liquid, and impurities are filtered out. During the wet spinning process, fibre filaments are made when the cellulose crystallises and these are then cut to staple length, washed and dried. The material is then ready to be made into new yarns, fabrics and textiles.

The process provides a consistently high-quality, circular alternative to conventional fibre production aligned to cotton, viscose and polyester, for example.

Adidas designed a collection of products that could be recycled. However, it found that products were not returned at the end of life: collection, sorting and consumer returns for recycling were very challenging to implement. To understand how to move from a linear to a circular ecosystem, the brand introduced the Textile Recycling Excellence (T-REX) research project, which identified a gap: lack of communication between the different actors and operators in the supply chain. Adidas coordinated the project and managed a consortium of 13 different operators that represented the different steps in the value/supply chain.

Funded by the EU's Horizon Europe research and innovation programme from 2022–2025, the project's aim was to create a circular system for post-consumer textile waste that had the potential to be scaled. It also aimed to demonstrate sustainable and economically feasible business models for each of the players in the value chain. Technical work streams focused on collecting, sorting and chemically recycling 3 groups of materials – cotton, polyamide and polyester – which provided challenges as the systems are in their infancy.

Technologies for recycling apparel and textiles are considered the circular innovation of the future; however, while post-consumer end-of-life technologies exist, the issue is how to make a sustainable business case to ensure their use. When the T-REX project was established, it was already known that the EU lacked an infrastructure for fibre-to-fibre recycling of post-consumer textile waste that would enable a closed-loop system.

Adidas explored these challenges with the T-REX project at length and found that even if a circular economy is possible, it cannot be realised without a business case. Technically it may be possible but, on investigation, the amount of water, chemicals and energy used make the process too expensive and environmentally unsustainable.

3.3 Circular innovation in recycling

The brand found that the mono-material approach it trialled in the project for products — especially shoes — had serious limitations. While Adidas did not compromise on its core business of performance, it found it had to compromise somewhat with the design.

One barrier was the limited number of consumers returning shoes for recycling, even with a viable returns scheme in place. Textile recycling also needs a consistent volume of clean items and someone to receive, collect and sort them into different qualities. There are challenges around securing a consistent long-term feedstock supply through a returns process, which should also be supported by standardised and harmonised data.

“We need governments to put some rules in place — policy. This is why we are involved in the T-REX project, which we did to work with the European Commission on what is possible, what is not and what needs to happen if we want to make this a reality and not just a circular dream.”

**- Gudrun Messias, Director
Sustainability Direction, adidas AG**

Seasalt Cornwall, based in Cornwall, UK, is a certified B Corp company, which means it meets high standards of social and environmental impact that include transparency, accountability and continuous improvement across all areas of business. Its environmental and social targets are to increase the use of certified sustainable materials and transition to become carbon net zero by 2040.

Circularity is a business choice embedded in the Seasalt ethos, which it perceives as an intellectual innovation. The brand considers approaches towards circularity from systems-thinking, design and life-cycle perspectives. Systems thinking is lean manufacturing involving effectiveness and efficiency, which, when combined with circularity principles, shifts the language to that of business within defined systems.

Circularity is considered from a design perspective and then across the complete life cycle of its products, focusing on what value they create instead of what waste. Design decisions about what products are made from and how they are made include how they are made to serve the customer. Seasalt clothing is created to be durable, and designed for longevity and repair, a service the brand offers. Its platform has allowed it to transition and adapt from using conventional materials to organic and responsible materials, and through doing so understand what traceability and due diligence are, alongside how to innovate in buying and sourcing.

3.3 Circular innovation in recycling

Seasalt works with the Circular Textiles Foundation, which provides an Infinittee mark for recyclable clothing — providing third-party assurance that a product has been designed to be recycled without intervention. This enables Seasalt to eco-modulate the taxation that applies to its products by trying to demonstrate and authenticate that as much of the range as possible is either made from recycled content or is truly recyclable.

When sustainability is understood as being prudent with raw materials/resources, saving money, energy and transportation, it demonstrates that there is a cost-consciousness about not being wasteful. That resonates with the finance, merchandising and operational teams, which understand that leanness equates to saving money. Building a systems approach into the business model, working across the value chain, ensures circularity isn't an isolated element of the business.

Seasalt has partnered with the Salvation Army Trading Company to buy re-yarned products. It sees textile-to-textile recycling and re-yarning as key areas that can be further developed. In 2025, Seasalt piloted small projects with Beyond Retro to develop post-consumer remade denim styles. It also works with several suppliers to make patchwork-panelled individual pieces from deadstock.

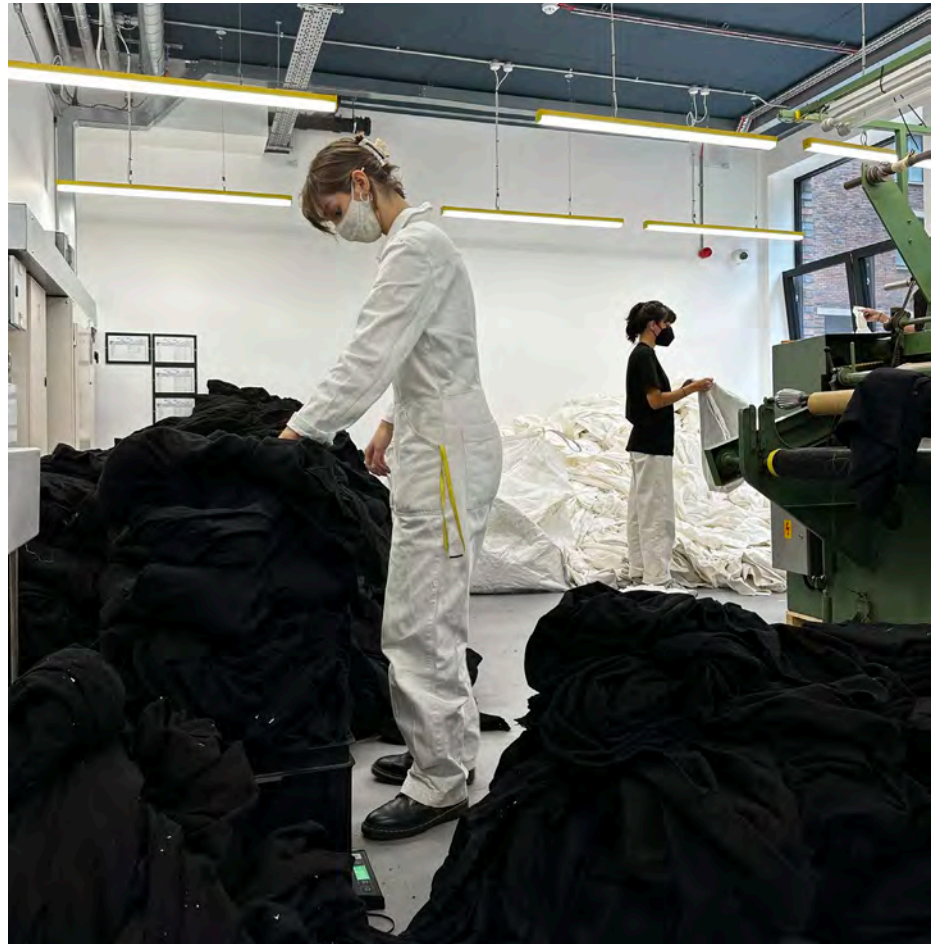
Conclusion

For textile-to-textile recycling garments to have the capability to be recycled, there are considerations to be made at the design stage, such as material choice, construction of the product and any embellishments.

Post-consumer textiles are more challenging to recycle because they can be constructed with mixed fibres and blends, be in different material conditions post-use and have unspecified dye and chemical content. With post-industrial textiles, the products have accompanying data about material content, dyes and chemicals used.

Closed-loop polyester recycling and the development of systems and technologies do exist and are evolving, but need a consistent volume of clean material to work with and make feasible. With post-industrial polyester textile waste, there is likely to be more volume of the same material, and it is easier to collect with systems and management of these within the manufacturers. Currently, there are few collection strategies operating to collect and sort consumer textile waste. Additionally, where trials have taken place, it has been identified that the consumer is confused as to what can be accepted. The widely variable material content, condition of the materials and chemicals within the textiles add to the complexity.

3.3 Circular innovation in recycling



**Material sorting within
FibreLab facilities**

Credit: Mooka Srisurayotin, FibreLab

Textile recycling needs to be supported by a business case — even though it may be technically possible, it is unlikely to progress without a viable economic business model. Additionally, there needs to be balance from an environment perspective between the amount of water, energy and chemicals used in the recycling process.

“We need to design products that are kinder to the planet — built smarter, built to last and built to be fixed. The real win isn’t recycling; it’s never needing to recycle in the first place. Every time we repair or reuse something, we’re saving the energy and resources it would take to make something new from scratch. Recycling and disposal aren’t solutions — they’re expensive last resorts. Keep products alive longer, and we all come out ahead.”

**- Peter Needle, Founder, Segura Systems and
Board Advisor & Head of Sustainability, Oii.ai**

3.3 Circular innovation in recycling

Extended producer responsibility (EPR) money could be used to invest in collection and sorting programmes. There needs to be investment in the infrastructure for fibre-to-fibre recycling. Government needs to put rules in place and create policy and legislation to have set standards to allow this innovation to scale.

A key factor that affects recycling of textiles, particularly post-consumer textiles, is the capability to sort the items. Currently there is no EPR money being collected to pay for the collection of unwearable garments, to facilitate this. Consumer confusion in sorting their unwanted garments and low engagement with return and collection schemes has hindered and obstructed take-up. Due to the complexity of mixed-fibre content in the pieces, unknown use of dyes and chemicals, and differentials in wear and tear, this is a problematic and complex area. In addition, garments often have disruptors that impede the process, such as buttons, zips and Velcro, which need to be removed before recycling.

Designing for longevity and durability, as well as pre-loved and vintage markets, keeps products in circulation for longer. Recycling is considered a last resort by some interviewees.

Brands are not the barrier to circularity; the barrier is economic issues such as taxation and profit margins. To bring this barrier down, legislation and consistent, enforceable standards will be necessary.

“Where innovation is going to make the largest impact for the fashion and textile industry is recycling innovations around non-virgin raw materials. If we utilise non-rewearable post-consumer waste, we have a valuable non-virgin source of new raw materials. There would need to be considerable investment in manufacturing and technology in recycling and, additionally, in the follow-on supply chain with regards to spinning for us to capture most of the value in the UK for those new materials. We need investment in the infrastructure for fibre-to-fibre recycling, and plans of how we are going to have regional and localised automated sorting facilities and preprocessing facilities that then feed into a series of ecosystems of fibre-to-fibre recycling. I think the biggest challenge is infrastructure and investment through public and private innovative and collaborative projects.”

- **Jaki Love, Director of Innovation & Sustainability,**

UKFT

3.4 Circular innovation in business models

Summary

The scope of the research mapping **circular innovation in business models** sourced through this research to date, drawing from the Matrix of Circular Innovation Industry Practices (ref.pp 158), is demonstrated in the following ways: repair businesses, repair as part of the design of the product, design for longevity and durability using quality materials and processes.

“The current innovation activity that I think is important is repair and alteration. We have a massive shortage of repair businesses and it’s a huge opportunity for small businesses. Setting up repair and alteration businesses, things to prolong the life of garments, could make a huge difference in terms of people’s ability to keep items in circulation longer, or to use an item they have purchased [that doesn’t fit], because industry-standard sizing does not match all people’s dimensions/proportions — we are not all standard sizes. [Imagine being] able to take a hem up or reshape a garment because your waist happens to be bigger or smaller than your hips, or a different proportion to what somebody else decided was right.”

- **Lisa Macintyre, Associate Professor, School of Textiles & Design, Heriot-Watt University**

The Matrix of Circular Innovation Industry Practices identifies 135 circular/sustainable apparel and textile innovations, which include **16** examples of **circular innovation in business models**. The following examples briefly outline a sample of the range of innovation.

Petit Pli has developed a model for expandable clothing and accessories, primarily for children. Essentially, the clothing grows with the child. **Lone Design Club** is an online retail platform that encourages online brands into physical spaces so consumers can discover new designers and interact with the products. Both the physical and digital platforms encourage consumers to discover and shop from independent brands with traceable and mindful practices.

3.4 Circular innovation in business models

Phoebe English is a slow-fashion brand that uses a circular-design approach to create high-quality, sustainable clothing from pre- and post-consumer textile waste with the planet's finite resources in mind. It produces limited runs and promotes conscious consumerism. **Save Your Wardrobe** is a platform that streamlines the post-purchase ecosystem, covering repairs, care, alterations, warranties, logistics, exchanges, compliance, customer experience and data reporting. It is a modular end-to-end solution that digitises and streamlines aftersales operations, enabling brands to scale repair, care and alteration services. **Sojo** aims to make clothing repairs mainstream and redefine what it means to value clothes. Repair processes can be digitised and scaled using its in-house operations. **Hiut Denim** makes quality jeans that are designed to last. With a yearly production limit of 10,011 pairs, it believes in scaling impact without scaling size — a no-growth innovative approach. **Rey House** produces well-made, well-fitting, durable clothes from good-quality materials for 40-60-year-old women. It has a unique sizing system that represents real women's sizes. **Clothes Doctor** aims to reduce clothing waste through clothing care. Products use natural ingredients and essential oils to extend their life. It also offers repair and alteration services, and customers can return lids, sprays and scent bags for a discount on their next order.

For the purposes of this research, the following **6 case studies** briefly evidence different aspects of **circular innovation in business models** for the fashion, wider apparel and textiles industry, that have gone through a significant level of development:

Case studies

Maria Grachvogel is a small-scale design and production company for women's apparel that has been in operation for over 30 years. It implemented a sustainable business model from the outset, with each garment designed for longevity and to have a timeless lifespan, with the potential to be repaired in house and passed on.

Its ready-to-wear and bespoke products are well crafted using good-quality fabrics from a limited range, and the company offers repair and alteration services. Building repair into the business model is an additional revenue stream but not an add on, as this allows products to remain in use for longer. Clients invest in these pieces, purchasing them at full price (there is no discounting of unsold stock). As fewer products are produced, customers know they are not going to get a discount, so the garments are treasured and have greater exclusivity. Customers know the garments are physically, as well as emotionally, durable and can be worn for years as they feel timeless, beautiful and appropriate for the individual. (Emotional durability, a term coined by design academic Jonathan Chapman, refers to a garment's ability to generate a long-lasting emotional connection with the wearer, leading them to take care of it, repair it and keep it for a long period of time.) In thinking about a garment from a longevity perspective, the brand's innovative design process with a client considers how garments are constructed,

3.4 Circular innovation in business models

how they might be worn and, therefore, how they might be cared for over time.

The brand's supply chain is closely combined with on-demand production: this translates into buying less fabric, with less wastage, a reduction in shipping from factories and fewer staff, which reduces all associated costs. Operating the business in this way for over 10 years has enabled quality control and the ability to adapt and move at pace. On-demand production can be done to scale but the system needs to change — the way that most production is currently set up is not for this type of manufacturing. Maria Grachvogel, however, tries to match supply and demand.

The relationship between price and value for consumers could be reshaped by a shift in values that places greater importance on clothing. While clothes could become more expensive, customers would purchase fewer items, choosing higher-quality, long-lasting, timeless pieces. Any financial incentives to stop people consuming would naturally slow down overproduction, which is necessary for better, more sustainable products, and for people to re-evaluate their consumption.

By rethinking structures and designing innovative/creative new systems, the apparel industry can simplify complex supply chains and production methods. The industry must want to make this shift, which would be helped by policy changes — there should be some mandates on minimum quality levels and how long items should last. Creativity should be at the forefront of a collaborative approach between suppliers, industry, designers and makers. The consumer needs to buy into these kinds of models too, so there must be policies in place that fundamentally change behaviour.

3.4 Circular innovation in business models

The business has grown sustainably via word of mouth and recommendations, with garments passed on by the user, e.g. from mother to daughter.

John Smedley has been manufacturing high-quality crafted fine knitwear at its Derbyshire factory since 1784. Its business structure integrates a waste-management system and its products predominantly use natural mono-material types of quality yarn — merino wool, sea island cotton, cashmere and silk. Historically, it was a vertical company, purchasing the raw material, which was dyed in Bradford, spinning it into yarn, and then knitting the garments at its factory ready for retail. Today the factory continues to produce knitted garment panels, linking them together into garments. It uses high-quality yarns purchased directly from long-established spinners. It has replaced its wash and



John Smedley recycled yarn
Credit: Alys Tomlinson

dye house with state-of-the-art dyeing facilities, which will significantly reduce energy and water usage. Rather than outsourcing packaging, John Smedley packages products for online purchases in house using 100% recyclable, plastic-free materials produced in the UK and made from FSC-certified sustainably sourced pulp.

The company produces enough product with limited waste to retain an eco-balanced business model. It has always tried to be circular, recognising that there is value in waste as resource. For centuries it has built waste collection into its business, separating waste streams and selling them on, and continues the practice today. Waste, or resource, is always created in the spinning and knitting processes through short fibres, oil or flaws in the knitted panels. It can be traced back to the source because the company is compliant with chemical and processing regulations, which aids recyclers. Central control of recycling methods would facilitate this further and encourage others.

3.4 Circular innovation in business models



John Smedley Harcourt jumper in Hemingway blue
Credit: John Smedley

Recycling in a circular way within the business incurs a cost because

waste must be broken down and created into something that can be spun, then spun into something that can be processed. The process must not add any water or chemicals; it must almost have a neutral footprint, which can be restrictive and is a challenge the company aims to overcome.

John Smedley is interested in revive and repair systems as they can be added to life-cycle analysis data, which shows consumers, for example, that a product can last 150 washes and will still be as good on its 50th or 100th wash as it was on its first. Although signs of wear and tear may appear, the product is high quality, resilient and can be repaired if needed. While buying new products maintains the business model, other models may be adopted, such as a take-back scheme. Here the quality garment is revived and sold at a different price point for another consumer to wear potentially for another 2 to 3 years, owing to the quality of the original product.

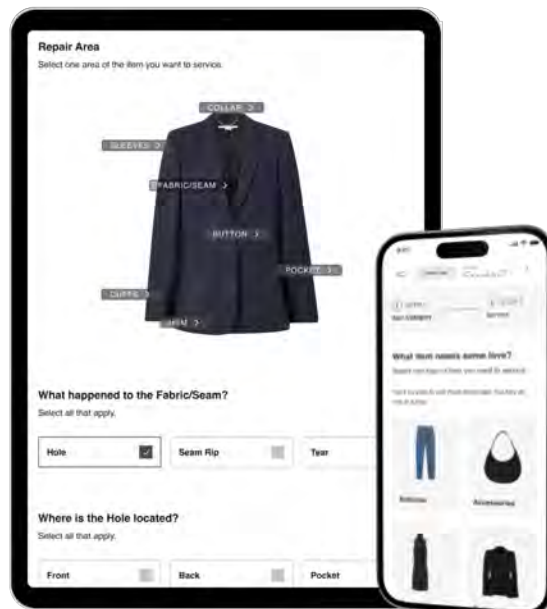
My Wardrobe HQ is the UK's first fashion rental marketplace platform for contemporary and luxury womenswear. Launched in 2019, it aims to extend the lifespan of products through rental, resale and subscription,

3.4 Circular innovation in business models

to reduce the number of items ending up in landfill. Customers can also purchase items and relist them on the platform when no longer wanted. It stocks clothes and accessories from over 500 high-end designers.

The brand believes rental is the solution to sustainable fashion consumption, and its business model is driven by sustainability criteria. Customers looking for more socially conscious and sustainable ways of consuming fashion can do so by giving new life to the platform's pre-loved and past-season goods.

My Wardrobe HQ's business model encompasses several strands:



Save Your Wardrobe app
Credit: Save Your Wardrobe

extending a garment's life cycle by up to 15 times; providing an additional way for brands and retailers to sell unsold pieces at the end of the season or prototypes that didn't make it to production; and encouraging customers to buy better and less through education, and recognise that better quality items are often made with more stringent processes that have less of an environmental impact. My Wardrobe HQ also plants a tree for every rental and sale to carbon off set every transaction. Returned items are dry cleaned by its partner **Blanc Living** with cleaning technology that uses only non-toxic, biodegradable detergents and water.

It also supports **DIRT**, a charity that works to support soil regeneration through biodynamic farming —this type of regenerative agriculture doesn't use chemicals and creates its own compost to fertilise the soil, making it healthier and nutrient rich.

3.4 Circular innovation in business models

Paynter Jacket Co's business model is to design and produce limited-edition jackets that are sold in batches 4 times a year. The label on each product is hand-numbered in the order in which they are sold, and each jacket takes approximately 6 to 8 weeks to make. The slow-fashion brand is based in east London and designs sustainable products that are handmade in a small family-run factory in Portugal. Opening up orders for new garments just 4 times a year means the company reduces wastage by only making what it has pre-sold, which means



Paynter Jacket Co chore jacket
Credit: Paynter Jacket Co

it never over-produces or has surplus stock. The model it follows is intentionally restrictive, allowing time to design, test and make limited-edition, quality garments that are durable and functional. Each batch consists of 1 style, in a range of colours across a full size range.

Its virtual platform takes customers behind the scenes, showing products being made in weekly video updates from the factory. The company says that if it made large collections multiple times a year, it would not have time to test the prototypes to understand where improvements could be made, and the customer engagement experience would be compromised. A team of 2 running the business means that every aspect, from design to customer service, is part of their working day. This hands-on approach gives a direct insight into customer requirements and preferences.

From a product perspective, operating a slow business means the brand can work on getting the product right before it is put into production. If a product needs another round of samples to improve the quality or fit, it can delay the launch until it is ready and there is no pressure from investors.

3.4 Circular innovation in business models

Marks & Spencer (M&S), a large-scale UK clothing retailer established in 1884, has developed a Family Matters Index. Based on UK research through interviews with existing and potential customers, it provides a granular understanding of people's lives and their priorities to help inform development of a more sustainable business model. One of the strongest concerns raised by consumers was how to address clothing waste. Consumers are increasingly looking to retailers to offer more services to help them lower their carbon footprint; through repair, a take-back scheme and use of recycled and/or better-quality cotton or recycled polyester materials. M&S also found that only 10% of those questioned felt confident enough to make their own repairs, as these skills have been lost over time. Consequently, it decided to integrate a repair service into its business model, developing a new scheme in collaboration with London-based startup Sojo (established in 2021), with the mission to make tailoring and repairs more accessible. Sojo has a team of over 20 people offering door-to-door tailoring and repairs for clothing, and is expanding nationally, often through partnerships with online and physical retailers. Sojo's business model includes the development and growth of relevant repair and making skills.

M&S Restored by Sojo has been well received, with repeat custom due to the good quality of the repairs. Increasing the longevity of products goes hand in hand with the quality and durability of product M&S wishes to be recognised for producing. M&S and Sojo have also developed care and repair videos that are easily accessible on its website, to encourage and inform customers about alternative repair methods. This initiative is part of M&S's wider strategy to help drive a circular economy and support its customers to achieve this.

John Lewis has invested significantly in its Circular Economy team positioned within the group's wider John Lewis and Waitrose Ethics and Sustainability team (approx. 35 people). Recognising the increasing necessity for interdisciplinary skills to help navigate sustainability issues across global supply chains, the Circular Economy team's skill set unusually spans design, STEM and economic capability to help inform the group's objectives. The John Lewis business model encompasses rental, repair and pre-loved provision. The business is substantial and also includes white goods reuse and recycling within the supply chain.

In terms of clothing, while vintage concepts have had significant influence, changing how people consume and revising their approaches to pre-loved products, from a business perspective John Lewis found that it cannot compete with vintage prices and supply mechanisms. It is currently exploring whether pre-loved could work at the mid-price point, which is challenging. Importantly, a conscious aim is keeping the sustainable business model simple, with a focus on making good-quality products and using better materials that last longer, so that customers will value products and pass them on. Digital Product Passports are considered crucial to engaging with customers about how to look after clothes, from storing to washing, in addition to the John Lewis repair service.

John Lewis's circular business model is increasingly centred around better design and material choices, with a focus on recyclability and certification from the outset. For example, it is using monofibres/

3.4 Circular innovation in business models

materials, moving away from material blends towards fibre-to-fibre recycling, and reducing unnecessary trims that make product care and recycling more challenging. For John Lewis products to meet circular design criteria, they either need to be suitable for recycling based on recyclers' parameters, or they need to fall into recycled content standards, underpinned by durability standards. For John Lewis, design needs to come first through elevation of the product, people's perception of the brand and trust that the brand develops quality products.

Conclusion

Circularity and sustainability is a business choice and an intellectual innovation. The key points regarding innovation in business models are to design for longevity intentionally from the outset, make a good-quality product and design for repair and reuse, building these initiatives into the business model and ensuring products are emotionally and physically durable.

Lean manufacturing, on-demand production done to scale and systems thinking are required to shift circularity to efficiency and effectiveness. Design and understanding the life cycle of the product are also critical.

Through creating a sound central business model that businesses can adapt to their own methods, providing they meet set criteria and with cultural values embedded within businesses, consumers and manufacturers could curtail over-production and over-consumption. Funding and policy to implement these initiatives is imperative.

4 Testing industry perception of circular innovation

Industry circular fashion and textiles workshop: testing circular innovation

Two workshops were designed to test industry perception of circular innovation and engage industry expertise directly in the research process, ensuring that the emerging findings from the wider research are tested against real operational conditions. The workshop aimed to explore how circular innovation is currently being understood, implemented and operationalised across the fashion, wider apparel and textiles industry.

It is currently often presumed that all circular innovation is sustainable innovation and therefore “good” for people and planet, but this is not necessarily a given. Rather than automatically treating circular innovation as positive, attendees were instructed to maintain an open approach, allowing them to deploy their individual and group interdisciplinary skills to interrogate whether fictitious examples of circular innovation work or not from their perspectives, and identify where unintended consequences or system barriers limit potential innovation and impact.

The purpose of the workshops was to:

- Explore what is meant by “circular innovation and sustainability” in practice: how it is defined by different actors, where it is being applied and whether common approaches are capable of delivering sustainable environmental benefit.
- Gather evidence from the industry on the feasibility, scalability and limitations of these approaches, in order to inform future research priorities, funding decisions and policy interventions.

Following the pattern of approach outlined in this report, the workshops focused on 4 circular innovation themes:

- **Circular innovation in material design**, examining how decisions made at the design stage shape durability, repairability, recyclability and overall system performance.
- **Circular innovation in material sourcing**, considering the implications of fibre choices, supply chain structures and sourcing strategies for circular outcomes.
- **Circular innovation in recycling**, covering the realities of existing recycling systems, including technical issues, infrastructure requirements and challenges of scale.
- **Circular innovation in business models**, valuing creation, capture and retention across product lifecycles.

4 Industry perception



Industry circular fashion and textiles workshop: Testing Perception of Circular Innovation
Credit: Adam Razvi

Prototype workshop 1: February 2025 (30 participants)

A prototype workshop at the University of Leeds provisionally explored how participants perceived and evaluated selected examples of circular and sustainable innovation in the fashion and textiles sectors. The workshop was flexibly designed as a pilot method and an exercise, testing how different stakeholder groups might make sense of circular innovations when presented with minimal context. It aimed to improve understanding of the assumptions, criteria and uncertainties that shape current knowledge of circularity in practice.

Thirty participants took part in a short session, drawn from a diverse mix of academics, PhD researchers and practitioners with direct or adjacent industry experience. Participants were randomly convened across 3 groups, with each one containing a broad mix of perspectives. Attendees were invited to share their professional skills and experience with the group (as opposed to only providing job titles, which rarely describe individual skills and experience). The diversity of the participants' backgrounds helped shape the workshop discussions, bringing together technical, economic, social and systems-level viewpoints. A mapping of participants' skills was captured, helping reflect how different forms of expertise may influence the ways in which circular innovation is assessed and prioritised.

4 Industry perception

Participants were introduced to 4 circular innovations positioned in the emerging matrix, with objective explanatory information. This was designed to elicit participants' own assumptions, questions and insight into how circularity is interpreted in the absence of detailed supporting data, using company information available on relevant websites. Across each group, participants discussed each innovation and recorded observations, comments and questions. To support the evaluation, they were asked to apply a traffic-light system — red, amber or green — across 4 areas of circular capability: economic viability (profit), environmental impact (planet), social considerations (people) and scalability. Participants reviewed the multiple and competing conditions required for circular innovations to succeed in practice, based on their own individual and group expertise.

The prototype workshop was a data-gathering exercise highlighting how interdisciplinary expertise may shape perceptions of circular innovation, and the value of a framework — for example, a traffic-light system enabled structured and open interdisciplinary discussion. The prototype workshop overall provided insight into the make-up of those participating, which directly informed the more formal design of a subsequent workshop.



Preliminary prototype workshop, February 2025
Credit: University of Leeds

Industry workshop 2: Testing Perception of Circular Innovation, December 2025 (31 participants)

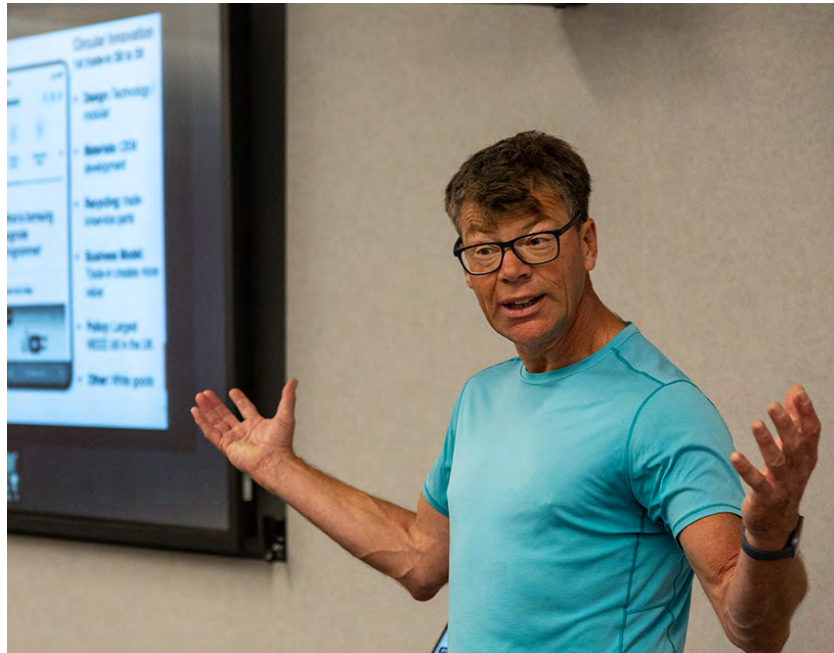
Research design

Building on the learning from the initial prototype, a second workshop was designed to provide a targeted, industry-specific lens on circular innovation. This workshop was conducted with 31 participants drawn primarily from UK-based small and medium-sized enterprises (SMEs) and wider industry organisations operating across the UK textile,

4 Industry perception

apparel and materials sectors. Participants were purposively invited to ensure representation across a range of textile and apparel disciplines, organisational sizes and geographic regions, including design, material sourcing, production, sustainability and recycling.

The follow-on workshop was designed to focus on insights accrued by introducing a commercially led, practitioner critique of circular innovation themes.



**Mark Hodgson at industry workshop 2:
Testing Perception of Circular
Innovation, December 2025**
Credit: Adam Razvi

Workshop structure

An external facilitator, Mark Hodgson (pp. 171), was selected to present the workshop. He has extensive experience in circularity and sustainable business practices across multiple global brands and sectors, including apparel. His role brought an intentional commercial, industry facing and non-academic perspective to the session, distinct from the academic framing of the wider research programme, and prototype workshop. Having guided numerous organisations through the implementation of circular economy strategies enabled him to facilitate the workshop effectively, support balanced discussion among participants and ensure that the exploration of circular innovation was business relevant.

The workshop opened with an introductory presentation, drawing on 5 circular innovation case studies from sectors beyond apparel and textiles. These examples were framed across the 4 circular innovation thematic areas and highlighted how circular innovation is shaped by regulation, customer drivers, operational change and strategic business thinking in other industries. This broader framing was intended to challenge conventional apparel-centric assumptions and encourage participants to consider transferable models and alternative pathways to scale.

Global electronics manufacturer (electronics)

- Looking to improve customer retention and reduce e-waste costs and material risks. Operates in a strong regulatory environment.

Circular innovations

- Material design for repair, enabling components to be swapped, repaired or upgraded.
- Trade-in and take-back business model to retain product value rather than losing assets at point of sale, allowing a shift from one-off sales to ongoing customer relationships, increasing loyalty and lifetime value.

UK stairlift manufacturer (mobility aids)

- Global exporter of stairlifts, which are highly durable, safety-critical products with long service lives, typically under-utilised and often discarded despite high residual value. Strong regulatory and safety constraints in markets.

Circular innovations

- Design for durability and material redesign to enable disassembly, refurbishment, reuse and recycling.
- Introduction of refurbished/reconditioned product lines business model to shift towards value retention across multiple life cycles rather than single ownership, allowing a multimarket reuse strategy.

UK commercial tyre retreader (material)

- Specialist in remanufactured truck tyres, facing price pressure from fleets focused on cost reduction.

Circular innovations

- Material redesign of tyres for fuel efficiency rather than longevity to address the real customer problem of fuel cost rather than tyre cost, and reducing overall carbon and operating costs.
- Remanufacturing and recycling loops enabled by full control of tyre recovery.
- Tyres-as-a-service business model for supermarket fleets, providing operating tyre fleet management service for customers.

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Bandvulc case study presented by Mark Hodgson at industry workshop 2, December 2025
Credit: Bandvulc



UK car manufacturer (automotive)

- Has a radical approach to car ownership, emissions and material use, driven by recognising that selling cars drives premature obsolescence and material loss.

Circular innovations

- Ultra-lightweight material design and extended design life, with modular components designed for return to suppliers. Strong incentives for suppliers to design for durability, recovery and reuse.
- Product-as-a-service business model, with vehicles always leased, never sold, including developing material leasing rather than ownership.



Riversimple case study presented by Mark Hodgson at industry workshop 2, December 2025
Credit: Riversimple

UK organic mattresses, beds and bedding manufacturer (interior product)

- Manufactures high-quality, organic, eco-fibre, non-toxic mattresses and beds as an alternative to conventional mattresses, which are difficult to recycle and chemically intensive.

Circular innovations

- Products are derived from natural material systems, with organic wool, natural latex.
- Material design for disassembly – components can be separated and recycled.
- Mattress and Bed for Life™ business model, which includes refurbishment, refresh or trade-in and donation of branded mattresses to UK-based charities. Services aligned with integrated reverse logistics using its own delivery network.
- Local sourcing and manufacturing, supporting regional farming



Naturalmat case study presented by Mark Hodgson at industry workshop 2, December 2025
Credit: Naturalmat

and skills.

The facilitator provided a global perspective on the environmental issues now apparent regarding the fashion, wider apparel and textiles industry, in particular, to illustrate how the consequences of overproduction and disposal are displaced rather than resolved as an environmental and social burden elsewhere. Thus, circular innovation can be stated in how value, capability and responsibility are distributed across global systems. However, as the industry is such a multi-faceted,

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multi-actor, global system, scaling circular innovation requires multiple changes across it.

This was followed by facilitated roundtable discussions and analysis of 4 hypothetical case studies, delivered across 2 x 1hr sessions. Attendees were pre-assigned to 3 interdisciplinary groups and tasked with evaluating the case studies. These were developed to prevent GDPR breaches and minimise bias associated with real companies, while still reflecting plausible and current circular innovation scenarios aligned with the 4 Back to Baselines thematic areas:

- **Hypothetical case study 1** — Circular innovation in material design: bio-based composite material development.
- **Hypothetical case study 2** — Circular innovation in material sourcing: mono-material performance apparel.
- **Hypothetical case study 3** — Circular innovation in recycling: recycling manmade textiles.
- **Hypothetical case study 4** — Circular innovation in business models: premium fashion rental and life extension.

Participants independently reviewed each case study for 10 minutes before engaging in a facilitated group discussion to identify perceived strengths, limitations and areas of uncertainty. Feedback was documented, anonymised and subsequently categorised according to participant discipline, industry sector, geographic location and business size, using the UK Government's definition of an SME (an enterprise with fewer than 250 staff and less than or equal to £44 million in annual turnover or a balance sheet total of less than or equal to £38 million).

Following the documented discussions generated by the 4 case studies, an invited industry panel discussion was held to further integrate perspectives from both large and small organisations, and to connect workshop insights to the wider research agenda. The panel comprised **Simon Platts, Responsible Sourcing and ESG consultant and founder of SP&KO; Hasna Kourda, CEO and Founder of Save Your Wardrobe; Maria Grachvogel, Founder and Creative Director of Maria Grachvogel; and Gudrun Messias, Director Sustainability Direction at Adidas**. Each panellist selected 1 circularity theme for discussion, reflecting on its relevance to their professional experience and organisational practice.

Panellists were asked to discuss key barriers to scale, identify conditions necessary to enable industry change and propose recommendations for progressing circularity across the sector. The discussion was recorded and transcribed, with analysis undertaken to extract cross-cutting themes and insights to inform the overall research findings.

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Fig. 2

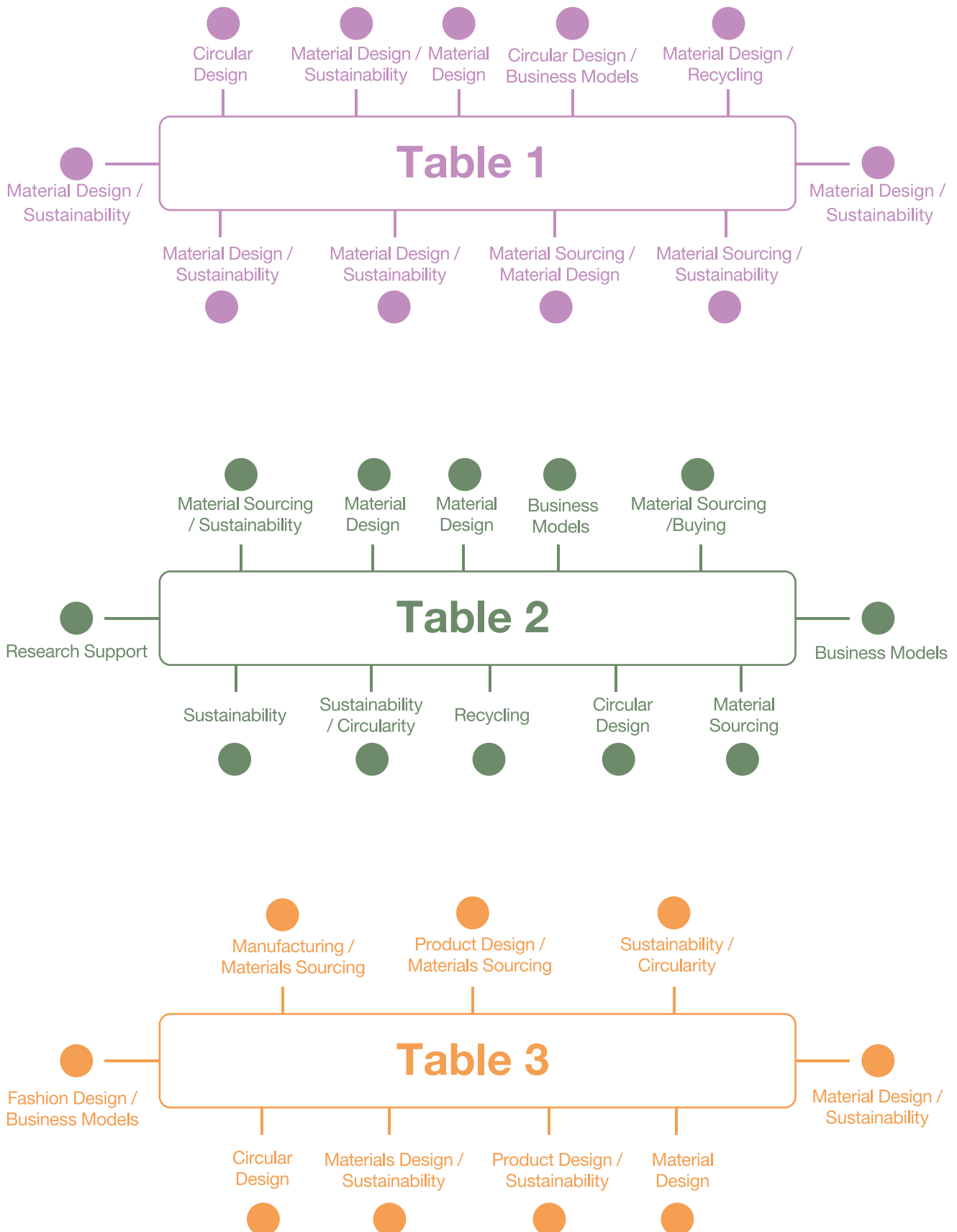
Table showing background information on industry attendees

Research support	Professor Jane Harris, Dr. Sheila Clark, Sally Denton, UAL FTTI, Leah Coxon, University of Leeds, and Mark Hodgson, QSA Associates.			
Skillset/discipline	Company type	Business size	Location	Table
Sustainability	Footwear	Large	Germany	Green
Sustainability/Circularity	Fashion	Large	London	Green
Recycling	Recycling	Small	Cheshire	Green
Circular design	Uniform	Medium	West Midlands	Green
Material sourcing	Deadstock fabric sales	Micro	London	Green
Material sourcing/Sustainability	Reuse	Small	London	Green
Material design	R&D	Micro	London	Green
Material sourcing/Buying	Fashion	Small	London	Green
Material design	Sustainability	Micro	London	Green
Business models	Luxury	Micro	London	Green
Fashion design/Business models	Fashion	Small	London	Orange
Manufacturing/Materials sourcing	Knitwear	Large	Derbyshire	Orange
Product design/Materials sourcing	Uniform	Medium	Cheshire	Orange
Sustainability/Circularity	Circularity	Small	London	Orange
Circular design	Upcycling	Micro	London	Orange
Materials design/Sustainability	Drying and finishing	Micro	London	Orange
Product design/Sustainability	Fashion	Micro	London	Orange
Material design	Traceability	Micro	London	Orange
Material design/Sustainability	Fashion	Medium	London	Orange
Material design/Sustainability	Fabrics	Micro	London	Pink
Material design/Sustainability	Drying and finishing	Micro	London	Pink
Material design/Sustainability	Fashion	Small	London	Pink
Material design/Sustainability	R&D	Micro	London	Pink
Material sourcing/Material design	Fabrics	Small	London	Pink
Material sourcing/Sustainability	Deadstock fabric sales	Micro	London	Pink
Circular design	Recycled footwear	Small	London	Pink
Material design/Sustainability	Consultancy	Micro	Leicestershire	Pink
Material design	Antimicrobial fabric finishes	Small	India/London	Pink
Material design/Recycling	Textile recycling	Micro	London	Pink
Circular design/Business models	Paint	Large	London	Pink

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Fig. 3

Workshop participants, showing interdisciplinary skills at each table



Industry circular fashion and textiles workshop: Testing Perception of Circular Innovation
Credit: Adam Razvi



Hypothetical case study summaries as examples for discussion

Hypothetical case study 1 — Circular innovation in material design: bio-based composite material development

SME converts low-value agricultural residues into bio-based composite sheet materials using circular design principles. Biomass from regional processors is transformed into engineered composites intended for reuse and mechanical recycling. Operations span several EU countries, with headquarters in Hamburg and core fabrication in western Poland. The material combines plant fibres, bio-based binders, recycled polyester or lyocell backings, and a partially biogenic coating, resulting in 65–80% renewable content. Sheet casting occurs in Poland, with optional finishing in Portugal and backing production in Austria or Italy. Annual output of 80–120 tonnes, which can be scaled to 250–300 tonnes. The materials support industrial composting of biodegradable fractions and are used by fashion, interior and mobility sectors seeking lower-impact alternatives.

Hypothetical case study 2 — Circular innovation in material sourcing: mono-material performance apparel

SME designs mono-material activewear using circular design principles. A team of 8-15 people develops technical garments made from 100% recycled polyester or nylon, with trims and fasteners selected to

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maintain fibre compatibility. Engineered knit structures provide stretch without elastane, and modular construction enables replacement of high-wear components. Certified domestic manufacturers handle production, while a take-back programme offers store credit for returned garments. Items are refurbished, recycled or downcycled based on condition, with mono-material composition allowing mechanical or chemical recycling into new yarns. Garments typically last 3 to 5 years. Annual production totals 8,000–10,000 units, with 1,500–2,000 returns; roughly 60% are recycled into new fibre streams for continued circularity.

Industry circular fashion and textiles workshop: Testing Perception of Circular Innovation
Credit: Adam Razvi



Hypothetical case study 3 — Circular innovation in recycling: recycling manmade textiles

SME specialises in mechanically recycling polyester textiles within circular supply chain and recovery models. Working from a central European facility, a 30-person team processes post-consumer garments, home textiles and clean industrial scraps sourced from Western European partners. Automated NIR sorting ensures polymer purity before materials undergo shredding, washing, melt filtration and re-extrusion into textile-grade rPET chips or pellets. Optional yarn spinning is completed through partners in Italy or Spain. The system diverts PET textiles from landfill, replaces virgin petrochemical feedstock and recirculates internal waste streams. Producing 10,000–14,000 tonnes per year, the SME supplies mills, spinners and non-woven producers across Northern and Western Europe seeking traceable, lower impact rPET.

Hypothetical case study 4 — Circular innovation in business models: premium fashion rental and life extension

SME operating from Southern Europe combines rental, shared use and life-extension models to circulate luxury fashion items. An online platform and central fulfilment hub support, with 20–28 staff who manage logistics, garment care and customer service. Customers rent items for 5–30 days; returned garments are then inspected, wet-cleaned, repaired and recirculated. Once no longer suitable for rental, items are resold or dismantled for recycling or component recovery. The assortment includes eveningwear, tailored clothing, handbags, small leather goods and selected footwear, chosen for durability and repairability. Mono-material textiles follow mechanical recycling routes, while accessories enable hardware reuse. Operating across Italy, Spain, France and Portugal, the SME targets consumers seeking occasional high-end items with reduced environmental impact.

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Industry circular fashion and textiles workshop: Testing Perception of Circular Innovation
Credit: Adam Razvi

Circular innovation analysis across the 4 thematic areas

Analysis of the case study feedback viewed circularity not as a set of individual actions but more of a system for understanding how material design, material sourcing, recycling and business models interact — for bio-based and fossil-fuel-based materials. Across all 4 themes, participants highlighted growing concerns about trade-offs, delivery challenges and unintended consequences, suggesting an understanding of moving from idealised solutions towards operational reality.

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1. Circular innovation in material design generated some of the strongest and most consistent statements across the feedback, with polyester as a central point of concern. Participants highlighted the sector's continued dependence on fossil-fuel-based fibres and questioned whether recycled polyester addresses issues such as microfibre pollution, finite recycling loops and long-term material durability.

There was a shift away from material substitution optimism. Bio-based and waste-derived materials were discussed with caution, with participants questioning whether such materials always belong in textile systems or whether they may be diverted from more appropriate biological or local cycles. The discussion reflected a recognition that all materials involve trade-offs rather than offering straightforward substitutional solutions.



Industry circular fashion and textiles workshop: Testing Perception of Circular Innovation
Credit: Adam Razvi

Key points from participants

- Polyester is perceived to be a systemic circularity challenge.
- Polyester is a recurring concern due to:
 - microfibre pollution
 - recycling limitations
 - dependence on virgin fossil inputs.
- There is scepticism about recycled polyester as a long-term solution.
- Cautious approach to biobased and waste-derived materials.
Questions included:
 - “Should agricultural or food waste have its own circular pathway?”
 - “Are we diverting materials from more appropriate systems?”

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- Caution against material substitution optimism
 - Increasing understanding of material trade-offs, rather than “best” fibres
- Feedback reflects awareness that:
- no material is impact-free
 - choices involve trade-offs (durability vs recyclability vs impact).

2. Circular innovation in material sourcing was consistently seen as an upstream decision point where circularity either becomes possible or is effectively locked out. Participants frequently highlighted that many products marketed as “circular” are not designed with disassembly, reuse or recycling in mind, particularly where blended fibres or complex constructions are involved.

The feedback highlighted frustration that downstream recycling solutions are often expected to compensate for design decisions made earlier in the value chain. This points to a structural disconnect between design practice and end-of-life realities, with limited feedback loops between designers, recyclers and material specialists.

Key points from participants

- Many products are not designed for recycling or disassembly.
- Blended fibres and complex constructions remain a major barrier.

Frequent criticism that:

- products are not designed for recycling
- blends and complex constructions dominate.

- Frustration that circular claims are undermined at design stage.
- Circularity failure is often designed in at the outset.

Participants often stated:

- “Circularity failure is often ‘locked in’ at design.”
- “Downstream solutions are compensating for unsustainable design decisions.”
- Weak integration between design teams and recycling expertise.

This signals that:

- designers lack understanding of recycling constraints
- recycling realities are not fed back into design briefs.

3. Circular innovation in recycling was discussed as a necessary but limited component of circular systems, rather than a definitive solution. Participants had clear awareness that most materials can only be recycled a finite number of times before quality loss occurs, raising concerns over what happens beyond those loops.

Chemical recycling, while recognised for its potential to address blended or contaminated materials, was approached with scepticism. Concerns focused on energy intensity, environmental trade-offs and the lack of transparent, large-scale evidence of net benefit. Recycling was seen as dependent on infrastructure, policy and system coordination,

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rather than something brands can solve themselves.

Key points from participants

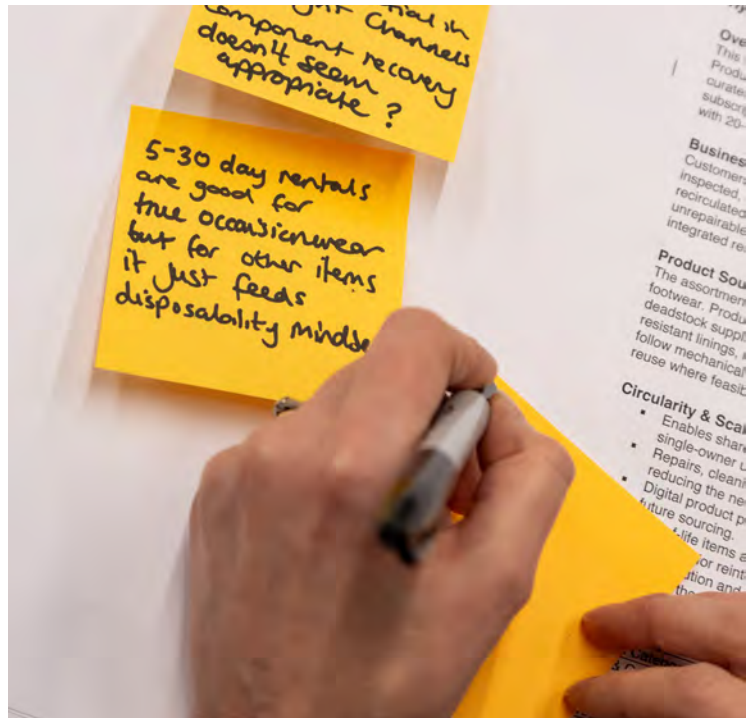
- Awareness of the limits of recycling.
Repeated questions:
 - “How many times can it be recycled?”
 - “What happens after that?”
- Chemical recycling not treated as a guaranteed solution.
Concerns raised about:
 - energy intensity
 - environmental trade-offs
 - unclear real-world impact.
- Acceptance that recycling depends on system-level infrastructure, not individual brands.
Recognition that:
 - recycling success depends on infrastructure
 - brand-level schemes cannot solve system-level gaps.
 - Strong awareness of fragmentation.

4. Circular innovation in business models focused on how circularity is operationalised in practice, particularly through take-back schemes, returns and reverse logistics. While these models were generally accepted as necessary components of circular systems, participants repeatedly questioned whether they were genuinely sustainable and reduced environmental impact or simply displaced it elsewhere in the system. Key concerns were the risk that convenience-led circular models may unintentionally reinforce linear consumption behaviours. Easy returns, for example, were seen as supporting resale and recycling pathways, but also as potentially encouraging over-ordering of new and resale items, increasing transport emissions and encouraging short product lifespans. Participants also expressed scepticism about whether circular business models can scale within existing apparel economics without structural change in the industry.

Key points from participants

- Take-back and return schemes are viewed as necessary but risky
Concern that easy returns may:
 - increase over-consumption
 - drive unnecessary transport emissions
 - undermine circular outcomes.
- Awareness of rebound effects linked to consumer behaviour
 - Doubts about scalability and financial viability at mass-market scale.
Circular models perceived as:
 - conceptually strong
 - operationally fragile.
 - Doubts about whether models can work:
 - at scale
 - at mass-market price points
 - without subsidy or regulation.

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Credit: Adam Razvi

Recognition that many circular models:

- often sit uncomfortably within volume-driven fashion economics
- risk becoming “add-ons” rather than transformational.

Cross-theme synthesis

Across all 4 themes, 3 patterns emerged. **First**, there was a clear perspective change from optimism to realism, with participants increasingly asking whether circular innovations deliver meaningful and sustainable impact at scale. **Second**, the feedback highlights the interdependence of material design, material sourcing, recycling and business models, suggesting that weaknesses in one area cannot be compensated for by advances in another. **Third**, there was a shift from sustainability claims toward evidence-based circularity, with calls for transparency, data and system-wide accountability.

The feedback highlights that circular innovation in the fashion, wider apparel and textiles sector is now less about the lack of ideas, and more about the challenge of aligning these 4 themes into coherent, mutually reinforcing systems. Circularity is understood not as a single intervention, but as a coordinated transition that spans design practice, material science, recycling infrastructure and business strategy.

1. From optimism > realism

Workshop participants were no longer asking “Is this circular?” but “Does this actually work — and, if so, at what cost?”

2. From product > system

Participants recognised that circularity cannot be solved any one factor alone. The failure points sit between the themes, not within them.

3. From claims > evidence

Questions increasingly target what really happens behind the scenes; how often; at what scale; and with what unintended consequences.

Analysis of pros, cons and queries in circular innovation across the 4 identified themes

1. Circular innovation in material design

Pros

Participants recognised that material innovation remains key to circular transition, with particular interest in bio-based and natural materials where the end-of-life impact may be lower. Digital product passports (DPP) were viewed positively for improving materials transparency. Pink-table participants emphasised the value of revisiting past innovations and craft traditions, and allowing longer development timelines so biomaterials can properly mature. Participants also recognised that materials such as polyester remain in use because of their performance, cost and supply reliability, making short-term substitution challenging.

Cons

Participants highlighted polyester as a fundamental and practical challenge, given its fossil-based origins, limited durability in certain applications and contribution to microfibre pollution. In rental and repair-based models, polyester activewear in particular was seen as not durable enough to sustain multiple use cycles, increasing the likelihood of landfill outcomes. Participants also cautioned that substituting synthetics without system-level analysis could simply shift environmental impacts, such as increased land or water use.

Queries

Questions focused on what problem material innovation is solving, and whether it genuinely reduces overall impact or merely displaces it through fibre substitution or recycling. Participants also questioned whether current research, investment and policy timelines align with the long-term development required for truly sustainable materials.

2. Circular innovation in material sourcing

Pros

Design was consistently seen as a critical enabler for circularity, particularly approaches that simplify material composition, design for repair and consider the “fate of the fabric” beyond first use. Design strategies drawing on craft, heritage practices and longer material life cycles, it was seen as offering a more credible foundation for circular innovation. Some participants found mono-material design appealing, particularly in enabling recyclability and clearer end-of-life pathways.

Cons

Participants expressed reservations about technical feasibility, especially in performance categories such as activewear and athleisure. Orange-table participants were explicit that mono-material solutions are often unrealistic in these contexts, as stretch, thermal regulation and recovery typically rely on material blends. Designs that ignore these functional requirements were seen as technically weak, regardless of circular intent. Participants also noted that design-led circularity is frequently undermined by speed, cost pressures and aesthetic demands within the fashion system, limiting its adoption beyond niche applications.

Queries

Questions focused on how circular design principles can be reconciled with functional performance and consumer expectations, and whether certain product categories may have inherent limits to circularity. Participants also queried how design success should be evaluated when durability, repair and long-term use are not easily captured by standard used metrics.

3. Circular innovation in recycling

Pros

Recycling was understood as a necessary transitional mechanism, especially given the volume of textiles already in circulation. Where recycling was described as closed-loop, EU-based and ethically controlled, participants recognised its potential to reintroduce materials into the production process in a more acceptable way. Recycling was seen as offering brands a clear intervention at end of life.

Cons

Recycling attracted scepticism across all tables. Both Green and Orange tables explicitly described some case studies as greenwashing, questioning how complex or blended products could realistically be recycled into equivalent garments. Chemical recycling was treated cautiously due to energy intensity, feedstock constraints and the

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difficulty of achieving circularity at scale. Another concern was the availability and quality of polyester feedstock. Participants questioned whether sufficient, suitable polyester exists to support new recycled-polyester business models at scale, arguing that sourcing clean, high-quality feedstock is “incredibly complicated” and may undermine feasibility.

There was also concern that recycling obscures the reality that many garments still end up in landfill, particularly when considering durability, contamination or material degradation.

Queries

Participants asked whether recycling can ever match current production volumes, and how many cycles materials such as polyester can realistically undergo before quality loss makes further reuse impossible. Questions were also asked around accountability for residual waste streams and whether recycling is being used to delay, rather than prevent, disposal.

4. Circular innovation in business models

Pros

All the tables accepted that circular business models such as rental, repair, resale and take-back represent attempts to respond to the failings of linear apparel systems. Some models were seen as potentially compelling, particularly where circularity was part of a broader brand identity rather than a bolt-on sustainability claim. There was also interest in models exploring localised or cooperative approaches, rather than viewing achieving global scale as the measure of success.

Cons

Business models attracted criticism, particularly from the Pink and Green tables. Several participants characterised the case studies as “plasters” on a fundamentally broken system, stating that many models still depend on continued production and consumption rather than addressing root causes. Recycling and rental models were particularly critiqued for preserving existing commercials while rebranding as circular.

Behavioural barriers were repeatedly highlighted, with doubts about everyday adoption of rental beyond special-occasion wear, alongside concerns about durability and repair cycles for frequently returned garments, potentially accelerating wear and early disposal. Economic viability was another major issue, with repair costs, logistics and garment depreciation potentially outweighing product value, leading to premature write-off compared to ownership models.

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Queries

Key unresolved questions centred on whether circular business models can succeed without fundamentally reducing throughput, and whether they risk legitimising over-consumption through circular narratives. Participants also queried whether hyper-local or diversified scaling models might be more viable than global rollouts, and what policy or fiscal incentives would be required to support genuinely transformative business models rather than incremental adaptations.

Workshop summary

The main commentary is not the rejection of circular innovation, but scepticism towards approaches that prioritise technical or downstream fixes without confronting systemic drivers. Business models and recycling strategies were most frequently challenged where they appeared to preserve linear logic under a circular label. Polyester functioned as a recurring stress-test, exposing tensions between durability, recyclability, feasibility and credibility. The strongest collective signal across the tables was a call to slow down, localise where appropriate, invest upstream and align education, policy and design, rather than relying on recycling or business model innovation alone to deliver circularity.

A reflection on the synthesis of tables (appendix, page 150) and sector skills: why an interdisciplinary approach to circularity matters

Across all 3 tables, participants consistently stated circular innovation, not as 4 separable challenges (material design, material sourcing, recycling and business models), but as a system in which weaknesses in 1 area cannot be compensated for by strength in another.

The value of the interdisciplinary-skills lay in exposing how different forms of expertise review the same innovation from fundamentally different risk lenses — and how those lenses surface tensions that would remain invisible in a single-discipline discussion.

- **System-critical perspectives (Pink table)** stressed material physics, thermodynamics and evidence. Their scepticism — particularly around polyester and chemical recycling — highlighted the risk of circular narratives being used to legitimise continued fossil-based throughput rather than reduce absolute impact. This lens repeatedly questioned whether claimed solutions genuinely reduce harm or merely displace it elsewhere in the system.
- **Operational and implementation perspectives (Green table)** accepted many of the same constraints but focused on what is feasible under current conditions. Recycling and take-back were stated as transitional tools rather than end-states, with emphasis on governance, infrastructure, cost and scaling realities. This group

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highlighted the gap between pilot-scale success and system-wide viability, and the danger of over-claiming progress without regulatory and financial alignment.

- **Design-led and consumer-facing perspectives (Orange table)** reframed the problem upstream, arguing that material complexity, blended fibres and opaque recycling claims undermine trust and behavioural change. From this view, durability, reparability and clear consumer narratives were seen as more impactful than downstream recyclability alone, reinforcing that many “recycling problems” are in fact design and business-model problems in disguise.

Taken together, the mixed-skills discussion revealed a core systemic risk: over-reliance on any single circular strategy — particularly recycling — to offset unresolved issues in material choice, product design or commercial incentives.

Industry circular fashion and textiles workshop: Testing Perception of Circular Innovation
Credit: Adam Razvi



It also demonstrated the strength of cross-disciplinary scrutiny. Where one group identified opportunity, another identified constraints or unintended consequences. This prevented circularity from being treated as a technical fix or branding exercise, and instead grounded it as a conditional, system-level intervention requiring alignment across disciplines, incentives and scales.

Overall, the diversity of skills sharpened the discussion, exposing where circular innovation is robust, where it is fragile and where claims of progress require closer examination.

Panel summary

Industry panel discussion:

Mark Hodgson, Lead Circular Business Partner, QSA Partners (Chair)

Maria Grachvogel, Founder and Creative Director, Maria Grachvogel (Panellist)

Hasna Kourda, CEO and Founder, Save Your Wardrobe (Panellist)

Simon Platts, Responsible Sourcing and ESG consultant and founder SP&KO (Panellist)

Gudrun Messias, Director Sustainability Direction, adidas AG (Panellist)

Tim Clark, Technical Director, John Smedley (Participant)

1. Circular innovation in material design: innovation constrained by transparency, performance and scale

Materials innovation was recognised as an area the industry has invested in heavily yet continues to face structural constraints. The panel emphasised that while new fibres, recycled materials and mono-material approaches are advancing, they are often limited by performance trade-offs, lack of transparency and insufficient demand certainty.



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Credit: Adam Razvi

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Sustainability claims and market demand can outpace verifiable supply, undermining confidence in material credentials and exposing brands to credibility risk. With the slow introduction of DPP, transparency will begin to change over time.

A key shared insight was that material innovation does not fail in the lab, it fails in the commercial marketplace. Performance requirements restrict how far circular purity can go without compromising consumer acceptance. The panel also pointed to a system problem: large brands are uniquely positioned to unlock material innovation by committing to buy at scale, thereby reducing risk for suppliers and recyclers. Without these signals, which are often lacking, innovation remains in pilot stages and at small scale.

“I think the task of bigger brands, and where I really see our role, is to give a signal to the industry. Specifically when it comes to sourcing better materials — we are the ones who can do that. We can give security to our suppliers that we, for example, will buy this recycled polyester made from textile waste; that we will buy this innovative fibre made from cotton waste. This is something we can do at scale and by making these commitments. This is also what then triggers an industry movement.”

- **Gudrun Messias**

Director Sustainability Direction, adidas AG

2. Circular innovation in material sourcing: the upstream decision that locks in circular outcomes

Design was positioned as the upstream lever that determines success or failure across all other circular themes. The panel saw design not just as aesthetics, but also as decisions that lock in durability, repairability, material compatibility and consumer behaviour from the outset.

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Well-designed products that fit properly, age well and carry emotional value naturally remain in use longer, reducing pressure on recycling systems and material supply. Conversely, poor design choices create waste from day 1, regardless of how circular downstream systems might be.

A particularly strong theme was the value of feedback loops between use, repair and design. Repair data was described as an underutilised asset that can inform better design decisions, reducing defects, returns and long-term costs. The panel acknowledged the tension between circular design constraints and creative or performance freedom, reinforcing the need for a balanced solution.

“Certainly, in the aeronautical and the car industries, they value their products. We often see the products we [in the fashion, wider apparel and textiles industry] produce as waste at end of life. We need to change our mindset, start to realise that’s a valuable asset and commodity.”

- **Simon Platts**

**Co-founder, Responsible Sourcing and ESG
consultant and founder SP&KO**

3. Circular innovation in recycling: necessary infrastructure, not a silver bullet

Recycling was discussed with realism. While it was acknowledged as a necessary component of circular systems, the panel was clear that recycling alone cannot compensate for overproduction, poor design or misaligned systems. The core challenge is not technological capability, but the lack of coordinated infrastructure, sufficient volumes and shared standards across brands.

The discussion highlighted a particular failure: technically recyclable products that cannot be recycled at scale because consumer participation is low, volumes are fragmented across geographies and recyclers cannot operate economically. This revealed a deeper systems issue: brands acting independently, each defining circularity differently, producing material streams that cannot be aggregated.

Recycling was framed as something that should sit after efforts to extend product life through design, repair and reuse. Several panellists

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implicitly challenged the industry's tendency to treat recycling as a moral offset for continued growth.

“In 202, we created a range called Made to be Remade of footwear and apparel that can be recycled and became a raw material again. We sold several hundred thousand of these products, but customers only returned a couple of thousand. That doesn't even fill a container for recyclers.”

- **Gudrun Messias**

Director Sustainability Direction, adidas AG

“New EU legislation is change the rules for fashion companies. Spare parts must be kept for at least 5 years and up to 10 years. Repairs offered for a minimum of 2 years, and crucially, repair must take priority over exchanges or refunds. It is fundamental shift in how the business has to operate and we have built the infrastructure to support it.”

- **Hasna Kourda**

CEO and Founder, Save Your Wardrobe

4. Circular innovation in business models: reframing value, not optimising waste

Across the panel discussion, business models emerged as the main reason for whether circularity can succeed at all. The panel repeatedly returned to the idea that circular outcomes cannot be delivered within business models that remain dependent on volume growth, rapid turnover and markdown-led pricing.

Rather than viewing circularity as an operational add-on, the panellists saw it as a redefinition of value creation: shifting from selling more units to keeping products in use for longer, protecting margin through durability and repair — for example, maximising apparel asset value over its lifetime, and reducing the often-hidden costs of overproduction, returns and discounting. Circular business models were not seen as idealistic alternatives, but as responses to inefficiencies already embedded in the current system.

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A recurring insight was that repair and longevity fundamentally change the economics of apparel, particularly in premium, rental and resale contexts. When products are designed and supported to last, the business case moves away from replacement and refund, toward value retention.

Conversely, where brands remain locked into short-term financial metrics, circular initiatives struggle to scale beyond pilots.

“We’ve transitioned from a regular fashion business model to something much more timeless, seasonless — which has given our customers permission to feel good about wearing their piece for longer.”

- **Maria Grachvogel**
Founder and Creative Director, Maria Grachvogel

“You can do many pilots — scaling is where it gets difficult.”

- **Gudrun Messias**
Director Sustainability Direction, adidas AG

Industry panel discussion summary

The panel’s discussion highlights that circular innovation is not constrained by a lack of ideas, but by misalignment across business models, recycling infrastructure, material systems and design intent. Progress in 1 area will quickly reach its limits without corresponding shifts in the others. The shared message was clear: circularity will only scale when the industry stops treating these themes as separate initiatives and begins managing them as interdependent parts of a single system, with value defined by longevity, coordination and real-world use, rather than speed and volume.

The panel positioned circularity as a systems redesign challenge. The tools and knowledge exist. The issue is whether the industry is willing to realign incentives, structures and collaboration models to allow circular innovation to move from exception to business as normal.

Why scaling circularity remains so difficult

The discussion made clear that the difficulty of scaling circularity does not come from a lack of innovation, intent or technical ability. Instead, it arises from the fact that circular solutions are being introduced into a system that is still designed for linear outcomes. Apparel's default operating logic remains centred on speed, volume and short-term financial performance, and this creates structural resistance to models that prioritise longevity, repair and value retention.

Economically, many circular interventions struggle because decision-making continues to be driven by intake margin, growth targets and quarterly performance rather than total system cost or lifetime value of the apparel asset to the business. As a result, inefficiencies such as overproduction, poor fit, returns and markdowns are normalised, while investments in durability, repair and transparency are perceived as additional costs rather than ways to reduce waste and support margins over time. This commercial approach limits circular initiatives to pilots or marginal programmes rather than allowing them to reshape core operations.

The panel suggested that technical barriers are often misunderstood. Some technologies for recycling, material innovation and traceability do exist, but they operate within fragmented and uncoordinated systems, making them inefficient. Products are designed differently, materials are specified inconsistently and brands define circularity in incompatible ways. This fragmentation prevents scale, particularly in recycling, where viable volumes depend on standardisation and aggregation. As discussed, even technically recyclable products fail to close the loop when return rates are low and material streams cannot be combined efficiently.

Regulatory conditions further complicate scaling. While regulation is increasingly pushing brands towards circular practices, it is not yet sufficiently consistent or aligned with appropriate infrastructure. Larger brands may have the capacity to respond, but mid-sized companies often feel the burden of compliance without the resources to adapt systems at pace.

Behavioural and organisational barriers also play a key role. Circularity requires coordination across design, sourcing, logistics, after-sales and sustainability teams, yet many organisations remain siloed and ill-equipped to manage circular systems holistically. At the same time, consumers are frequently expected to compensate for system shortcomings by dealing with complex return, repair or recycling schemes. When circular participation is inconvenient or confusing, engagement remains low, undermining scale.

“We need a connected, standardised ecosystem. When we have an ecosystem that has higher efficiency, the cost will come down. This efficiency starts from how we collect products at end of life, how they’re graded, how they’re sorted, if they can be recycled or not. Recycling technology is not the issue any more. We have a lot of technologies — there’s no reason to point to technology that’s already there. Is it perfect? No, but it can do a lot. What we need is standardisation and efficiencies and simplicity for the consumer.”

- Gudrun Messias

Director Sustainability Direction, adidas AG

What needs to shift to accelerate the transition

To move beyond pilots and incremental change, the panel emphasised the need for several linked shifts. Policy was widely seen as critical, not because regulation alone can solve the problem (such as DPP, textile EPR, ESPR) but because it can create the shared rules, standards and incentives required for coordination. Without a standard regulatory context, brands have little commercial incentive to standardise materials, product design or end-of-life pathways, and fragmentation remains.

Investment return thinking also needs to change. The challenge is less about access to capital or short-term return on investment and more about longer time horizons. Circular models often deliver value through reduced waste, lower returns and longer product life — benefits that accrue over time. Accelerating transition therefore requires longer-term thinking and a willingness to invest ahead of immediate financial returns.

Technological progress, while important, must shift away from novelty towards interoperability and scale. Rather than developing ever more bespoke solutions, the industry needs technologies that work across brands, regions and product categories. This applies equally to material systems, data platforms and recycling infrastructure.

Collaboration emerged as another key factor. Circularity cannot be achieved by individual brands — even large ones — acting alone; it

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depends on shared infrastructure, common definitions and collective action. Competitive advantage is unlikely to come from proprietary circular claims, but from participation in systems that work at scale.

Equally important is a shift in skills and mindset. Circularity demands systems thinking — an understanding of how design decisions affect repair, how materials influence recycling and how business models shape consumer behaviour. This requires new capabilities across design, commercial and supply-chain teams, not just sustainability specialists.

Finally, the panel suggested that consumer behaviour is often misunderstood. Consumers are already engaging in circular practices when systems make sense, as demonstrated by the growth of resale platforms. The task for the industry is therefore not to educate consumers into complexity, but to design circular systems that are simple, intuitive and desirable. Fundamentally, consumers want more circular solutions, but the industry is not listening or providing them.

“What’s missing is the political framework and some common rules that will enable infrastructure for a scalable circular ecosystem.”

- **Gudrun Messias**

Director Sustainability Direction, adidas AG

“Greater consumer education is still needed on the true value of a product—particularly in terms of fabric, design, and manufacturing quality. However, we are beginning to see a shift in awareness, as clients recognise the decline in quality between newer and older products. This is clearly demonstrated in the continued growth of the resale market.”

- **Maria Grachvogel**

Founder and Creative Director, Maria Grachvogel

“The key is not to over-produce. Produce for what you’ve sold and only what you’ve sold, to try and reduce the after sale and sale market.”

- **Tim Clark**

Technical Director, John Smedley

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Industry circular fashion and textiles workshop: Testing Perception of Circular Innovation

Credit: Adam Razvi



A collective call to action for industry

The discussion pointed towards a clear, collective call to action. The industry must define how it understands value. Instead of equating success with speed and volume, value needs to be measured in longevity, use and retained apparel worth. This change underpins the other circular outcomes.

Design must be recognised as the key leverage point. Waste cannot be avoided at the end of a product's life if it has been designed in from the beginning. Products that fit well, last longer and are repairable, naturally reduce pressure on materials and recycling systems.

The industry must also move beyond the point of just transactional sale. Repair and reuse feedback from the use-phase need to become core to operational functions, and is essential for improving design, reducing defects and lowering long-term costs.

Transparency and traceability must be treated as key aspects, not optional enhancements. Without visibility in materials and supply chains, claims of circularity are undermined and systems cannot be optimised.

Most importantly, brands must act collectively. Circularity will not scale through isolated pilots or competitive positioning around sustainability stories. It will scale when companies align on standards, share infrastructure and accept that systemic change requires cooperation as much as innovation.

“We are trying to work in isolation, and this all goes back to education and knowing where your products from and what you can do to actually make it better. I think it’s all about education and working together.”

- **Tim Clark**

Technical Director, John Smedley

A recurring insight was that repair and longevity fundamentally change the economics of apparel, particularly in premium, rental and resale contexts. When products are designed and supported to last, the business case moves away from replacement and refund, toward value retention. Conversely, where brands remain locked into short-term financial metrics, circular initiatives struggle to scale beyond pilots.

The panel’s key message is that the question is no longer what needs to be done, but whether the industry is willing to realign its incentives, structures and behaviours to allow circularity to move from the margins to the mainstream.

Industry workshop conclusion

This workshop demonstrates that **circularity, in and of itself, is neither synonymous with sustainability nor universally viable. Across all discussions, case study evaluation, table feedback and panel reflection, the main finding was that circular innovation is highly conditional.** Its effectiveness depends not on the ingenuity of individual solutions, but on the alignment of policy, infrastructure, consumer understanding, market design, organisational incentives and governance structures that are, at present, largely absent or fragmented. Where these enabling conditions are missing, circular models risk under-delivering on commercial and environmental outcomes, regardless of their technical sophistication or narrative appeal.

This reflects a maturing industry understanding. **After more than a decade of pilots, laboratories and proof-of-concept initiatives, practitioners are increasingly able to distinguish between what is theoretically circular and what is operationally sustainable. The workshop revealed a sector that is no longer in thrall to circularity as an ideal, but is instead grappling with its real-world limits, trade-offs and unintended consequences.** In this sense, the scepticism expressed throughout the workshop should be understood not as resistance, but as evidence of learning.

One of the key insights to emerge is that the **primary systemic constraint facing circular innovation is not technical capability, but consumption.** This could be reframed as the industry being obsessed with producing more for consumption, yet the consumer is not being

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provided with the right commercial offer that does not require increased consumption. This has led to a huge legacy of apparel stock in the system, which is not being addressed. Participants repeatedly returned to the concern that circular models that enable continued or increased throughput — whether through recycling, rental or take-back schemes — risk reproducing the same structural problems that characterise the linear system they are intended to replace.

Circular innovation emerges as a set of tools whose impact is dependent on how and at what scale they are applied. The workshop suggests that **certain forms of circular innovation may be viable and meaningful when operating within appropriately bounded systems. These include SMEs, place-based ecosystems, premium or specialist product categories and tightly defined material loops where governance, traceability and volumes can be controlled.** In such contexts, circularity can support consumer needs without over consumption, addressing durability, repair, value retention and material stewardship while acknowledging unrealistic assumptions of infinite scale.

The workshop casts doubt on the assumption that circularity must scale vertically through global consolidation to be effective. An alternative vision begins to emerge: one of horizontal scaling through replication rather than expansion. Under this model, smaller, resilient circular systems are repeated across geographies and contexts, rather than aggregated into a single global solution. This approach aligns more closely with the realities identified by participants, particularly around infrastructure limits, consumer behaviour and material flows.

It also highlights that circular business innovation cannot be developed or judged through siloed expertise, as circularity functions as a tightly coupled system where weaknesses in materials, design, recycling or business models cannot be offset elsewhere. The workshop demonstrated that **convening interdisciplinary skills — across technical, strategic and creative domains — is essential to advancing circular and sustainable outcomes, enabling knowledge sharing, innovation and more integrated approaches in both industry and education.** The mixed-skills discussion showed how different disciplines assess the same innovation through distinct risk lenses — testing environmental validity, operational feasibility, scale and the upstream design choices that shape downstream impact and trust. This cross-disciplinary scrutiny exposed a core business risk: over-reliance on single circular strategies, particularly recycling, to compensate for unresolved material, design or incentive failures. By surfacing constraints and unintended consequences invisible within any single discipline, mixed expertise grounded circularity as a system-level business strategy rather than a technical fix or branding exercise. This is a core learning for any business wishing to drive circular innovation and indeed a wider learning for education as our world becomes ever more linked and complex.

Policy alignment was identified as a decisive factor in determining which circular innovations become viable. Emerging European regulation,

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textile extended producer responsibility frameworks and shifts in global manufacturing geographies could all reshape the commercial and operating conditions for circular models. The workshop also made clear that **regulation alone is insufficient unless it is accompanied by enabling infrastructure, shared standards and investment horizons that support long-term system change**. Without this, regulation risks increasing compliance costs without delivering corresponding environmental benefit.

Insights drawn from other sectors, such as automotive, infrastructure and long-life consumer products, offer both inspiration and caution. These industries demonstrate that circularity can be operationalised to meet consumer demands, and where products are designed for longevity, value is retained over time and governance structures support coordination across multiple actors. At the same time, they underline the scale of institutional, regulatory and market understanding required to make such systems function, reinforcing the conclusion that circular apparel cannot be achieved through isolated brand action or technological fixes alone.

Situated within the wider Back to Baselines research programme, **the workshop provides an evidence-based articulation of industry judgment at a moment of transition. It offers a grounded view to both circularity and the industry, and a realistic understanding of constraints, opportunities and system dynamics.** It strengthens the programme's ability to inform future policy, research and the innovation agenda, anchoring them not in aspiration, but in the lived realities of implementation.

Ultimately, the workshop suggests that the central question facing the fashion, wider apparel and textiles sector is no longer whether circularity is desirable, but whether the industry is willing to confront the deeper structural changes required to make it meaningful. Circular innovation remains necessary — but it is no longer sufficient on its own to be sustainable.

Industry recommendations towards circular innovation:

1. Reposition “value” around longevity and utilisation, not unit throughput

Shift commercial metrics from sell-through and volume to lifetime value retention: durability, repair rates, active use-days, reduced returns/markdowns and resale/refurb value. See circular business models as margin protection and returns and waste avoidance strategies, not PR add-ons.

Caveats:

- **If brand incentives remain volume-led, circular approaches will stay pilot-scale or be bolt-ons.**
- **Without guardrails (pricing, limits, design choices, customer nudges), repair/resale/returns can increase emissions and**

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waste rather than reduce them.

2. Make circularity “designed in” by setting product rules that recyclers can deal with

Establish design standards that lock in circular outcomes upstream: minimise blends, standardise trims/fasteners, enable disassembly, build modular repair points and specify end-of-life routes at brief stage. Create feedback loops from repair/refurb data back into design (defect reduction, better construction, fewer returns).

Caveats:

- **Performance categories may have real technical limits to mono-material purity; forcing purity can degrade function and adoption.**
- **Design rules only work if buying, merchandising and cost targets stop complexity and speed.**

3. Treat polyester as a managed-risk material system, not a solved problem

Put polyester (and blended synthetics) into a risk-managed transition plan: reduce unnecessary use, prioritise durability where it remains, design out blends where possible and apply tighter claims discipline (what “recycled” really means; expected loop count; end destinations). Integrate microfibre mitigation into product specs and care guidance.

Caveats:

- **rPET is often a transitional necessity, not a long-term destination; closed-loop is still rare and feedstock quality/availability constrains scale.**
- **Substitution to bio-based/natural fibres can shift burdens (land/water/chemistry) if done without system-level assessment.**

4. Move recycling from “brand projects” to shared infrastructure with common standards

Focus less on isolated take-back schemes and more on interoperable, collective systems: shared sorting standards, polymer/fibre specifications, consistent labelling/data, aggregation of volumes and coordinated regional logistics. Prioritise mechanical routes where credible, and demand transparent evidence for chemical routes (energy, yields, pollution, net benefit).

Caveats:

- **Recycling capacity without stable feedstock, standards and participation becomes economically fragile and environmentally ambiguous.**
- **Chemical recycling is not a guaranteed solution; it must clear high bars for energy intensity, real-world yields and net impacts.**

5. Reorient circular innovation around consumer outcomes, not perpetual newness

Challenge persistent misreadings of consumer behaviour. Brands often assume demand for constant novelty, when many consumers prioritise outcomes such as fit, function, confidence, durability and ease of use. Circular innovation should focus on delivering reliable utility over time — through better design, repairability, care, access and service models — positioning longevity and use-value as core customer propositions rather than sustainability add-ons.

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6. Caveats:

- Consumers should not be required to navigate complexity; circular systems must be intuitive and low-friction.
- Without changes to volume-led commercial incentives, outcomes-led narratives risk reinforcing rebound consumption.
- Consumer needs vary by category and context; assumptions must be tested with robust use-phase evidence.

7. Embed product stewardship to address legacy materials, chemicals and provenance

Treat circular innovation as an ongoing stewardship obligation, not solely a forward-looking design challenge. Brands must take responsibility for products already in circulation by developing mechanisms to manage legacy materials, historical chemical use and uncertain provenance. This includes funding and designing recovery pathways where viable, improving traceability over time, and collaborating to address contamination risks that undermine reuse and recycling. Caveats:

- **Legacy challenges cannot be resolved at brand level alone; they require shared infrastructure, disclosure standards and regulatory alignment.**
- **Product recovery as feedstock is constrained by contamination, material degradation and unknown chemical histories, limiting realistic circular outcomes.**
- **Stewardship adds near-term cost and complexity and is unlikely to scale without policy support, such as extended producer responsibility frameworks.**



Industry circular fashion and textiles workshop: Testing Perception of Circular Innovation

Credit: Adam Razvi

Phoebe English
Credit: Asia Werbel



5 Recommendations

Final report

recommendations

General

- **Government awareness and knowledge of the impact of the textile/material industry must be improved.** These sectors interface with nearly every physical environment and industrial sector, including military, automotive, construction, interiors, medical and personal hygiene industries, and wider apparel.
- **Cohesive data sharing, collaboration and transparency between suppliers would facilitate better digital systems,** optimising demand forecasting, traceability and supply chains.
- **Adopting methods and technologies that facilitate on-demand design, production, manufacturing and distribution could begin to solve the problem of overproduction** that results in material waste.
- **Supply-chain traceability would support the effective use of resources and create greater social impact awareness** with fair conditions and pay for workers.
- **Regulation must be accompanied by enabling infrastructure, shared standards and investment** that facilitates long-term systemic change.
- **Extended producer responsibility (EPR), when introduced for apparel and textiles in the UK, could include a mechanism for investing any funds accrued in supporting and developing infrastructure for textile waste collection,** sorting, reuse and recycling.
- **Universities should be endowed with grant-making responsibilities and associated infrastructure,** to support business development and sustainable growth.

Policy

- **Policies for combined circular/sustainable innovation would consolidate industry standards and better inform consumer understanding of more circular/sustainable apparel and textile systems,** with a potential impact on purchasing behaviour. Circularity on its own does not guarantee sustainability — and vice versa.
- **Policymakers must connect with industry to develop meaningful industry-focused policies that reflect the distinct characteristics of these sectors.** Industry and government must collaborate to shape effective guidelines. Achieving systemic change requires a collaborative effort from all key stakeholders in the sector.
- **Policy infrastructure needs to align with consumer understanding, market design, organisational incentives and governance structures** to determine which circular innovations are viable.

5 Recommendations

- **Policy incentives are needed to promote high-quality data transparency, standardised procedures and system-wide accountability.** Establishing set databases and sharing data requires investment in digital infrastructures. Big data sets, gathered through machine learning, artificial intelligence and statistical analysis, can support material factorisation, characterisation and life-cycle evaluation.
- **The cost and complexity of trade post-Brexit must be reduced, to increase access to global markets and improve competitiveness,** particularly for start-ups and SMEs, e.g. through tax breaks and transparency, while also removing barriers to onshoring, such as cost and unfavourable policy conditions.

“From a policy standpoint there is an urgent need for standardisation.”

- **Peter Needle, Founder, Segura Systems and Board Advisor & Head of Sustainability, Oii.ai**

“Start-ups often receive Innovate UK funding, but many can’t scale in the UK and end up moving abroad. Most of our funding has been for research, and although we’ve kept our headquarters here to retain value in the UK, Brexit forced us to move production to Spain. We’re an international company, but we keep our warehouse here to maintain quality control. It’s not that businesses don’t want to produce in the UK — smaller enterprises simply need more government support, or the UK risks losing the innovation it creates.”

- **Dr Raquel Prado, former Head of Research, Ananas Anam**

Skills

- **Reskilling or upskilling employees alongside improved conditions and sustainability standards would reform and strengthen the UK workforce with circular/sustainable product and service-development expertise.**
- **Development of an industrial strategy behind the concept of feasible, affordable and practical terms for the manufacturing industry** would support circular/sustainable apparel and textiles innovation.
- **Interdisciplinary training from early years to doctoral and CPD level is essential to develop circular and sustainable skills across relevant fields for industry**, as well as building an understanding of AI, robotics and machine learning.
- **Developing the skills needed for a circular and sustainable economy requires co-development between industry and academia**, including integrating design with STEM capabilities to foster a better understanding of materials, manufacturing, environmental science and social welfare of workers.
- **More investment in collaborative, interdisciplinary research is needed to facilitate the development of circular/sustainable skills**, connecting material science, data science and sustainability.
- **Planned educational programmes should integrate interdisciplinary skills elements at all levels** to future-proof an informed workforce.
- **The ability to speak and understand different languages, terminology and methods across a variety of disciplines is critical** and can be fostered through education. Industry and education sectors must be at liberty to innovate through teaching skills and encouraged to develop those skills into products and processes for a future vision.

“Every discipline comes with its own terminology — speaking with different scientists from various backgrounds often leads to clashes in terminology, resulting in misunderstanding.”

- **Dr Matteo Gallidabino, Lecturer in Forensic Chemistry, King’s College London**

“Interdisciplinary skills are good for one person, but I think it’s important to have teams of people who have different strengths and try to develop a common vocabulary so people can communicate effectively.”

- **Mary Glasper, Lead Technician — Fashion, Textiles, and Colour, University of Leeds**

“I think people see science and design as two different entities, but it shouldn’t be that way. It’s about making things in a way that makes our world better, and the best designers recognise that.”

- **Jane Shepherdson, Industry Consultant and Chair, My Wardrobe HQ (previously CEO, Whistles)**

“It’s not just about scientifically solving problems; this is also about rethinking systems and quite often creative minds have interesting and different solutions — including having creativity at the forefront of collaborative partnerships between suppliers, industry, designers, makers.”

- **Maria Grachvogel, Founder and Creative Director, Maria Grachvogel**

5.1 Conclusion

This research identifies circular innovation within the fashion, wider apparel and textiles industry across 4 thematic areas: circular innovation in material design; circular innovation in material sourcing; circular innovation in recycling; and circular innovation in business models. These areas must be aligned within robust, well-supported systems to enable credible circular outcomes. Individually, each area contributes to progress, while collectively, they determine the strength, scalability and validity of circular and sustainable claims.

Circular innovation in material design illustrates the growing role of bioderived, biosourced and wasted materials, alongside advances in biotechnology and regenerative cultivation. These innovations challenge the dominance of oil-derived materials and demonstrate how interdisciplinary approaches to design and science capabilities can generate alternative material solutions. However, despite technical feasibility, the transition from laboratory-scale innovation to industrial adoption remains constrained by challenges of scale, cost, infrastructure and policy.

Circular innovation in material sourcing is foundational to building circular systems. Innovations in regenerative agriculture, responsible animal fibre standards, traceability platforms and supplier management tools respond to increased responsibility and impending legislation for manufacturers and producers, such as extended producer responsibility, and growing consumer demand for transparency. Circular sourcing ensures that environmental, social and animal welfare considerations are embedded at the point of raw material extraction. It enables accountability across complex supply chains and supports the credibility of circular material choices made at the design stage.

Circular innovation in recycling is a highly technically advanced yet systemically constrained area of circular innovation. Mechanical and chemical recycling technologies, fibre-to-fibre processes and closed-loop systems demonstrate that recycling is possible for both synthetic and natural fibres. However, post-consumer textile recycling remains limited by inconsistent feedstock, material complexity, insufficient collection and sorting infrastructure, and weak economic incentives. Scaling recycling solutions will require coordinated investment, aligned data standards and supportive legislation to establish viable business cases.

Circular innovation in business models reframes sustainability as a strategic and intellectual shift rather than a peripheral activity. Models based on longevity, repair, reuse, rental, resale and on-demand production show how circular principles can be embedded into commercial practice. These approaches challenge conventional growth models by valuing quality, emotional durability and resource efficiency. However, their success depends on consumer engagement, cultural change and policy frameworks that incentivise circular behaviour and discourage overproduction.

Circularity represents a coordinated systemic transition across these 4 areas, requiring collaboration between industry and academia, involving policymakers, designers, scientists, manufacturers and consumers to deliver impact at scale. Ultimately, the research indicates that brands are not the primary barrier to achieving circularity; the problems lie with economic structures such as taxation and profit margins, fragmented systems and insufficient legislative alignment. The deleterious strategies employed by fast-fashion brands based in nations where costs are minimal and environmental regulation non-existent are well documented; but closer to home, we have found that brands show a fundamental willingness to “do the right thing” — from startups to well-known high-street names. Drawing on that goodwill and achieving a circular transition will require robust policy, targeted investment and shared standards to support system-wide change and move towards a more resilient, equitable and sustainable future that genuinely supports circular innovation.

5 Recommendations

Theory of change: problem statement. Not all circular innovation is necessarily “sustainable or good”.



6.1 Glossary

Term	Definition
Acid dyes	Water-soluble, negatively charged dyes for protein fibres
Agro-industrial	Relating to agriculture combined with industrial processing activities
Algae	A type of microorganism that lives in aqueous conditions
Alginate	A polysaccharide, a long chain of carbohydrate molecules
Alkaline	Having a high pH; basic, not acidic
Amino acid	An organic molecule made up of a basic amino group ($-NH_2$), an acidic carboxyl group ($-COOH$), and an organic R group (or side chain) that is unique to each amino acid
Antibacterial	Prevents or inhibits bacterial growth
Antimicrobial	Inhibits or kills microbes
Antioxidant	Prevents oxidation by neutralising harmful free radicals
Aqueous-based	A solution with water as solvent
Aromatic	An organic compound with a benzene-like ring
Bacterial cellulose (BC)/ bacterial nano cellulose	A natural and renewable nanomaterial characterised by a unique three-dimensional structure that endows it with excellent mechanical properties and high water-holding capability. BC is a very pure, crystalline and biocompatible polymer
Bacteriologist	Scientist who studies bacteria and related microorganisms
Bacterium	Single-celled microorganism
B Corp	Certified B Corporations are companies verified by B Lab to meet high standards of social and environmental performance, transparency and accountability
Bagasse	Dry, fibrous material that remains after extracting juice from sugarcane or sorghum stalks
Berger scale	Measures colour strength or intensity in pigments
Baseline	Value of impacts (on nature) or state (of nature) against which an actor's targets are assessed in a particular previous year or particular previous years
Bast fibre	Fibres obtained from the inner, fibrous stems of plants (the phloem and xylem)
Bioactive	How substances interact with living systems, encompassing effects at the cellular, tissue or organismal level
Biobased	Biobased material is wholly or partly derived from material of biological origin, excluding materials embedded in geological formations and/or fossilised
Biobleaching	Using microorganisms or enzymes to whiten materials environmentally
Biocomposite	Material made by combining natural fibres with a biodegradable or biobased matrix
Biodegradable	Rapidly decomposable by microorganisms under natural conditions (aerobic and/or anaerobic)
Bioderived	Sourced from living things

6.1 Glossary

Term	Definition
Biodiversity	The variety of life found in a place on Earth or, often, the total variety of life on Earth
Biodynamic	Holistic, ecological and ethical approach to farming, gardening, food and nutrition
Biorefinery	A facility that converts biomass into a variety of biobased products and energy, aiming to maximise resource efficiency and sustainability
Biofuel	Any fuel derived from plant, algae material or animal waste
Biofunctionalism	A theoretical framework that integrates insights from cognitive sciences and emphasises the interconnectedness of human functioning
Biogenic	Produced or originating from a living organism
Biomass	Organic material from plants and animals
Biomaterial	A substance engineered to take a form which, alone or as part of a complex system, is used to direct, by control of interactions with components of living systems, the course of any therapeutic or diagnostic procedure
Biopolishing	A finishing process carried out before, during or after dyeing to reduce hairiness and pilling of cellulose fabric
Bioprocessing	Using biological systems to produce or transform materials
Bio reactor	Vessel that supports controlled biological reactions or growth
Bioretting	Using microbes to separate fibres from plant stalks
Biosourcing	Obtaining materials from renewable biological resources
Biosourced	Obtained from renewable biological materials
Biotechnology/biotech	Using living systems to develop useful products
Bio-upcycling	Sustainable process using microorganisms or enzymes to break down waste materials, primarily plastics, and convert them into higher-value products
Brackish	Slightly salty water, between freshwater and seawater
Carbon footprint	Total greenhouse gases produced by activities or products
Carbon nanotube-decorated	Coated with carbon nanotubes for enhanced properties
Carcinogenic	Capable of causing cancer in living tissues
Carding	Brushing fibres to align and clean them
Cellulose	A type of carbohydrate produced by plants using photosynthesis. Fibres found in plant seeds, stems or leaves are made from cellulose to keep them rigid. Cellulose sourced from wood can be regenerated with chemicals to form man-made cellulotics (MMCs)
Cellulose carbamate fibre	Regenerated cellulose fibre modified with carbamate groups
Cellulose II hydrate	Water-swollen regenerated cellulose in its stable form
Cellulose macromolecules	Long chains of glucose units forming structural fibre
Chatham House Rule	Information can be shared, but speaker identities stay confidential

6.1 Glossary

Term	Definition
Chemical recycling	Manufacturing processes that convert waste materials into feedstock by changing the chemical structure of waste materials to be used in the production of new polymers, monomers, intermediates or other materials
Chitosan	Biopolymer from chitin with antimicrobial and biodegradable properties
Circular business models	By design, keep products and materials circulating in the economy at their highest value, increasing their use while effectively decoupling revenue streams from production and resource use
Circular economy	An alternative to the traditional linear economy (make, use and dispose). Under a circular economy, products, components and materials are kept in use for as long as possible to extract the maximum value. After their usable life, they are reused, repaired or recycled
Circular system	A system where resources loop continuously, reducing waste and environmental impact
Circularity	Designing systems to reuse resources and eliminate waste
Collagen	A type of protein with a fibrous shape that makes up connective tissue like skin; 30% of all protein found in mammals is collagen. Leather is a collagen-based material
Closed-loop production	Usually referring to recycling (e.g. closed loop recycling), this means keeping material within its product cycle
Closed loop recycling	A system by which textile products are used and then recovered and turned into new textile products indefinitely, without losing their inherent properties
Closed-loop systems	Processes whereby materials are continually reused without waste
Ecofriendly	Not harmful to the environment; supports sustainable practices
Compostable	Breaks down naturally into non-toxic, soil-safe components
Cross-linked	Formation of bonds between polymer chains so the chains are linked together. Cross-linking is used to change physical properties of polymers, for example to make them more rigid. In some cases it can also change the degradation rate (how fast a polymer breaks down)
Cross-linker	Chemical that bonds polymer chains together
Crystallisation	Physical or chemical process or action which results in the formation of regularly shaped, sized and patterned solid forms known as crystals
Cuticles (from wool)	Outer scale layers protecting wool fibres
Cutinase	Enzyme that breaks down cutin in plant or fibre surfaces
Deadstock	Unsold or unused inventory kept in storage and no longer needed
Delignification	Removing lignin from plant fibres or pulp
Direct dyes	Water-soluble dyes that can be applied directly to fibers, particularly cellulose fibres like cotton, without the need for a binding agent or mordant
Desizing	Removing size materials from fabrics before further processing
Disperse dyes	Non-ionic dyes for hydrophobic fibres like polyester
Disruptor	An element or hard point present on a textile product (e.g. fastener, button, zip, fabric patch etc.) that may disrupt the recycling process and needs to be removed before the product is suitable as feedstock for recycling
Downcycled	Reprocessed into lower-quality materials with reduced performance or value

6.1 Glossary

Term	Definition
Eco-balanced	Designed to maintain environmental equilibrium by reducing harm and resource use
Ecodesign	Designing products to minimise environmental impact across their lifecycle
Eco-efficiency indicators	Metrics showing environmental performance relative to economic output
Eco labels	Certifications showing products meet environmental standards
Eco-modulate	Adjust product design or fees based on environmental impact levels
Ecosystem	A dynamic complex of plant, animal and microorganism communities and the non-living environment interacting as a functional unit
Ecotoxic	Harmful or toxic to organisms in the environment
Effluent	The wastewater discharge from industrial facilities
Elastomer	Polymer material that stretches easily and returns to original shape
Electro-cracking	The process of using electric energy to heat and convert hydrocarbons into valuable chemicals, particularly olefins used in the production of plastics
Emotionally durable design	A term coined by Jonathan Chapman to denote emotional attachment to garments and other products
Endocrine disruptors	Chemicals that interfere with hormone signalling systems
End of life	Stage when a product can't be used further and needs disposal
Enzyme	Proteins that can speed up reactions without being used up themselves. They act as 'biological catalysts', which means they help make more products in a shorter space of time. Enzymes are used widely in laundry formulations to enable washing at lower temperatures
Enzymatic	Involving or caused by enzyme-based biochemical reactions
Enzymatic wash	Using enzymes to clean or soften textiles efficiently
Enzymatic hydrolysis	Enzymes breaking molecules into smaller components
Enzymatic modification	Enzymes altering material properties through specific reactions
Espase	Protease enzyme used for textile bio-processing
Esterase	Enzyme that breaks ester bonds into acids and alcohols
Eutectic	Relating to or denoting a mixture of substances (in fixed proportions) that melts and freezes at a single temperature that is lower than the melting points of the separate constituents or of any other mixture of them
Eutrophication	The undesirable overgrowth of vegetation caused by high concentrates of plant nutrients in bodies of water
E-waste	Electronic waste
Feedstock	A material used in the manufacturing of a product. A feedstock may be in the final product, or be used to help make the final product. In biomanufacturing, a 'bio-feedstock' can refer to multiple things, from what is 'fed' into the process (e.g. biomass) to nutrition for an organism (e.g. sugar), or even the organism itself (e.g. bacteria)
Fermentation	Microbial conversion of substances into simpler products
Fermentor	Vessel supporting controlled microbial growth for production processes

6.1 Glossary

Term	Definition
Fibre-to fibre recycling	The closed loop reprocessing of non-reusable textiles back into fibres to produce new textile materials
Fibroin	A protein that is the chief constituent of silk
Fixng agent	Helps dyes bond firmly to fibres
Formaldehyde	Volatile chemical used industrially
Fossil-based	Made from non-renewable resources derived from coal, oil or gas
Fossil-fuel-based	Fossil resources include coal, oil and natural gas, which are non-renewable. They were made millions of years ago from the remains of plants and animals that cannot be remade. This type of resource has a high amount of carbon and stores chemical energy that is released as heat when burned. When burned, fossil resources release greenhouse gasses which contribute to global warming
Free radical	A highly reactive chemical species carrying no charge and having a single unpaired electron in an orbital
Free-radical initiator	Chemical that starts free-radical chain reactions
Fructose dehydrogenase	Enzyme that oxidises fructose into ketofructose
Garnetting	Opening and separating textile waste into reusable fibres
Green public procurement	Buying goods with lower environmental impacts
Greenwashing	Misleading claims suggesting something is eco-friendly when it is not
Hydrological	Relating to the study of water on the Earth
Hydrolysis	The reaction of a substance with water or its ions
Hydrophilicity	Hydrophilicity is the tendency of a molecule to be solvated by water
Hydrophobic	Repels water due to non-polar surface properties
Isomorphism	In mathematics, an isomorphism is a structure-preserving mapping or morphism between two structures of the same type that can be reversed by an inverse mapping
Keratin	A type of protein found in animal cells with a fibrous structure. Keratin creates a tough outer layer on the inside and outer surfaces of organisms and is the main protein in hair, scales, feathers and horns
Lean manufacturing	Lean manufacturing is a production process based on an ideology of maximising productivity while simultaneously minimising waste within a manufacturing operation. The lean principle sees waste as anything that doesn't add value that customers are willing to pay for
Linear system	Resources are taken, used once, then discarded as waste
Lipase	An enzyme that helps the body digest fats. Its main role is to break down triglycerides, a type of fat, into smaller molecules called fatty acids and glycerol
Lipolytic	The biological process of breaking down fats, specifically triglycerides, into smaller components the body can use for energy
Lysozyme	A naturally occurring enzyme produced by animals that functions as a non-specific defense against microorganisms, forming part of the innate immune system

6.1 Glossary

Term	Definition
Life-cycle assessment/analysis	A systematic set of procedures for evaluating the environmental impact of products throughout their life cycle
Mechanical recycling	Mechanical recycling processes based on physical forces, e.g. compounding, drying, grinding, re-granulating, separating, shredding and washing
Melt-spinning	A high-speed manufacturing process that converts molten polymers or metals into continuous fibers or ribbons through rapid cooling and solidification
Micellar	Tiny clusters of cleansing molecules called micelles, which are suspended in water
Microbial	Relating to microbes
Microencapsulation	The process of enclosing tiny particles or droplets within a protective coating to form microcapsules, which control release, protect sensitive materials, and enhance stability
Microfibre	Extremely fine synthetic fibre that sheds tiny particles during use
Microplastic	A small piece of plastic debris measuring 5mm or less, found in the environment from the disposal or breakdown of consumer products or industrial waste. Synthetic fibre fragments are considered microplastics
Microorganism	A very small organism that can only be seen in detail under a microscope, like bacteria or yeast. They can live in water, soil, air or even in the human body
Mono-material	A mono-material is a product composed of a single type of material. Products could be made out of paper, plastic, glass, fabric, metal or other materials
Monomer	A molecule of any of a class of compounds, mostly organic, that can react with other molecules to form very large molecules, or polymers
Mordant	A chemical that fixes a dye in or on a substance by combining with the dye to form an insoluble compound
Mulesing	Removing wool-bearing skin to prevent flystrike in sheep
Mungo	Shredding old and new hard rags such as tailors' shreds, coats, caps and second-hand clothes
Mycellium	The mass of branched, tubular filaments (hyphae) of fungi
Nanocellulose	Nanocellulose refers to various nanostructured forms of cellulose, including cellulose nanocrystals (CNC), cellulose nanofibres (CNF), and bacterial nanocellulose
Nanotechnology	Manipulates matter at the atomic and molecular scale
Neoprene	A synthetic rubber known for its excellent resistance to weather, oils and heat
Next-gen	Refers to the newest, most advanced technology or approach
Non-toxic	Safe materials that don't release harmful chemicals into people or environments
Non-virgin	Made from previously used materials instead of newly extracted resources
Oligomer	A low molecular weight polymer comprising a small number of repeat units whose physical properties are significantly dependant on the length of the chain
On-demand manufacturing/production	A production model where goods are created only after an order is placed

6.1 Glossary

Term	Definition
Organic	Not using artificial chemicals in the growing of plants and animals for food and other products
Organism	Any living being, from microbes to plants and animals
Oxidases	Enzymes that catalyze redox reactions, using molecular oxygen (O ₂) as an electron acceptor
Oxidation	A chemical reaction that involves the loss of electrons by an atom, ion, or molecule
Oxidoreductases	A broad group of enzymes that catalyse electron transfer from one molecule (a reductive molecule or an electron donor) to another (the oxidant or the electron acceptor)
Over-consumption	Using more resources than needed, driving waste and environmental pressure
Over-production	Making more goods than needed, creating excess stock and unnecessary waste
Ozone	Reactive oxygen gas used for bleaching and disinfection
Paludiculture	The productive use of wet and rewetted peatlands, enabling farming systems that maintain high water tables while keeping land economically viable
Papain	A proteolytic enzyme extracted from the raw fruit of the papaya plant
Pastazzo	An Italian term referring to the organic waste left over from the production of citrus juice
Pectinase	An enzyme that catalyzes the hydrolysis of pectin, a complex polysaccharide found in plant cell walls
Peptides	Short chains of amino acids forming simple biological molecules
Perfluorinated	Perfluorinated compounds (PFCs) are synthetic chemicals in which all hydrogen atoms in a carbon chain are replaced by fluorine, making them highly stable and resistant to degradation
Peroxidases	Oxidoreductases produced by a number of microorganisms and plants
Peroxide	A compound containing oxygen in the -1 oxidation state
Phenol	Also known as carbolic acid. An aromatic organic compound, usually in the form of colourless or white crystals
Photosynthesis	Plants converting sunlight into energy using chlorophyll
Pilling	The formation of small, fuzzy balls of fibre, commonly called 'pills', on the surface of a fabric
Pilot	Small-scale version of a process used to test feasibility before full production
Polyamide	Any polymer (substance composed of long, multiple-unit molecules) in which the repeating units in the molecular chain are linked together by amide groups. Amide groups have the general chemical formula CO-NH
Polyester	A class of synthetic polymers built up from multiple chemical repeating units linked together by ester (CO-O) groups
Polyethylene glycol	Water-soluble polymer used in coatings and processing
Polylactic acid	Biodegradable plastic made from renewable plant sugars
Poly-lyocell	Fabric blend combining polyester with lyocell for durability and softness

6.1 Glossary

Term	Definition
Polymer	A large, chain-like molecule. The larger molecule is made up of smaller molecules that repeat to form the chain
Polymeric	Concerned with, or being a polymer
Polyphenols	Antioxidant plant compounds with multiple phenolic groups
Post-consumer	Textiles that have been purchased, used, and then discarded for reuse or disposal, by households or by commercial, industrial and institutional facilities in their role as end users. This excludes unused returned items
Post-industrial	Fibres, yarns, fabrics and products from the textile manufacturing process. These can either be finished materials/products that are suitable for use/sale, or unusable materials
Pre-consumer material	Material diverted from the waste stream during the manufacturing process. Excluded is the reutilisation of materials such as rework, regrind, or scrap generated in a process and capable of being reclaimed within the same process that generated it
Pre-loved	Previously owned items given a new life through reuse or resale
Product as a service	Customers use products via subscription, while companies retain ownership
Proteolytic	Enzymes that break down proteins into peptides
Protease	Also called peptidases or proteinases. A large and diverse group of enzymes found across all forms of life, from bacteria to humans
Quercetin	Plant antioxidant flavonoid with anti-inflammatory properties
Radical-coupling	Joining molecules via reactive free-radical intermediates
Random-blended	Fibres mixed without controlled ratio or uniform distribution
Reactive dyes	Form covalent bonds with fibres for permanent colouring
Recyclable	Can be processed and reused to make new products
Recycling/recycled	The process of reducing a product back to its basic material level, reprocessing those materials, and using them in new products, components or materials
Regenerated	Fibre made by reforming dissolved natural polymers into filaments
Regenerated cellulose	Dissolved natural cellulose re-formed into new fibres
Regenerative	Restoring and enhancing life in a system
Regenerative agriculture/cultivation	Farming that enhances the farm's ecosystem and builds its capacity to evolve, renew and replenish the resources it needs to thrive
Regenerative cultivation	Farming that restores soil, biodiversity and ecosystem health
Regranulate	Melt and reform plastic waste into new granules
Renewable feedstock	Materials sourced from replenishable biological or natural resources
Rental	Business model whereby each garment or collection of garments can be hired/rented for a limited time
Repair	Business model of replacing or repairing components of a garment that are faulty or close to failure back to a useable state, or altering a garment for a better fit/style

6.1 Glossary

Term	Definition
Resale	Business model to generate revenue from additional sales of a garment after the first sale. Recovering own-brand products through a takeback scheme to be resold through the brand or via a partner. Selling secondhand garments of any brand/origin
Reuse	Operation whereby a product or component is used repeatedly and for long periods of time, for its original purpose, without being significantly modified, remade, or recycled. Products might need to be 'prepared for reuse', which often involves cleaning, repairs, or small modifications so that they can continue to be used over time and by multiple users
Rewetting	Restoring water to dried-out ecosystems to revive soils, biodiversity and function
Rhizomatous	Having underground stems (rhizomes) that spread and regenerate
Ring-spun	Fibres twisted tightly for stronger, softer yarn
Selvedge	The tightly woven, self-finished edge of fabric
Semi-mechanical recycling	Partly machine-processed fibre recovery with limited manual steps
Sericine	Silk protein acting as a natural glue around fibroin
Serine protease	Enzyme that cleaves proteins using a serine residue
Sheath-core	Fibre with outer sheath surrounding a different inner core
Shrink-proofing	Treatment preventing wool or fabrics from felting shrinkage
Shoddy	Recycled wool fibres made from shredded textile waste
Slow fashion	Approach promoting durable, timeless clothing made sustainably and consumed mindfully
Solid waste	Discarded materials no longer usable or needed
Sono-chemical	Power ultrasound that enhances chemical and physical changes in a liquid medium through the generation and subsequent destruction of cavitation bubbles
Sorghum	A versatile cereal grain from the grass family, used for food, animal feed and biofuel
Spectroscopic	The scientific study of how matter interacts with electromagnetic radiation, allowing scientists to analyse the composition, structure, and properties of substances
Spent dyebath	Used dye solution remaining after textile dyeing
Stirred tank reactors	Mixed vessels enabling controlled chemical or biological reactions
Submerged cultivation	Growing microorganisms fully immersed in liquid nutrient media
Supercritical fluid	A substance at temperature above its critical temperature
Superhydrophobic	Extremely water-repellent surface with very high contact angle
Supply chain	Network moving materials from production to final consumer
System-level	Relating to overall system behaviour rather than individual components
System-wide	Affects or considers the entire system, not just individual parts
Take-back schemes	Programmes whereby companies collect used products for recycling or reuse

6.1 Glossary

Term	Definition
Tensile strength	The maximum stress a material can withstand while being stretched or pulled before breaking
Textile-to-textile	Recycling old fabrics into new textiles without downcycling material quality
Thermo-dynamics	Study of energy, heat and work, and how they transform
Thermo-mechanical	Combining heat and mechanical force to process materials
Thermoset	Plastic that permanently hardens when heated and cannot be remelted
Toxic	Harmful or poisonous to living organisms
Traceability	The ability to verify the history, location and processing steps of fibres and materials in a supply chain, by means of recorded identification
Traceability platforms	Systems tracking materials and processes across the supply chain
Upcycling	Transforming waste materials into higher-value products with improved usefulness
Urea	Nitrogen-rich compound used in fertilisers, textiles, resins and chemicals
Valorisation	Turning waste or by-products into useful, higher-value materials or products
VAT dyes	Water-insoluble dyes reduced to soluble form for dyeing
Vintage	Clothing or materials between 20 and 100 years old that recognisably follow the style of the era in which they were produced
Viscose	Regenerated cellulose fibre made using the viscose process
Waste-derived	Made from materials recovered from waste streams
Waste feedstock	Discarded materials reused as inputs for production
Waste management	Handling, reducing and processing waste to minimise environmental and health impacts
Water repellent	Treated surface that resists water absorption
Wetland	Complex ecosystem characterised by flooding or saturation of the soil, which creates low-oxygen environments that favour a specialised assemblage of plants, animals and microbes
Wet spinning	A fibre-forming process in which the polymer is dissolved in a solvent and the solution is extruded into a chemical bath
Wettability	The ability of a liquid to maintain contact with a surface
Wicking	The ability of a fabric to pull sweat away from skin, spread it across the fabric's outer surface, and let it evaporate

6.1 Glossary – acronyms

Acronym	Definition	Acronym	Definition
Ag	Silver	LCIA	Life-cycle impact assessment
AHRC	Arts and Humanities Research Council	MIL	Material Innovation Lab
AI	Artificial intelligence	M&S	Marks & Spencer
BLC	BLC Leather Technology Centre	NaOH	Sodium hydroxide
CEO	Chief Executive Officer	NERC	Natural Environment Research Council
CPD	Continuing professional development	NIR	Near-infrared. NIR spectroscopy is a technique that shines light in the 700 to 2,500 nanometer wavelength range at a material and measures what gets absorbed
CO2	Carbon dioxide		
CTF	Circular Textiles Foundation		
DABSA	Diiminobenzenesulfonic acid		
DMDHEU	Dimethylol dihydroxyethelene urea	NPF	Nativa Precious Fibre
DNA	Deoxyribonucleic acid	NZM	New Zealand Merino Company
DPP	Digital Product Passport	OII	Segura's digital AI-optimisation tool
EPR	Extended Producer Responsibility	PACT	Pact Group
ESG	Environmental, Social and Governance	PALF	Pineapple leaf fibre
ESPR	Ecodesign for Sustainable products Regulation	PEF	Product Environmental Footprint
EU	European Union	PEM	pan-Euro-Mediterranean preferential rules of origin
F&T	Fashion & Textiles	PET	Polyester - Polyethylene Terephthlate
FSC	Certified sustainably sourced pulp. The Forest Stewardship Council	PFA	Polyfluoroalkyl
FTTI	Fashion, Textiles and Technology Institute	PFC	Perfluorocarbons
GDPR	General Data Protection Regulation	pH	Logarithmic scale used to specify the acidity or basicity of aqueous solutions
GJ	Gigajoules	PLA	Polylactic acid
GM	Genetically modified	PU	Polyuerethane
GOTS	Global Organic Textile Standard	rPET	Recycled polyester
HEI	Higher Education Institution	QR code	Quick response code
IL	Ionic liquid	RAF	Ressponsible Animal Fiber
IoT	Internet of Things	RAS	Responsible Alpaca Standard
ISO	International Organisation of Standardisation	R&D	Research & Development
LCA	Life-cycle assessment	RMS	Responsible Mohair Standard
LCA	Life-cycle analysis	RWS	Responsible Wool Standard
		REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals

6.1 Glossary - Acronyms

Acronym	Definition
SFA	Sustainable Fibre Alliance
SME	Small and medium-sized enterprises
STEM	Science, Technology, Engineering and Mathematics
TEMPO	Mediated oxidation of trehalose
TPU	Thermoplastic polyurethane
T-REX	Textile Recycling Excellence
UKRI	United Kingdom Research and Innovation
USES-LCA	Uniform System for the Evaluation of Substances-Life Cycle Assessment
UV	Ultra violet
VAT	Value added tax
VOC	Volatile organic compound
WRAP	Waste and Resources Action Programme
ZQ	Merino wool certification

6.2 B2B interview participants

	Participant name	Role	Organisation	Location
1	Professor Amanda Briggs-Goode	Head of Department for Fashion, Textiles and Knitwear Design	Nottingham Trent University	Nottingham
2	Christian Jermyn	Director of ESG	Seasalt	Cornwall
3	Professor Effie Kesidou	Chair in Economics of Innovation & Sustainability	University of Bath School of Management	Bath
4	Gudrun Messias	Director Sustainability Direction	adidas AG	Germany
5	Jaki Love	Director of Innovation & Sustainability	UKFT	London
6	Professor James Busfield	Professor of Materials and Director of Strategy and Deputy Head of School at the School of Engineering and Materials Science	Queen Mary University of London	London
7	Dr Jane Scott	Newcastle University Academic Track Fellow, and Leader, The Living Textiles Research Group, Hub for Biotechnology in the Built Environment	Newcastle University	Newcastle
8	Jane Shepherdson	Industry Consultant and Chair, My Wardrobe HQ	Former CEO, Whistles	London
9	Jessica Connell	Circular Economy & Climate Change Specialist	John Lewis Partnership	London
10	Katharine Beacham	Head of Materials and Sustainability	Marks & Spencer	London
11	Laura Watson	Chief Creative Officer	Seasalt	Cornwall
12	Dr Lisa Macintyre	Associate Professor, School of Textiles & Design	Heriot-Watt University	Scotland
13	Professor Liz Barnes	Head of Manchester Fashion Institute	Manchester Metropolitan University	Manchester
14	Maria Grachvogel	Founder and Creative Director	Maria Grachvogel	London
15	Marie Stenton	Senior Scientist	PACT	Cambridge
16	Mark Sumner	Programme Lead for Textiles	WRAP	London
17	Mary Glasper	Lead Technician — Fashion, Textiles and Colour	University of Leeds	Leeds
18	Dr Matteo Gallidabino	Lecturer in Forensic Chemistry	King's College London	London
19	Merryn Haines-Gadd	Senior Specialist – Textiles, Circular Business Models, Design and Innovation	WRAP	London and Australia
20	Dr Miriam Ribul	Senior Research Fellow in Materials Circularity for Distributed Manufacture, Centre for Materials Science & Culture	Royal College of Art	London

6.2 B2B interview participants

	Participant name	Role	Organisation	Location
21	Professor Parik	Director, Technical Textiles Research	University of	Huddersfield
22	Peter Needle	Founder at Segura Systems, Board Advisor & Head of Sustainability at Oii.ai	Segura	Loughborough
23	Rachel Gray	Behaviour Change Manager	WRAP	
24	Dr Raquel Prado	Former Head of Research	Ananas Anam	London
25	Simon Platts	Responsible Sourcing and ESG consultant and Founder	SP&KO	
26	Stella Claxton	Researcher in Fashion and Sustainability	Nottingham Trent University	Nottingham
27	Steven Bethell	Co-founder	Bank & Vogue, BVH Services and Beyond Retro	Ontario
28	Professor Stephen J Russell	Professor of Textile Materials & Technology	University of Leeds	Leeds
29	Sumit Dargad	Vice President Operations — Product Quality, Innovation and Industrialisation	Burberry	London
30	Professor Susan Postlethwaite	Professor of Fashion Technologies and Principal Investigator and Director of Robotics Living Lab, Manchester Fashion Institute	Manchester Metropolitan University	Manchester
31	Su Thomas	Founder	Eco-Luxe	London
32	Tim Clark	Technical Director	John Smedley	Derbyshire
33	Tim Cross	Founder and CEO	Project Plan B	Plymouth

6.3 Industry workshop attendees

First name	Surname	Job title	Company/ institute	Skillset/ discipline	Company type	Business Size	Location
Leah	Coxon	Network Co-ordinator	Leeds Institute of Textiles and Colour	Research Support	HE	Large	West Yorkshire
Gudrun	Messias	Director Sustainability Direction	adidas AG	Sustainability	-	Large	Germany
Harriet	Radford	CSR and Sustainability Manager	TFG Brands	Sustainability	Fashion	Large	London
Paul	Roberts	Director	Roberts Recycling	Recycling	Recycling	Small	Cheshire
Ana	Dieaconu	Circular Product Design Developer	Beeswift	Circular design	Uniform	Medium	West Midlands
Lavinia	Santovetti	Co-founder	The Materialist	Material sourcing	Deadstock fabric sales	Micro	London
Sophie	Rochester	Founder	Yodomo	Material sourcing	Reuse	Small	London
Annalisa	Dunn	Co-founder	The Stitch Archive	Material design	R&D	Micro	London
Stephanie	Firth	Buyer	Penelope Chilvers	Material sourcing	Fashion	Small	London
Piarvé	Wetshi	Co-founder	Colèchi	Material design	Sustainability	Micro	London
David	Watts	Luxury brand consultant	-	Business models	-	-	London
Maria	Grachvogel	Founder and Creative Director	Maria Grachvogel	Design/ Business models	Fashion	Small	London
Tim	Clark	Technical Director	John Smedley	Material design	Knitwear	Large	Derbyshire
Ryan	Cooke	Head of Product Innovation	David Luke/ The Parently Group	Business models	Uniform	Medium	Cheshire

6.3 December industry workshop attendees

First	Surname	Job Title	Company/	Skillset/	Company	Business	Location
Hasna	Kourda	Co-founder	Save Your Wardrobe	Social science	Circularity	Small	London
Janelle	Hanna	Founder, Director	White Weft	Circular design	Upcycling	Micro	London
Hannes	Hulstaert	Co-founder	Post Carbon Lab	Research	Drying and Finishing	Micro	London
Phoebe	Hunter-Mcilveen	Co-founder	Project Pico	Material design	Fashion	Micro	London
Jessica	Garvey Birch	Founder	Base B	Material design	Traceability	Micro	London
Chelsea	Franklin	Head of Advanced Concept Design	Pangaia	Material design	Fashion	Medium	London
June	Swindell	Founder	Salt	Material design	Fabrics	Micro	London
Dian-Jen	Lin	Co-founder	Post Carbon Lab	Research	Drying and finishing	Micro	London
Leanne	Jae	Consultant and Denim Wash Lab Manager	Blackhorse Lane Ateliers	Material design	Fashion	Small	London
Lisa	Salama	Co-founder	The Stitch Archive	Material design	R&D	Micro	London
Nancy	Johnson	Founder	Tengri	Material sourcing	Fabrics	Small	London
Liv	Khan	Co-founder	The Materialist	Material sourcing	Deadstock fabric sales	Micro	London
Helen	Kirkum	Founder	Helen Kirkham Studio	Material design	Recycled footwear	Small	London
Simon	Platts	Founder	SP&KO	Sustainability	Consultancy	Micro	Leicestershire
Gayatri Hela	Pamidipati	Managing Director	Reseda Lifesciences	Chemical alternatives	Antimicrobial fabric finishes	Small	India/London
Su	Thomas	Founder	Eco-Luxe	Material design	Textile recycling	Micro	London
Karen	Walsh	Studio Director and Senior Producer	Farrow & Ball	Business models	Paint	Large	London

6.4 Hypothetical circular innovation case study outcomes from industry workshop 2 (page 93)

Hypothetical case study 1 — circular innovation in material design: summary of pros, cons and queries raised by all workshop attendees.

Pros	Cons/risks	Key queries/unknowns
Use of waste streams — valorisation of agricultural or by-product waste, avoiding virgin feedstocks	End-of-life uncertainty — material not clearly designed for recycling or reuse, risk of linear outcomes	Will the material actually be recycled or composted in practice?
Lower environmental impact (in principle) — potential CO ₂ and energy savings compared to conventional fibres	High transport footprint — waste, processing and manufacturing often geographically dispersed	What is the true carbon footprint once transport is included?
Bio-based/renewable feedstock — aligns with circular and bio-economy narratives	Manufacturing intensity — concerns over energy, water and chemical use during processing	How energy- and chemical-intensive is the manufacturing process?
Potential farmer value — offers alternative revenue or disposal routes for agricultural waste	Industrial dependency — often reliant on industrial composting or specialist infrastructure	Is industrial composting required, and is that infrastructure available at scale?
Local/regional production potential — opportunity for EU-based or regional supply chains	Blended material challenges — blends may undermine recyclability and circular claims	Can blended fibres (e.g. poly-lyocell) be recycled effectively?
Better than fossil-based alternatives — viewed as preferable to conventional synthetics	Scalability concerns — unclear ability to scale supply, processing and demand simultaneously	Is the business model genuinely scalable beyond niche volumes?
Strong narrative for brands — compelling sustainability story if communicated transparently	Consumer value unclear — benefits may be abstract or invisible to end users	What is the tangible benefit for the consumer (performance, cost, durability)?
Material versatility — potential for multiple applications if developed further	Design limitations — questions around colour, finish, performance and durability	Does the material meet design, colour and performance requirements?
Alignment with circular intent — demonstrates innovation beyond virgin material substitution	System dependency — success relies on aligned policy, infrastructure and behaviour	Where is the material sourced, and how resilient is the supply chain?

Hypothetical case study 1 — circular innovation in material design: summary of pros, cons and queries raised by all workshop attendees, mapped against the 4 circular innovation themes.

Theme	Pros	Cons/risks	Key queries
Material design	• Uses bio-based or waste-derived feedstocks • Reduces reliance on virgin fossil inputs • Strong sustainability narrative	• True environmental benefit unclear once processing and transport included • Potentially high chemical, water and energy inputs	What is the full LCA including transport, processing and yield losses?
Material sourcing	• Potential versatility across applications • Opportunity to design out virgin inputs	• Blending with synthetics undermines circularity • Performance, durability and colour constraints	Can the material meet performance and aesthetic requirements without blends?
Recycling	• Some alignment with compostable or biodegradable narratives	• End-of-life pathways unclear or infrastructure-dependent • Risk of downcycling or disposal	Is there a credible, scalable end-of-life route in current systems?
Business models	• New value streams for waste and agricultural by-products • Attractive storytelling for brands	• Scalability uncertain • Dependent on policy, infrastructure and consumer behaviour	Can this model scale beyond niche volumes without subsidy or exception handling?

Hypothetical case study 2 — circular innovation in material sourcing: summary of pros, cons and queries raised by all workshop attendees.

Pros	Cons/risks	Key queries/unknowns
Clear circular intent — explicitly framed around closing loops and reducing waste	High system dependency — effectiveness relies on aligned infrastructure, policy and coordination	Under what system conditions does this deliver genuine sustainability benefits?
Potential reduction in waste and leakage — aims to divert materials from disposal pathways	Operational complexity — requires coordination across multiple actors and stages	How manageable is this model in real-world, fragmented supply chains?
Improved transparency and traceability — greater visibility of material flows and outcomes	Data and monitoring burden — tracking and verification may be resource-intensive	Who owns, manages and funds ongoing data collection and verification?
Alignment with regulatory and policy direction — fits emerging extended producer responsibility and circular policy agendas	Cost implications unclear — additional operational and compliance costs may be significant	How are additional costs distributed across the value chain?
Encourages shared responsibility — shifts focus away from single-actor solutions	Governance ambiguity — unclear accountability if outcomes fall short	Who is ultimately responsible for performance and compliance?
Scalable in principle — could be expanded across regions or product categories	Scalability unproven in practice — pilot success may not translate to scale	What barriers emerge when moving from pilot to system-wide deployment?
Learning value for the sector — surfaces structural barriers and leverage points	Risk of formalising inefficiency — system may optimise around existing consumption patterns	Does this reduce absolute impacts or mainly improve system management?
Supports stronger sustainability narratives — credible framework if implemented well	Behavioural reliance — depends on sustained engagement by organisations and users	What level of behavioural change can realistically be expected and maintained?

Hypothetical case study 2 — circular innovation in material sourcing: summary of pros, cons and queries raised by all workshop attendees, mapped against the 4 circular innovation themes.

Theme	Pros	Cons/risks	Key queries
Material design	• System-level design improves transparency and traceability • Enables better monitoring of material flows	• Design complexity increases administrative and data burdens • Risk of prioritising management over impact reduction	Does improved tracking translate into lower environmental impact?
Material sourcing	• Focus on retaining materials within managed loops • Potential reduction in leakage and waste	• Material impact depends on system compliance rather than material properties • Limited influence on upstream material choice	Does this materially reduce virgin material demand?
Recycling	• Strengthens collection, sorting and recovery coordination • Aligns with extended producer responsibility principles	• Effectiveness depends on local infrastructure and participation • Recycling outcomes remain uneven across regions	Are recovery pathways sufficiently available and consistent at scale?
Business models	• Embeds shared responsibility across the value chain • Aligns well with emerging regulatory frameworks	• Cost allocation unclear • Governance and accountability risks at scale	Who pays, who benefits and who is accountable if targets are missed?

Hypothetical case study 3 — circular innovation in recycling: summary of pros, cons and queries raised by all workshop attendees.

Pros	Cons/risks	Key queries/unknowns
Reduced reliance on virgin materials — substitution away from fossil-based or high-impact inputs	System dependency — environmental benefits rely on specific infrastructure, policy alignment and behaviour	Under what conditions does this solution deliver net environmental benefit?
Clear circular intent — design explicitly framed around circular principles	Scale limitations — feasibility beyond pilot or niche volumes is unclear	Can this scale commercially without bespoke handling or subsidy?
Potential for material recovery — conceptually compatible with recycling or reuse pathways	Operational complexity — sorting, processing or separation may be impractical at scale	How realistic are recovery rates in real-world systems?
Innovation beyond incremental efficiency — challenges linear production logic	Cost competitiveness — higher costs relative to incumbent materials or processes	Who bears the additional cost, and is there willingness to pay?
Alignment with sustainability narratives — attractive for brand positioning and signalling	Risk of burden shifting — impacts may be displaced to other lifecycle stages	Does improvement in 1 stage worsen impacts elsewhere?
Encourages cross-sector collaboration — requires engagement across value chain	Governance gaps — unclear ownership of responsibility across life cycle	Who is accountable for performance at end of life?
Learning value for the sector — highlights practical constraints and trade-offs	Consumer benefit unclear — limited visible value for end users	What is the tangible consumer proposition (performance, durability, cost)?
Potential policy relevance — exposes where regulation could unlock impact	Fragile circular loops — feedback loops are weak or theoretical	What policy or infrastructure changes are required to make loops viable?

Hypothetical case study 3 — circular innovation in recycling: summary of pros, cons and queries raised by all workshop attendees, mapped against the 4 circular innovation themes.

Theme	Pros	Cons/risks	Key queries
Material design	• Design framed explicitly around circular principles • Moves beyond incremental efficiency improvements	• Added complexity may undermine robustness • Limited clarity on performance and durability	Does the design deliver equivalent or superior functional performance?
Material sourcing	• Reduced reliance on virgin or high-impact inputs • Intentional shift away from fossil-based materials	• Environmental gains highly conditional on system context • Risk of burden shifting across life cycle stages	What is the full life-cycle impact once all stages are considered?
Recycling	• Conceptually compatible with recovery or recycling pathways • Signals intent to close material loops	• Sorting, separation or processing may be impractical at scale • Circular loops appear fragile or theoretical	Are recovery pathways viable within existing infrastructure?
Business models	• Encourages cross-value-chain collaboration • Offers learning value for future system design • Strong alignment with sustainability narratives	• Cost competitiveness remains uncertain • Scale beyond pilots unclear • Responsibility for end-of-life governance poorly defined	Who pays, who benefits and who is accountable at scale?

Hypothetical case study 4 — circular innovation in business models: summary of pros, cons and queries raised by all workshop attendees.

Pros	Cons/risks	Key queries/unknowns
Clear circular ambition — intervention explicitly designed to disrupt linear models	System reliance — effectiveness depends on aligned infrastructure and governance	Under what system conditions does this deliver real sustainability gains?
Potential to reduce material waste — aims to keep materials in use for longer	Limited impact at scale — benefits may diminish when expanded beyond pilots	Can this operate effectively at commercial scale?
Improved resource efficiency — better utilisation of existing assets/materials	Operational complexity — coordination across actors adds friction and cost	How complex is implementation across real-world supply chains?
Supports circular narratives for industry — aligns with policy and brand sustainability agendas	Economic viability unclear — cost structure and margins not well evidenced	Is the model financially viable without ongoing support or subsidy?
Encourages collaboration across value chain — shared responsibility rather than single-actor solution	Governance ambiguity — unclear ownership of outcomes and liabilities	Who is responsible for performance and outcomes over time?
Learning value for future innovation — exposes practical trade-offs and constraints	Risk of rebound effects — efficiency gains may enable increased throughput	Does this reduce absolute impacts or simply improve efficiency?
Potential policy relevance — highlights where regulation could enable impact	Behavioural dependence — relies on changes in user or organisational behaviour	What level of behaviour change is realistically achievable?
Flexible in principle — could be adapted to different contexts or sectors	Context specificity — transferability between regions or sectors uncertain	How transferable is this model across markets and geographies?

Hypothetical case study 4 – circular innovation in business models: Summary of pros, cons and queries raised by all workshop attendees, mapped against the 4 circular innovation themes.

Theme	Pros	Cons/risks	Key queries
Material design	- Designed to challenge linear patterns of use - Emphasises longevity and better resource utilisation	- Design effectiveness depends on consistent user or organisational engagement - Complexity may reduce uptake	How robust is the design under real-world conditions and user behaviour?
Material sourcing	- Focus on extending use of existing materials rather than introducing new virgin inputs - Potential reduction in material waste	- Absolute material impact may be limited at scale - Risk that efficiency gains enable higher throughput	Does this reduce total material demand or only improve utilisation?
Recycling	Indirectly supports waste reduction by keeping materials in use longer	- Does not directly resolve end-of-life challenges - Recycling remains downstream and external to the model	How does this interact with existing recycling or disposal systems?
Business models	- Strong emphasis on shared responsibility and collaboration across actors - Potential alignment with policy and circular economy narratives	- Economic viability uncertain without scale or policy support - Governance and accountability unclear	Who captures value, who bears cost and who is accountable at scale?

Matrix of Circular Innovation

Industry Practices

Disclaimer:

All information is correct at the time of publication. UAL FTTI is not responsible for the content on any external websites.

This Matrix of Circular Innovation Industry Practices contains a synopsis of information published on each individual company's website. Although every attempt has been made to ensure accurate representation, UAL FTTI cannot be held responsible for content. It is advised to visit individual websites for the latest information.

29acacia UK

<https://29acacia.com/>

29acacia produces natural textiles made from 100% agricultural banana waste, as an alternative to cotton and viscose. The company reports a 90% lower carbon footprint than that of conventional cotton, and a transparent supply chain, from plant to finished fabric. Through ethical sourcing that supports communities, the company pays low-income farmers for agricultural waste that's usually discarded.

Aeropowder UK

<https://www.aeropowder.com/>

Aeropowder utilises chicken feathers from the food industry and harnesses their properties to create a range of products, from insulation to structural reinforcement in biocomposites. An example of this is PluumoPlus, designed to replace expanded polystyrene as a thermal packaging material for life science or pharmaceutical deliveries. This approach aims to replace the use of polystyrene, reducing waste and repurposing end-of-life feathers.

Aerseeds UK

<https://www.rca.ac.uk/business/terra-carta-design-lab-projects/aerseeds/>

Aerseeds is a reforestation and ecosystem recovery concept offering wind-dispersed pods containing seed and nutrients made from food waste accelerating the regeneration process. The pods aim to reach degraded or hard-to-access land, improve soil conditions and raise seed survival rates, supporting biodiversity and forest recovery through a distributed network of local and global partners.

Airlite® International

<https://airlite.com/en/>

Airlite® is an innovative microbial paint and coating that actively purifies the air and eliminates odours. Copying lightning in nature, its patented semiconductor technology neutralises pollutants present in the air once they come into contact with Airlite®. The paint and coatings have a lower impact due to being made from 40% recycled materials in a factory powered by 100% renewable energy. The coating has been used on the Falabella Tiny tote bags by Stella McCartney.

Alexander Clementine UK

<https://alexanderclementine.com/>

Alexander Clementine produces underwear using fabric made from a blend of SeaCell seaweed fibre and Tencel wood pulp, both produced through closed-loop processes that minimise chemical waste and resource use. The seaweed is sourced from Icelandic fjords, and selectively harvested and untreated to enable embedded nutrients remain active in the fibre and may offer skin benefits.

Algreen UK

www.algreen.tech

Algreen has developed a fully biocomposite, biodegradable polyurethane (PU) intended to replace petroleum-derived PU plastics across industries including fashion, cosmetics, packaging, automotive and medical manufacturing. Produced from renewable feedstocks, it provides a lower-carbon alternative for applications such as adhesives, coatings, foams, vegan leather and sequins, reducing reliance on fossil-based chemicals in material production.

AltMat International

<https://altmat.in/>

AltMat converts agricultural and food-crop waste into cellulose fibres and yarns, which can be blended with materials such as cotton, modal or recycled polyester to reduce environmental impact. The company develops scalable material technologies for textiles, packaging and composites, and has progressed its Alttag fibre from laboratory research to pilot production and industrial-scale manufacturing.

Amphico International

<https://www.amphico.uk/>

Amphico has developed Amphitex™, a PFAS-free waterproof and breathable textile based on polyolefin layers designed to form a mono-material system. Its microporous membrane blocks liquid water while allowing vapour to pass, aiming to match the performance of conventional waterproof textiles. The company states that the material can be recycled with compatible fabrics, potentially enabling garments and production offcuts to be processed within the same material stream.

AMSilk International

<https://www.amsilk.com/>

AMSilk produces silk proteins through microbial fermentation, creating fibres and yarns for textile, medical and technical applications. Using protein engineering and biotechnology, the company develops materials inspired by natural silk that can be processed using conventional textile manufacturing methods. AMSilk states that its silk protein fibres are fully bioderived and designed to be recyclable or biodegradable at the end of their life cycle.

Ananas Anam — Piñatex® International

<https://www.ananas-anam.com/>

Ananas Anam develops materials from pineapple leaf fibre (PALF), an agricultural by-product of pineapple harvesting. The fibre is used to produce Piñatex®, a non-woven textile used as an alternative to leather in products such as footwear, bags and interiors.

Ananas Anam International

<https://www.ananas-anam.com/>

Ananas Anam also uses pineapple leaf fibres to create Piñayarn®, a yarn blended with other plant-based fibres such as Tencel for textile applications. By valorising agricultural waste that is often burned, the process aims to reduce emissions while creating additional income streams for farming communities in the Philippines.

Arda UK

<https://arda.bio/>

Arda develops materials from spent grain, a by-product of beer and whisky production. Using plant proteins extracted from this waste stream, the company produces New Grain™, a plastic-free, leather-like material designed for applications in fashion, automotive and interiors. The material aims to transform abundant brewing by-products into higher-value alternatives to conventional synthetic or animal-based materials.

Balena International
<https://balena.science/>

Balena makes bioderived thermoplastics for circular products. Its BioCir®flex elastomers, from renewable feedstocks, replace conventional plastics in moulded and 3D-printed items. Variants include BioCir®flex3D, industrially compostable for additive manufacturing, and BioCir®Foam, a lightweight cushioning material for footwear and performance uses.

Bananatex® International
<https://bananatex.info/>

Bananatex® is a durable, breathable textile made from abacá banana plant fibres grown in pesticide-free agroforestry systems in the Philippines. The fibres are spun and woven into fabric for bags, apparel and accessories, and the plant-based material is designed to be biodegradable and compostable at end of life.

Biofabricate International
<https://www.biofabricate.co/>

Biofabricate promotes a shift to materials grown with biology, uniting design and biotechnology to help start-ups and brands develop biofabricated materials and applications. It focuses on replacing animal-, agriculture- and fossil-derived inputs with renewable, low-impact biological systems, supporting a more sustainable, circular and innovation-driven material economy.

BioFluff International
<https://bio-fluff.com/>

BioFluff developed Savian, a range of plant-based fur, shearling and plush alternatives, from natural fibres. The materials are designed to replace animal and synthetic fibres while remaining compatible with conventional textile manufacturing. The process can significantly reduce CO2 emissions compared with conventional fur and synthetic plush materials.

Bolt Threads International
<https://boltthreads.com>

Bolt Threads develops biocomposite materials using biotechnology and mycelium. Microsilk™ is a GMO-free silk-like fibre made by fermenting engineered yeast, while Mylo™ is a mycelium-grown, leather-like alternative for fashion and accessories.

Buyo International
<https://buyoplastic.com/our-products/our-products.html>

Buyo develops bioplastics from organic waste using proprietary fermentation and material processing technologies. The Vietnam-based company converts agricultural and food waste into bioplastics and biocomposites designed for medical, cosmetic and industrial applications. Buyo states that its materials are biodegradable and offer a lower-carbon alternative to conventional plastics.

CelluComp UK
<https://www.cellucomp.com/>

CelluComp's Curran® is a microfibrillated cellulose made from the residual pulp of root vegetables, primarily sugar beet. Extracted as microscopic, platelet-like fibre bundles, it delivers strong mechanical and rheological performance for applications from packaging to coatings. By avoiding isolated nanofibres, Curran® offers nano-scale benefits without the economic, safety or environmental drawbacks.

Citribel UK
<https://www.aeropowder.com/>

Citribel develops MycaNova®, a mycelium-based material produced through fermentation and processed into a versatile powder that can be formulated into different bioderived materials. By upcycling high-volume mycelium generated in its bioprocesses, the material is designed for applications including packaging, fashion, footwear, furniture and automotive interiors.

Colorifix UK
<https://www.colorifix.com/>

Colorifix uses engineered microbes to produce and fix colour directly onto textiles, replacing chemical dye extraction and application. By identifying natural pigments in DNA databases and fermenting colour-producing microbes on simple, non-hazardous feedstocks, it enables low-water, low-chemical dyeing for natural and synthetic fibres, delivering industrial-grade performance with far lower environmental impact.

Coronet International
<https://coronetspa.it/en/>

Coronet's Yatay™ materials are alternative leathers combining biocomposite content, recycled fibres and mycelium with polyurethane to reduce reliance on animal leather and fossil inputs. Variants include solvent-free and biocomposite options designed to cut chemical use and environmental impact while fitting existing manufacturing processes.

Deap International
<https://www.deap-store.com/en/249-p-from-sea-weed-to-fibre-deap-store>

Deap develops seaweed-based fibres produced through the Lyocell process, using renewable seaweed that grows without freshwater or fertiliser. The fibres are compostable, thermoregulating and naturally contain minerals associated with skin-contact textiles. The material is produced in Austria and holds EU and OEKO-TEX® certifications.

Doppelhaus Ltd UK Cloudwool®
<https://cloudwool.co.uk/>

Doppelhaus's Cloudwool® is a lightweight, non-woven textile made from British and European wool, mechanically bonded without chemical binders. Designed for fashion uses, it offers flexibility and breathability, uses locally sourced wool that might otherwise be wasted, and retains the fibre's natural compostability.

Ecovative International
<https://ecovative.com/>

Ecovative's Mushroom Packaging is a mycelium-and-hemp alternative to foam packaging, grown rather than manufactured. The material forms in seven days, creating a naturally insulating, water-resistant structure that is fully home-compostable within 45 days. Custom shapes are grown in moulds, dried to stop growth, and used as protective, low-impact packaging for shipping.

Eranova International
<https://eranovabioplastics.com>

Eranova makes bioderived ALGX resins from green macroalgae collected from polluted shorelines, turning a waste problem into recyclable and compostable bioplastics. Its patented process yields more biomass and starch than land crops, enabling durable, low-impact formulations that support circular plastics with reduced land use.

FISHSkin International
<https://www.fishskinhorizon.org/>

FISHSkin is a Horizon 2020 research initiative exploring how waste fish skins from European aquaculture can be transformed into a viable, circular raw material for fashion. The consortium developed modern, low-impact tanning, printing and adhesion techniques, created tools for designing and simulating fish-leather products, and outlined strategies to scale fish-skin leather and integrate it into European markets and circular aquaculture-fashion value chains.

Fulgar International
<https://www.fulgar.com>

Fulgar develops lower-impact polyamide yarns that maintain conventional performance while using alternative feedstocks or end-of-life routes. These include landfill-degradable Amni Soul Eco®, biocomposite Evo®, mass-balance Q-Cycle® from end-of-life tyres, and Q-Geo®, a partially biocomposite polyamide from renewable sources.

Hydefy International
<https://www.hydefy.com/>

Hydefy develops materials based on Fy™, a fungal protein produced through fermentation. The protein is combined with plant-derived inputs, including sugarcane by-products, to create textile materials designed as alternatives to leather and synthetic-coated fabrics. The process aims to reduce resource use while remaining compatible with existing manufacturing and supply chains.

Hylo Athletics International
<https://hyloathletics.com/blogs/champions-of-tomor->

Hylo Athletics makes performance running shoes with a lower footprint by using biocomposite materials, local supply chains and recyclable design. Its PureGlide™ midsoles and CleanTech™ outsoles use plant-based, data-driven engineering, while castor-bean uppers add comfort and breathability. The brand focuses on continual carbon reduction and improved recycling.

Keel Labs International
<https://www.keellabs.com>

Keel Labs' Kelsun™ is a seaweed-based fibre made from fast-growing marine biopolymers that require no freshwater or arable land. Suitable for woven and non-woven textiles, it is bioderived, biodegradable under tested conditions, and offers inherent flame-resistant and antibacterial properties.

Keracol UK
<https://www.keracolscience.com/>

Keracol develops natural ingredients and materials through sustainable sourcing and green chemistry. It extracts and analyses raw materials to create functional formulations for cosmetics, colouration and bioderived materials, offering R&D services including sourcing, testing, formulation development and scale-up support.

Kraig Biocraft International
<https://www.kraiglabs.com/>

Kraig Biocraft develops spider-silk fibres using genetic engineering. The company inserts spider-silk gene sequences into domesticated silkworms, enabling them to produce silk with properties similar to natural spider silk. This approach aims to enable scalable production of high-performance fibres for textile and technical applications.

Kuori International
<https://www.kuori.ch>

Kuori develops biocomposite elastomers and polymers from food-industry by-products like olive pits and nutshells. Its range includes Biowa® thermoplastic elastomers, faster-degrading Biowa HC, PHA-based Material B for items like footwear soles, and Material C, a vulcanised rubber designed for chemical recycling each compatible with existing manufacturing.

LabFresh International
<https://labfresh.co.uk/pages/fresh-take-on-sustainability>

LabFresh aims to create long-lasting clothing using FreshCore, a yarn-level technology that wraps each fibre to deliver durable stain, odour and wrinkle resistance without surface coatings. By enabling garments to be worn more and washed less, the brand reduces waste, resource use and environmental impact while pairing performance with timeless design.

LanzaTech International
<https://lanzatech.com/>

LanzaTech converts industrial CO₂ and carbon-rich waste gases into new materials using proprietary biofermentation, giving captured carbon a second life in products such as sustainable aviation fuel. By partnering with heavy-emitting industries and downstream brands, it integrates recycled carbon into supply chains, reducing emissions while creating circular, low-carbon materials.

Loop Biotech International

<https://loop-biotech.com/mission/>

Loop Biotech grows fully natural, biodegradable funeral products from mycelium and locally sourced plant fibres, creating coffins, beds and shrouds that enrich soil rather than pollute it. By harnessing mycelium's ability to transform organic matter into nutrients, it offers regenerative, earth-positive alternatives to conventional burial materials.

LaundRe UK

<https://www.laundre.co.uk/>

LaundRe uses laser, ozone and nebulising technologies to create low-impact denim finishes, helping brands cut waste, carbon emissions and overproduction. Through its ReFinish, ReShoring and ReEducate programmes, it supports circular denim processing, on-demand UK finishing and industry training for a cleaner, more resilient supply chain.

Mabel International

<https://mabelindustries.com>

Mabel's Uppeal™ is a partly bio-derived, vegan leather alternative made from apple-processing waste collected in Northern Italy. By converting dehydrated apple pulp, skins and seeds into Frumat Apple Powder and combining it with polyurethane for durability, Mabel creates a waterproof, versatile material that replaces fossil-based inputs through local industrial symbiosis.

Modern Meadow International

<https://www.modernmeadow.com/>

Modern Meadow's Innovera™ is an animal-free leather alternative made from plant-based proteins, biopolymers and recycled rubber. Designed to mimic collagen's structure for fashion and footwear, it offers consistent quality, fits existing manufacturing without major changes, and provides a scalable, cost-efficient, more sustainable next-gen material.

Modern Synthesis UK

<https://www.modernsynthesis.com/>

Modern Synthesis creates biocomposite materials using bacterial nanocellulose produced via fermentation. Microbes convert sugars into nanocellulose fibres, which form biofilms that can be combined with textile backings into composites. These bioderived materials are designed to replace leather and synthetic-coated textiles while remaining compatible with existing industrial processes.

Natural Fiber Welding, Inc. (NFW) International

<https://nfw.earth/>

Natural Fiber Welding creates plant-based material technologies to replace fossil-based plastics. Clarus® strengthens natural and recycled fibres for high-performance textiles; Mirum® is a leather alternative made from natural ingredients; Tunera™ is a biocomposite foam for footwear and cushioning; and Pliant™ is a natural-rubber outsole material all compatible with existing manufacturing.

Nature Coatings UK

<https://www.naturecoating-sinc.com/>

Nature Coatings' BioBlack® is a biocomposite black pigment made from FSC-certified industrial wood waste via an oxygen-limited process. Designed as a sustainable alternative to petroleum-based carbon black, it works in textiles, leather, coatings and packaging, with drop-in options like BioBlack TX™ and water-based dispersions.

NatureWorks International

<https://www.natureworksllc.com>

NatureWorks' Ingeo™ is a PLA biopolymer made from plant sugars fermented from renewable feedstocks like corn, sugarcane and cassava. It's used for fibres, nonwovens and plastics as alternatives to petroleum-based materials. The company is also researching microbial pathways that turn greenhouse gases or biomass into lactic acid for future production.

Octarine Bio International

<https://www.octarinebio.com/>

Octarine's PurePalette™ dyes are non-toxic, fermentation-derived colourants made from renewable resources. Engineered through microbial design, they offer strong colour, broad fibre compatibility and ambient-condition dyeing, cutting water, energy and chemical use while integrating easily into existing supply chains.

On UK

<https://www.on.com/en-gb/>

CleanCloud® is a carbon-based EVA foam created by On with LanzaTech and Borealis, turning captured industrial emissions into high-performance cushioning for running shoes. Carbon monoxide is fermented into ethanol, converted to ethylene and polymerised into EVA pellets, enabling a scalable, lower-carbon material that can replace conventional fossil-based foams across footwear applications.

Orange Fiber International

<https://orangefiber.it/>

Orange Fiber creates circular cellulose fibres from citrus-juice by-products, transforming pastazzo waste into a cotton-like material that can be spun into yarns and fabrics. By partnering with Lenzing to produce Tencel™ x Orange Fiber, it reduces reliance on virgin resources, diverts significant citrus waste and continually improves efficiency and environmental impact across its process.

Pact UK

<https://pact.earth/>

Pact's Oval™ transforms upcycled collagen from industries like cosmetics and pharmaceuticals into flexible sheets for textiles and leather-like materials. Made with natural ingredients and compatible finishing processes, it creates adaptable, bioderived materials designed to integrate smoothly into existing manufacturing systems.

Phycolabs International

<https://www.phycolabs.com/>

Phycolabs uses fast-growing seaweed as a renewable raw material to create high-performance threads that offer a lower-impact alternative to conventional textiles and strengthen local value chains. Its approach blends nature-inspired efficiency with scalable innovation for a more sustainable fashion system.

Pili International

<https://www.pili.bio/en/homepage/>

Pili makes bioderived colourants using fermentation and organic chemistry to replace petroleum-based dyes. Made from renewable agricultural resources, the pigments cut toxic chemicals and fossil inputs, target up to 50% lower CO2 emissions, and provide drop-in options such as bio-composite indigo that match petrochemical performance in existing dyeing systems.

Planet of the Grapes International

<https://planetofthegrapes.fr/>

Planet of the Grapes turns grape-marc waste from Provence vineyards into an 84% bioderived, REACH-compliant leather alternative. Made through a short, low-carbon, traceable supply chain with a bio-PU blend for durability, it is co-developed with partners to enhance performance and scale responsibly.

Ponda UK

<https://www.ponda.bio/>

Ponda's BioPuff® is a regenerative insulation made from bulrush grown on rewetted, carbon-sequestering wetlands. The fast-growing plants restore peatlands, support biodiversity and provide farmers with new income. BioPuff® is lightweight, warm and water-repellent, replacing feather and synthetic fills while remaining fully traceable from wetland to product.

Positive Materials International

<https://www.positivematerials.com/>

Positive Materials creates biosynthetic and bioderived textiles inspired by nature, using regenerative agriculture, green chemistry and circular design. It reduces waste through recyclability, textile-to-textile systems and upcycled crop or food residues. As part of PDS Group, it scales sustainable material innovation through global manufacturing and responsible fibre development.

Post Carbon Lab UK

<https://www.postcarbonlab.com/>

Post Carbon Lab develops microbial colour, pigment and coating technologies that use photosynthesis to turn carbon emissions into dyes. Its living finishes capture CO2, reduce chemical dyeing and enable photosynthetic or pollution-filtering textiles, offering regenerative, low-impact alternatives to conventional wet-processing for climate-positive production.

QWSTION International

<https://qwstion.com/>

QWSTION develops plant-based bags and everyday goods, centred on its Cradle to Cradle Certified™ and fully biodegradable textile Bananatex®, made from regeneratively grown banana plants. Guided by Swiss modernist principles, the brand continually refines material performance, construction and sustainability, ensuring every component meets high standards of durability, functionality and responsible design.

Resilin International

<https://www.smartresilin.com/>

Resilin is a biodegradable, non-toxic protein originally found in insects and known for exceptional elasticity. By inserting resilin-coding DNA into bacteria, the company produces scalable, tailored proteins with near-perfect elasticity for uses from adhesives and sports goods to flexible electronics, cosmetics and 3D printing offering a high-performance, lower-impact alternative to synthetic elastomers.

Rheon™ UK

<https://rheonlabs.com/>

Rheon™ is a NASA-origin super-polymer that behaves as a metamaterial: soft and flexible in motion but dynamically stiffening on impact to dissipate far more energy than static materials. Developed over 15 years at Imperial College London, it dampens vibration, adapts to movement and can be injection-moulded or integrated into textiles for bespoke, high-performance protection and comfort.

SaltyCo UK

<https://litac.leeds.ac.uk/funded-projects/saltyco/>

SaltyCo grows salt-tolerant, fibre-bearing plants using saline agriculture to create the first natural textiles that require no freshwater. Its climate-positive fibres and insulation prototypes offer vegan, petroleum-free alternatives to down and polyester, while regenerating salt-damaged land, sequestering carbon and reducing the fashion industry's dependence on freshwater and fossil-based materials.

Scindo UK

<https://scindo.bio/>

Scindo engineers enzymes using proprietary datasets and AI to replace fossil-based chemistry with renewable or recycled carbon feedstocks. Its advanced biocatalysts break down plastics, reduce reliance on crude oil and enable low-energy, low-waste synthesis of ingredients for sectors like cosmetics, nutrition and materials.

Sequinova UK

<https://www.sequinova.com/>

Sequinova creates plant-based, biodegradable sequins made from sustainably sourced cellulose, offering a fully compostable alternative to plastic embellishments. Using a green chemical process and pigments from bioengineered microorganisms, it is also developing high-performance bioderived colours to replace fossil-derived dyes, bringing circularity and lower-impact design to fashion embellishment systems.

Seprify International
<https://seprify.com/categories/other>

Resilin is a biodegradable, non-toxic protein originally found in insects and known for exceptional elasticity. By inserting resilin-coding DNA into bacteria, the company produces scalable, tailored proteins with near-perfect elasticity for uses from adhesives and sports goods to flexible electronics, cosmetics and 3D printing offering a high-performance, lower-impact alternative to synthetic elastomers.

Söktaş International
<https://www.soktas.com.tr/sustainability/>

Söktaş applies an integrated sustainability approach across its vertically controlled cotton supply chain. In partnership with Türkiye's Cotton Research Institute, it developed Meander 71, a cotton variety with exceptionally fine, strong, silky fibres. Fully traceable and grown regeneratively, it rivals premium Egyptian cotton and underpins Söktaş's super-fine, durable fabrics.

Solena Materials UK
<https://www.solena-materials.com/>

Solena Materials designs AI-engineered proteins to create biodegradable, non-oil-derived fibres for apparel. Built for scalable, solvent-free manufacturing, these fibres match or exceed natural and synthetic performance. Automated labs and rapid testing feed data into deep-learning models, accelerating the development of tailored next-generation biomaterials.

Solum UK
<https://solumtread.com/>

Solum™ replaces petrochemical additives in rubber outsoles with 100% bioderived plant nutrients. Its Bio-Tread™ technology releases beneficial nutrients that support soil and plant health. Verdura™ is a plant-derived, low-cost alternative to petrochemical processing aids; delivery reinforcement, plasticisation, dispersion, tack, antioxidant protection and processing efficiency, offering a durable, renewable alternative to fossil-based additives.

Sparxell UK
<https://sparxell.com>

Sparxell creates 100% natural, biodegradable structural colour pigments inspired by the iridescence of plants and animals. Made from cellulose, its photonic pigments, films, foils and sequins deliver vivid, fade-resistant colour and shine without metals, minerals or microplastics. This biomimetic platform gives designers high-performance, sustainable alternatives to conventional pigments and embellishments.

Spiber International
<https://spiber.inc/en>

Spiber's Brewed Protein™ is a biodegradable, non-oil-derived protein fibre produced through fermentation using plant-based sugars, offering significantly lower emissions and water use than cashmere. Engineered at the molecular level, it mimics the qualities of cashmere, wool and silk, and can be spun into textures ranging from smooth and luxurious to fleece-like. Automated processing of staple fibres allows precise control over porosity, twist and performance, enabling versatile, high-quality textiles.

Stella McCartney x Veuve Clicquot UK
<https://www.stellamccartney.com/gb/en/stellas-world/veuve-clicquot-grape-based-vegan-alternative.html>

Stella McCartney and Veuve Clicquot's Vegea® is a grape-based, vegan leather alternative made from 80% renewable and recycled plant materials. Using regeneratively grown grape stems and a solvent and metal-free process, it cuts global-warming impact by 40% and water use by 50% compared with fossil-based alternatives, supporting circular and regenerative design commitments.

SQIM International
<https://www.sqim.bio/>

SQIM develops mycelium-based, bioderived materials through fermentation, combining biotechnology, design and vertical farming to create scalable alternatives for fashion, interiors and architecture. Its pure-mycelium Ephea™ offers supple, premium biofabricated textiles, while Mogu turns organic residues into durable acoustic and interior products showcasing how fungal systems regenerate waste into versatile, low-impact materials.

SwitchDye UK
<https://www.switchdye.co.uk/>

SwitchDye is a drop-in dyehouse technology developed at the University of Leeds that replaces multiple auxiliaries with a single intelligent chemical, activated by small amounts of CO₂. It delivers industry-standard colour with fewer rinses, cleaner water, lower energy use and major cuts to chemical load and Scope 3 emissions all without changing equipment or disrupting production.

TômTex International
<https://www.tomtex.com/>

TômTex creates bioderived, biodegradable, petrochemical-free materials from chitosan sourced from seafood waste (Series WS) or mushrooms (Series M). Cast via a roll-to-roll process, the materials can be tuned for colour, texture, drape and thickness, replicating leather-like aesthetics or enabling new designer-driven material expressions.

Uncaged Innovations UK
<https://uncagedinnovations.com/>

Uncaged Innovations produces grain-based bio-leather that mimics the fibril structure of animal collagen, delivering leather-like strength, durability and feel without animals or petrochemicals. Its BioFuze technology engineers plant proteins into a high-performance material customisable in thickness, texture, colour and flexibility for scalable use in fashion, automotive and home goods.

Vegea® UK
<https://www.vegeacompany.com/>

Vegea® produces a plant-based leather alternative made from grape pomace the pulp, skins, seeds and stems left from Italian wine production turning agricultural waste into high-value materials. Using a solvent- and metal-free process, it blends grape biomass with vegetal oils and water-based PU to create soft, versatile, cruelty-free biomaterials that reduce reliance on virgin synthetics and animal leather while supporting circular, nature-based manufacturing.

Material Design	Virustatic® UK https://virustatic.com/	Werewool International https://sofinnovapartners.com/portfolio/werewool	Yugen UK https://www.yugencompany.com/	Zer Collection International https://bcn3d.com/zer-collection-and-technology/		
	Virustatic®'s Viruferrin® is a biomimetic, protein-based antimicrobial coating for textiles that traps, agglomerates and deactivates viruses, bacteria and fungi through a molecular-sieve mechanism. Made from naturally occurring antiviral proteins, it offers an eco-friendly alternative to conventional treatments and remains 99.8% effective after multiple washes, reducing contact-based transmission risks.	Werewool engineers protein-based textile fibres with colour, stretch, strength and moisture management programmed directly into their DNA, eliminating the need for dyes, synthetics and chemical finishes. Inspired by natural systems such as coral, its biomimetic approach creates biodegradable, high-performance fibres designed to replace polyester, nylon, spandex and other petrochemical materials at scale.	Yugen transforms pomegranate-peel agricultural waste into Pomeco, a bioderived vegan leather alternative for fashion, automotive and interiors. Its process embeds circularity from the start, converting discarded biomass into durable, high-quality materials that reduce reliance on finite resources and synthetics while supporting a closed-loop, low-impact materials ecosystem.	Zer Collection uses digital fabrication and 3D printing to create innovative textiles while maintaining a strict zero-waste philosophy. Its locally produced garments prioritise material origin, impact and full resource efficiency. By pushing technological boundaries in fashion, the brand shows how advanced tools like 3D printing can enable sustainable, design-driven, circular production.		
Material Sourcing	Been UK https://been.london/	Kering International https://www.kering.com	Laxtons UK https://www.laxtons.com	Made2Flow UK https://www.made2flow.com/	Materra® International https://www.materra.tech/	Nativa™ International https://www.nativaprecious-fiber.com/
	Been develops products using waste derived and recycled materials, including alternatives made from fruit byproducts, reclaimed plastics, regenerated nylon, and recycled textiles. Other initiatives include Cotton Ace's AI-based pest monitoring system for cotton farming and the Global Organic Textile Standard, which certifies organic fibre textiles through environmental, social, and quality criteria.	Kering's Material Innovation Lab sources and evaluates sustainable materials across the supply chain. It works with suppliers, supports certification, and maintains an archive of certified fabrics. The Lab develops assessment tools, tests new fibres and dyeing technologies, and helps Kering brands choose more sustainable materials.	Laxtons' Wooltrace provides fully traceable yarn designed to support transparency, farmer pay and animal welfare, enabling each batch to be tracked back to its farm. Sheepsoft is a 100% British wool range produced within 50 miles, using specific breeds to ensure durability, traceability and support for UK farming and manufacturing.	Made2Flow is a data-driven platform that measures environmental impact and supports supply chain decarbonisation. It standardises and analyses diverse data sources, uses a large supplier database to enrich datasets, and provides real time tools to identify impact hotspots. Its system recommends practical, cost saving interventions to help brands reduce emissions efficiently.	Materra® supports brands in sourcing fully traceable regenerative cotton, offering extensive data visibility and alignment with major certifications. Its model provides a simplified supply chain setup, on the ground support in India and direct fibre sourcing programmes designed to ensure farmer premiums, lower project costs and reliable access to regenerative cotton.	Nativa™ provides fully traceable wool, cotton and cashmere, certifying each stage from farm to fibre and using blockchain to document supply chain transparency. The programme sets standards for environmental management, animal welfare and social responsibility. NativaRegen™ focuses on improving soil health, supporting farmers and ensuring responsible practices across the wool value chain.

Material Sourcing	Responsible Animal Fibre (RAF) International https://icea.bio/en/certifications/non-food/biological-and-sustainable-textile-products	Segura UK https://www.segura.co.uk/	Sustainable Fibre Alliance (SFA) UK https://sustainablefibre.org/	TextileGenesis™ International https://textilegenesis.com/		
	Responsible Animal Fibre (RAF) is a voluntary Textile Exchange standard combining the Responsible Wool, Alpaca and Mohair Standards. It sets requirements for animal welfare based on the Five Provisions and promotes responsible land management, ensuring farms follow practices that support both animals and the environment.	Segura provides supply chain visibility software that consolidates supplier, order and compliance data into a single system. It maps multitier supply chains, validates supplier relationships and offers detailed reporting and scorecards. The platform helps organisations monitor risks, assess ethical and sustainability performance and analyse supply chain information through centralised dashboards and insights.	The Sustainable Fibre Alliance (SFA) is a nonprofit organisation promoting responsible practices in natural fibre supply chains, particularly cashmere. Its Animal Fibre Standard outlines principles for animal welfare, biodiversity protection, land stewardship, fibre quality and decent work. The SFA's holistic approach reflects traditional pastoral systems and connects herders with global brands.	TextileGenesis™ is a blockchain-based traceability platform that tracks sustainable and conventional fibres from origin to finished product. Using its Fibrecoin™ digital token system, it enables article-level verification across textiles, leather and footwear. The platform integrates with certification schemes and provides real time data to support transparency and regulatory compliance.		
Recycling	Allbirds UK https://www.allbirds.co.uk	Antex International https://antex.net/processes/recycling/	Aquafil International https://www.aquafil.com/the-group/	Carbios International https://www.carbios.com/newsroom/en/about-carbios/	Circular Flow UK https://circularflow.net/	Circulose® International https://circulo.se/en/
	Allbirds developed a net zero carbon shoe using carbon negative materials, including regenerative wool and sugarcane-based green EVA. Working with a regenerative farm in New Zealand, the brand applies wool across the shoe to balance emissions. Only 500 pairs of the Mo.onshot Zero were produced, each individually numbered.	Antex recycles textile waste through thermomechanical processes to produce reusable polymer and a range of recycled yarns. Its Ynviron and Yarnback lines use postconsumer and production waste, while Yarnaway supports accelerated biodegradation. As a Seaqual partner, Antex also creates polyester fibres containing marine plastics to support circularity.	Aquafil produces Econyl®, a regenerated nylon made entirely from waste such as fishing nets, carpets and industrial plastics using a chemical recycling process that maintains material quality. The Azores EcoBlue project converts marine litter and algae from the Azores coastline into new textile and construction materials, transforming around 40 tonnes of waste over two years.	Carbios is a biotechnology company developing enzyme-based processes to break down plastics and textiles. Its technologies for PET bio-recycling and PLA biodegradation aim to reduce pollution and support a circular economy, and are currently being scaled for industrial and commercial use.	Circular Flow addresses neoprene waste by recycling discarded wetsuits into Renoprene®, a reconstituted neoprene material. Its process preserves the textile laminate and produces stable sheets for new products. Developed over six years, the system removes hardware, processes shredded neoprene and enables items to be recycled again at end of life.	Circulose® is a material made from 100% recycled textile waste, replacing virgin cellulose sources like wood pulp. Textile waste is collected, processed into dissolving pulp and converted into regenerated fibres for new fabrics. The process removes contaminants, producing sheets of pure cellulose that are supplied to fibre manufacturers.

Coleo UK

<https://coleo.es/?la=en>

Coleo develops scalable circular solutions by collecting, sorting and processing postconsumer textiles using AI-driven classification and mechanical recycling. Its system removes nonfabric components, optimises material flows and transforms sorted textiles into new fibres and yarns. Products retain inherited colours, avoiding dyeing, and eco-design tools help reduce impacts throughout production.

DyeRecycle UK

<https://www.dyerecycle.com/>

DyeRecycle develops green chemistry technology that recovers dyes from textile waste, addressing both dye pollution and discarded garments. Its process enables chemical circularity by extracting usable colourants from old textiles and reapplying them to new materials, extending dye life while supporting fibre to fibre recycling.

Ecoalf International

<https://ecoalf.com/en-gb/pages/historia>

Ecoalf develops recycled materials and mono-material products to reduce waste, emissions and resource use, aiming for carbon neutrality by 2030. Its DyeRecycle technologies recover dyes and fibres for reuse, while partnerships enable fully recyclable cotton collections. The Ecoalf Foundation collects and recycles marine waste with thousands of fishers across multiple countries.

Eco-Luxe UK

<https://eco-luxe.co.uk/>

Eco-Luxe recycles wool and cashmere offcuts from Savile Row tailors, converting discarded textiles into new luxury cloth. Offcuts are cleaned, garneted and blended with British natural fibres before being spun and woven in the UK. The process preserves traditional craftsmanship while increasing recycled content and supporting circular production.

Elvis & Kresse UK

<https://www.elvisandkresse.com>

Elvis & Kresse repurposes decommissioned fire hoses and other reclaimed materials into accessories while donating half of Fire Hose Collection profits to charity. Its UK-based production uses renewable energy, reclaimed packaging and local supply chains. The company continually develops new uses for waste materials, supporting

Epoch Biodesign UK

<https://www.epochbiodesign.com/>

Epoch Biodesign uses Aldesigned enzymes to recycle hard to process materials, enabling low-temperature breakdown of mixed plastics and textiles. Its platform produces virgin quality polymers with lower emissions and offers a circular solution for nylon 6,6, recovering it from diverse waste streams including coated fabrics, laminates and elastane blends.

Evrnu® International

<https://www.evrnu.com/>

Evrnu® develops regeneration technologies that convert cotton rich textile waste into new recyclable fibres. Its Nucycl® process transforms discarded garments into lyocell fibre through shredding, liquefying and purification, producing material comparable to virgin fibre. The technology is being expanded to support full recyclability across the textile industry.

Fairbrics UK

<https://fairbrics.co/>

Fairbrics develops technology that converts captured industrial CO2 into chemicals used to make polyester, reducing reliance on fossil fuels. Its catalytic and electrochemical processes produce synthetic fibres from emissions, with the long-term aim of creating carbon negative, fully recyclable PET and scaling CO2-based alternatives for textiles and other industries.

FastFeetGrinded International

<https://www.fastfeetgrinded.eu/>

FastFeetGrinded recycles discarded footwear by collecting, dismantling and separating shoes into reusable materials such as foam, rubber, textiles and leather. Its system enables these outputs to be used in new products, playground surfaces and circular footwear, reducing waste and resource use. The company has expanded its capabilities under the Heilig Group.

FibreLab UK

<https://www.fibrelab.co.uk/>

FibreLab is a London-based textile recycling service that mechanically shreds pre-consumer and commercial textile waste into recycled fibre. It tailors processes to client needs, develops new fibre applications and operates a hyperlocal circular model that keeps collection, sorting and remanufacturing entirely within the UK.

Global Recycled Standard (GRS) & Recycled Claim Standard (RCS) UK

<https://www.scsglobal-services.com>

The Global Recycled Standard (GRS) and Recycled Claim Standard (RCS) both provide third-party certification for recycled materials and chain of custody. Each verifies recycled content using aligned definitions, but GRS adds social, environmental and chemical requirements. Certified products are audited across the supply chain and may carry RCS or GRS labels.

Infinited Fiber International

<https://infinitedfiber.com/>

Infinited Fiber produces Infinna™, a regenerated textile fibre made from cotton-rich waste. The process removes noncellulosic components, converts cellulose into a dissolvable carbamate powder and spins it into new fibres suitable for various products. The fibre can be recycled repeatedly, supporting circularity and using ZDHC-compliant chemistry.

LanzaTech International
<https://lanzatech.com/>

LanzaTech uses biofermentation to convert industrial emissions, carbon dioxide and gasified waste into recycled ethanol, which serves as a feedstock for products such as sustainable aviation fuel and textiles. Its CarbonSmart™ polyester incorporates carbon captured through this process, supporting reduced reliance on fossil resources.

Marks & Spencer (M&S) and Oxfam UK
<https://ukft.org/act-uk-ms-and-oxfam/>

M&S and Oxfam trialled a postal donation scheme allowing customers to send both wearable and unwearable clothing for reuse or recycling. The initiative supported the ACT UK project by testing ways to divert damaged garments from waste streams and improve sorting for circular textile systems.

Parley UK
<https://parley.tv/>

Parley Ocean Plastic® is made from intercepted marine plastic collected from beaches, islands and coastal communities. The material is sorted, cleaned, pelletised and spun into yarn for use in fashion, sports and design products. The programme aligns with Parley's AIR strategy and operates global cleanup and recycling partnerships.

Patagonia International
<https://eu.patagonia.com/gb/en/our-footprint/polyester.html>

Patagonia uses recycled polyester to reduce reliance on virgin petroleum, lower emissions and support new recycling streams. It works with certified supply chain partners, explores secondary waste sources and incorporates OceanCycle® certified materials. Recycled polyester is used across many product lines, with the brand aiming to replace remaining virgin polyester entirely.

Project Re:claim UK
<https://project-reclaim.co.uk/>

Project Re:claim, run by Project Plan B and SATCoL, recycles 100% polyester textiles from end of life workwear. Using a heat extrusion process, polyester garments are shredded, filtered and pelletised into PET pellets, which can be spun into new polyester fibres or used for moulding, creating a closed loop recycling system.

Qingdao Amino International
<https://www.qdamino.com/jrwm>

Qingdao Amino's Re:lastane system separates and recycles polyester from blended fabrics. The technology identifies polyester at low temperatures and normal pressure, breaking it down into high purity monomers. This enables the recovery of polyester from mixtures containing cotton, nylon, spandex and other fibres, supporting improved recycling of complex textiles.

Reju International
<https://www.reju.com/>

Reju produces polyester made entirely from textile waste using a regeneration process that avoids bottle-based inputs. Its system delivers traceable, lower emission recycled polyester with fewer impurities and no thermal damage. The resulting fibre aims to be more durable, with improved performance and comfort compared with conventional or mechanically recycled alternatives.

Reskinned UK
<https://www.reskinned.clothing/>

Reskinned supports circular fashion by enabling resale, repair and fibre to fibre recycling. It works with brands to repurpose end of life garments, mechanically recycling pure cotton and selected blends. The service removes nontextile components, shreds materials for processing and invests in new technologies to expand recycling options and reduce reliance on new fabrics.

Resortecs International
<https://resortecs.com/about-us/>

Resortecs offers textile waste solutions through design for disassembly. Its Smart Stitch™ heat-dissolvable threads and Smart Disassembly™ thermal system automate the separation of multi-material garments, boosting recycling efficiency. The system helps brands, sorters and recyclers dismantle pre- and post-consumer garments across fashion, workwear and other sectors.

Re-Verso™ International
<https://www.re-verso.com/en/about-us/>

Re-Verso™ is a certified, traceable supply chain that recovers post- and pre-consumer wool and cashmere. Green Line manages collection and sorting, Nuova Fratelli Boretti transforms waste into raw material, and partners such as Filpucci, Mapel and Antica Valserchio create regenerated yarns, fabrics and accessories through a collaborative circular system.

Rewritten UK
<https://wearerewritten.com>

Rewritten focuses on reducing material impact by working with manufacturers to incorporate eco-conscious fabrics and digital pattern laying to minimise waste. Its collections use recycled polyester satin, bamboo satin and Lenzing™ EcoVero™ viscose, selected for lower resource use, reduced emissions and improved recyclability compared with conventional alternatives.

Rubi International
<https://www.rubi.earth/purpose>

Rubi converts captured CO2 into cellulose using a cell free enzymatic process, producing carbon negative, resource neutral fibres such as viscose and lyocell. The cellulose integrates into existing textile manufacturing, enabling conventional yarn production. Rubi aims to build scalable planet positive supply chains and apply its technology to additional material sectors.

Recycling	Seasalt UK https://www.seasaltcornwall.com/sustainability	Textile Exchange UK https://textileexchange.org	Worn Again Technologies UK https://wornagain.co.uk/			
	Seasalt works to increase its use of certified sustainable materials while meeting strict ethical standards. It aims for net zero carbon by 2040 and prioritises recycled fibres, recirculation of clothing and waste reducing collections. The company is GOTS certified, an ETI member and has validated, science-based environmental targets.	Textile Exchange is consolidating its standards into the Materials Matter Standard, covering raw material production and primary processing across the fashion and textile industry. Effective from late 2026, it sets requirements on resource use, working conditions, animal welfare, emissions and waste, providing a unified framework to substantiate sustainability claims and support market access.	Worn Again Technologies develops closed-loop chemical recycling that converts polycotton textiles into new PET and cellulosic materials. Its process separates and purifies polyester and cotton from blended fabrics, restores chemicals for reuse and produces raw equivalent outputs. A Textile to Fibre Accelerator plant is under construction to scale the technology.			
Business Models	Beyond Retro UK https://www.beyondretro.com/	Biorestore UK https://www.bio-restore.com/	Clothes Doctor UK https://clothes-doctor.com/	Community Clothing UK https://communityclothing.co.uk	Hiut UK https://hiutdenim.co.uk/pages/about	John Smedley UK https://www.johnsmedley.com/uk/discover
	Beyond Retro presents itself as a major vintage retailer operating in the UK, Sweden and Finland, sourcing second-hand fashion since 2002. The company positions its work as part of wider efforts toward circularity, stating that it diverts large volumes of used textiles from landfill and collaborates with brands on upcycled products.	Biorestore presents its Laundry ReTergent™ treatments as a way to refresh worn garments by combining scientific and craft-based approaches to fabric care. The company frames its work as reviving traditional clothing care practices disrupted by fast fashion and, since 2020, has developed several products aimed at extending the lifespan of clothing.	Clothes Doctor's products are naturally inspired, science-based formulations designed to help garments last longer. The company links modern laundry habits to unnecessary wear and waste, and frames its detergents and care products as gentler alternatives that clean, refresh between washes, protect fibres and support longer-term clothing maintenance.	Community Clothing is a UK-based manufacturer using sustainably sourced natural fibres to produce everyday garments. The organisation links its approach to supporting local jobs and regional industry, stating that making clothing domestically can strengthen communities while offering lower-priced alternatives to typical premium brands through its business model.	Hiut, a family-owned Welsh denim maker, is focused on craftsmanship and small-scale production. The company highlights its use of carefully selected fabrics and labour intensive techniques that limit output and reduce overproduction, presenting its jeans as long-lasting garments made by skilled makers and intended to prioritise quality over volume.	John Smedley describes integrating waste management into its operations and primarily using natural mono-material yarns such as wool, cotton, cashmere and silk. The company depicts an eco-balanced business model, embracing circular principles by recognising that waste materials can retain value as reusable resources.

Lone Design Club UK
<https://lonedesignclub.com/>

Lone Design Club is a platform that connects customers with ethical, independent fashion and lifestyle brands through short term concept stores and a digital marketplace. It presents physical retail as important for online brands and positions its spaces as venues for storytelling, events and discovering designers with traceable, mindful practices.

Maria Grachvogel UK
<https://www.mariagrachvogel.com/>

Maria Grachvogel presents a slow fashion approach centred on thoughtful, seasonless design, producing limited quantity or made to order pieces to minimise waste. The brand emphasises local production in its Mayfair atelier, long-term wear, repair services and craftsmanship, including hand painted prints and patternmaking directly on the body to create tailored, enduring garments.

Marks & Spencer (M&S) and Sojo UK
<https://www.marksandspencer.com>
<https://www.sojo.uk>

Marks & Spencer and Sojo present a circular fashion model focused on re-wear, repair, recycling and resale to extend the life of clothing. The partnership offers customers door-to-door repair services, aiming to keep garments in use longer and provide new routes for unwanted items.

My Wardrobe HQ (MWHQ) UK
<https://www.mywardrobehq.com>

My Wardrobe HQ is a circular social shopping platform enabling users to rent or resell clothing, including items from brands, retailers and individual wardrobes. It presents rental as a way to extend garment lifecycles, offering both rental and purchase options and promoting higher quality, lower impact fashion choices through its curated selection.

Paynter Jacket Co UK
<https://paynter.co.uk/>

Paynter Jacket Co presents a made-to-order model in which limited edition jackets are produced four times a year to avoid excess stock and reduce waste. Designed in London and manufactured in a small Portuguese factory, each jacket is batch numbered, created over several weeks, and supported by recycled offcuts and waiting list redistribution.

Petit Pli UK
<https://shop.petitpli.com>

Petit Pli is a material technology company creating expandable childrenswear using engineering and origami-inspired structures to fit multiple sizes. The company highlights limited production, local manufacturing and mono-material fabrics to support recyclability, along with repair services, durability testing and supply chain transparency aimed at reducing waste and extending garment use.

Phoebe English UK
<https://www.phoebeenglish.com/>

Phoebe English presents a design approach rooted in textile craft and reduced environmental impact, using circular methods and limited production to work within planetary boundaries. The studio focuses on reusing pre- and post-consumer textile waste, developing collections that experiment with less extractive systems and aim to create considered garments from existing materials.

Rey House UK
<https://rey-house.com/pages/sustainability>

Rey House develops collections with women aged 40–60, focusing on longevity, comfort and well-fitting wardrobe staples designed to be worn repeatedly. The brand uses a sizing system based on real bodies and selects high quality materials such as Italian yarns and organic cottons to support longer garment use and alternatives to fast fashion.

Save Your Wardrobe UK
<https://www.saveyourwardrobe.com/en-gb/for-consumers>

Save Your Wardrobe is an end-to-end platform for brands and consumers to access repair, care and aftersales services through a centralised, tech-enabled system. The app connects users with local specialists, supports wardrobe digitisation and offers services such as alterations, eco-cleaning and upcycling to extend garment use and streamline post-purchase processes.

Sojo UK
<https://www.sojo.uk/>

Sojo presents a digital repair platform designed to make clothing care more accessible for brands and consumers. It offers automated repair portals, inhouse operations, fast turnaround times and data dashboards that track environmental savings. The company positions collaborative industry action as key to scaling repair services and improving garment longevity.

With special thanks to all who have kindly participated, and contributed to the development of this research, from across the fashion, wider apparel, textiles and technology industry.

Facilitator for industry circular fashion and textiles workshop

- Testing Perception of Circular Innovation: The workshop was facilitated by **Mark Hodgson**, QSA Partners, whose role was to help convene collective thinking away from “circular ideas” as a given, and towards circular innovation models capable of surviving in terms of regulation, operations, finance and customers. With over 2 decades of experience working in circular innovation and sustainable business strategy across multiple sectors, from electronics to automotive, furniture to apparel, he has a proven track record of translating circular principles into operational and commercial reality.

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Cover image: Anam PALF®, textile-grade fibre made from waste pineapple leaves by Ananas Anam. Credit: Ananas Anam