Part of the conference series
Breakthrough science and technologies
Transforming our future

Sustainable fashion: transdisciplinary approaches to innovation

23 May 2023

Conference report

THE ROYAL SOCIETY

Introduction

On 23 May 2023, this Royal Society conference explored the role of science in reducing the environmental impact of the UK's fashion industry. It sought to examine the sector's largest sustainability challenges and identify areas where transdisciplinary approaches to innovation are required to drive progress.

Image: Dr Alicia Greated, member of the Royal Society Science, Industry and Translation Committee.

The meeting brought together key stakeholders from across industry, academia, policy and finance to explore themes such as manufacturing efficiency, material innovation, recycling infrastructure and design.

The conference forms part of the Society's wider Transforming our Future series and the agenda was shaped with the help of Professor Jane Harris, Director of the University of the Arts London (UAL), Fashion, Textiles and Technology Institute; Professor Richard Thompson OBE FRS, University of Plymouth; and Andrew Yip, PANGAIA.

Each conference in the Transforming our Future series brings together key stakeholders from across a sector to address a major scientific and technical challenge of the next decade. The series is organised through the Royal Society's Science and Industry programme which supports the Society's commitment to integrate science and industry across its activities, and to promote science and its value by building relationships and fostering translation.

This report is not a verbatim record, but a summary of the discussions that took place during the day and the key points raised. Comments and recommendations reflect the views and opinions of the speakers and not necessarily those of the Royal Society.

"Many of us want to help benefit society. To do that we have to be operating across disciplines, collaborating with other people, and working together to deal with these big problems."

Dr Alicia Greated, member of the Royal Society Science, Industry and Translation Committee.

Executive summary

The global fashion supply chain is the third largest emitter of greenhouse gas[1], the second largest water user[2] and is on track to exceed the Paris aligned 1.5°C target by 50%[3].

In the UK, the most carbon intensive stages of the garment supply chain are during fibre production and manufacturing, with over a quarter of material being lost as supply chain waste[4]. At the recycling end of the supply chain, although the UK has one of the highest recycling collection rates of used clothes per capita, factors such as poor quality of feedstock and insufficient domestic recycling infrastructure means that under 5% of collected clothing is recycled (2017)[5]. The industry's environmental footprint is further worsened by the shift towards 'fast fashion' culture.

The cultural and economic benefits of the industry are clear, with fashion and textiles contributing almost £20 billion to the UK's economy and employing 500,000 people across England, Wales and Scotland[6]. For the sector to decrease its environmental impact while also maintaining its current creative and economic value, innovation and cross-sector collaboration are essential. The focus of this conference was to discuss the role of emerging science and technology to assist in this challenge.

Key recommended actions from the conference were:

- **Adopt environmentally- driven design principles**
  The environmental damage occurring in a garment's life cycle can often be isolated and designed out from the offset. Eliminating the cause of the damage saves the need for developing innovative mitigation solutions further down the supply chain.
- **Strengthen end-of-life infrastructure**
  In a truly circular fashion economy, clothing 'waste' would be considered a valuable resource. For this to be possible, better end-of-life infrastructure is needed, as well as policies surrounding the definition and approach to 'waste' in the industry.
- **Accommodate the customer**
  Expectation should not be placed on the customer to make sustainable fashion decisions, but rather the system to offer attractive sustainable options. Sustainable garments must be affordable, fashionable and align with customer buying habits.
- **Incorporate sustainability into the regulatory framework**
  Policy and regulation should recognise and incentivise sustainable innovation.
- **Encourage transdisciplinary collaboration**
  Collaboration between stakeholders at all stages of a garment's life cycle will encourage a more holistic approach to sustainability that will benefit the whole supply chain. All interventions should be backed by science to avoid the adoption of solutions that are ineffective, or even inadvertently harmful.

> "Circularity is a systems problem that requires transdisciplinary collaboration at every stage of the value chain."
>
> Professor Kate Goldsworthy, Chair of Circular Design and Innovation at University of the Arts London (UAL).

1. World Economic Forum, 2021, Net-Zero Challenge: The supply chain opportunity. See: https://www3.weforum.org/docs/WEF_Net_Zero_Challenge_The_Supply_Chain_Opportunity_2021.pdf (accessed 7 November 2023).
2. Bailey, Kerrice, Aman Basu, and Sapna Sharma. 2022. 'The Environmental Impacts of Fast Fashion on Water Quality: A Systematic Review' Water 14, no. 7: 1073. https://doi.org/10.3390/w14071073 (accessed 7 November 2023).
3. McKinsey & Company, 2020, Fashion on climate: How the fashion industry can urgently act to reduce its greenhouse gas emissions. See: https://www.mckinsey.com/~/media/mckinsey/industries/retail/our%20insights/fashion%20on%20climate/fashion-on-climate-full-report.pdf (accessed 7 November 2023).
4. The Waste and Resources Action Programme WRAP, 2017. Valuing Our Clothes: the cost of UK fashion. See: https://wrap.org.uk/resources/report/valuing-our-clothes-cost-uk-fashion (accessed 7 November 2023).
5. Institute of positive fashion, 2021, The circular fashion ecosystem: a blueprint for the future. See: https://instituteofpositivefashion.com/uploads/files/1/CFE/Circular_Fashion_Ecosytem_Report.pdf (accessed 7 November 2023).
6. UK Fashion & Textile Association, 2020, UKFT's Compendium of Industry Statistics and Anaylsis 2020. See: https://ukft.s3.eu-west-1.amazonaws.com/wp-content/uploads/2021/11/24095453/UKFTs-Compendium-of-Industry-Statistics-and-Analysis-2020-Executive-Summary.pdf (accessed 7 November 2023).

KEYNOTE

Sustainable fashion: the challenges ahead for the sector

The opening keynote, given by Professor Richard Thompson OBE FRS, Director of the University of Plymouth Marine Institute, discussed the role of environmental science in monitoring the downstream impact of sustainability interventions in the fashion industry, and in identifying and driving the solutions that will most effectively reduce the industry's environmental impact over the coming years.

Image: Professor Richard Thompson OBE FRS, Director of the University of Plymouth Marine Institute.

The fashion market is expanding rapidly, with global production doubling in the last 15 years. While the value of the apparel and footwear market is undisputed, estimated at up to £58 billion in the UK in 2020[7], it is causing significant environmental damage across the whole supply chain. There are negative impacts at every stage of a typical garment's life cycle from material choice, design, manufacture and use to disposal. Whilst there is now sufficient evidence for the environmental problems surrounding how garments and apparel are currently designed, used and disposed of, details on the efficacy of specific solutions are lacking at a more granular level.

Key issues

- **Raw materials**
  Synthetic fibres produced from non-renewable based feedstocks do not degrade and thus persist in the environment, substantially contributing to microplastic pollution. Many natural fibres require vast quantities of water, pesticides, fertilisers, and extensive land use.
- **Manufacturing**
  Water is an increasingly scarce resource. Once overseas production is accounted for, the water footprint of clothing in the UK is up to eight billion cubic metres. Growing and producing cotton fibres is particularly water intensive[8]. In addition, significant quantities of applied dyes and chemicals from textile production and finishing fail to bind with fibres and are released into the environment as harmful effluent.
- **Carbon**
  It has been estimated that the carbon emissions from the fashion industry are equivalent to those of aviation and shipping combined, and account for roughly 10% of greenhouse gas emissions globally[9].
- **Waste**
  One tonne of textile waste is generated per minute in the UK. Much of this is produced within supply chains from processing, production to end of life.

7. Fashion United, 2022, UK fashion industry statistics (online). See: https://fashionunited.uk/uk-fashion-industry-statistics (accessed 7 November 2023).
8. The Waste and Resources Action Programme (WRAP), Valuing Our Clothes: the cost of UK fashion, July 2017
9. Frontiers in Environmental Science, 2022, Sec. Toxicology, Pollution and the Environment, Volume 10 – 2022. See: https://doi.org/10.3389/fenvs.2022.973102 (accessed 7 November 2023).

Evidence-based intervention

The environmental problems associated with the fashion industry are well-documented. The challenge now is to tackle these problems while preserving the benefits of the apparel sector. An evidence-informed and transdisciplinary approach is essential to stop the accidental adoption of solutions that are ineffective and could even have negative environmental consequences.

An example of how science can assess the downstream impact of possible interventions, and identify effective solutions, is in microfibre shedding. Most interventions to reduce shedding currently focus on wastewater treatment, which can capture up to 98% of microplastics. However, it is common practice to apply the resultant sludge to agricultural land as a biosolid – thus returning any microplastics captured back to the environment.

Additionally, 50% of fibres shredded over a garment's lifetime are released into the air during use and so interventions via wastewater treatment are of limited efficacy. In contrast there is evidence that changes in textile and fibre design could reduce shedding by 80%[10]. Design interventions have the potential to reduce emissions that occur when a garment is being worn as well as washed and will also be more effective in countries with less developed wastewater infrastructure.

Next steps

Minimising the fashion industry's environmental impact will require a multi-pronged approach that considers impacts and interventions across the entire value chain. Successful identification and implementation of solutions will involve collaboration between environmental, social, and material scientists, designers, retailers, customers, and those involved in re-use and recycling. Legislation, education, and behavioural change will also be needed to catalyse action at the scale and speed required. One key step forward is the recently funded UKRI circular fashion and textile programme: NetworkPlus[11].

"We know that 'reduce, reuse, recycle' are essential. But we lack the granular detailed evidence of which materials we should reuse, which we recycle or which we don't need at all."

"We need to be careful that we don't re-invent the wheel and create different problems."

Professor Richard Thompson OBE FRS, Director of the University of Plymouth Marine Institute.

10. Science Direct, 2016, Release of synthetic microplastic plastic fibres from domestic washing machines: Effects of fabric type and washing conditions, Marine Pollution Bulletin, Volume 112, Issues 1–2
11. UK Research and Innovation, 2023, UKRI circular fashion and textile programme: NetworkPlus (online). See: https://www.ukri.org/opportunity/ukri-circular-fashion-and-textile-programme-networkplus/ (accessed 7 November 2023).

Challenging perceptions of fast and slow fashion: 1960s paper dresses and the concept of disposable garments

Dr Liz Tregenza, Lecturer in Cultural and Historical Studies at UAL, London College of Fashion and Hannah Auerbach George, Business of Fashion Textiles and Technology Research Fellow at the Victoria and Albert Museum, outlined how historic approaches to fashion and textile manufacturing could inspire contemporary innovation and inform future sustainability models.

Image: (Left) Hannah Auerbach George, Business of Fashion Textiles and Technology Research Fellow at the Victoria and Albert Museum and (right) Dr Liz Tregenza, Lecturer in Cultural and Historical Studies at UAL, London College of Fashion.

Between 2000 and 2015, clothing production doubled worldwide. As people buy new clothes to keep pace with rapidly changing fashion trends, they also discard them more quickly. Fewer than 1% of garments worldwide are currently recycled into new textiles[12].

Previous approaches to sustainable fashion have advocated the slow fashion framework by enhancing the longevity of garments to tackle textile waste. However, slow fashion is limited in scope and may fail to account for situations where customers value other garment traits, such as aesthetic, over longevity. Developing a sustainable framework that can accommodate the existing fast fashion culture could provide a more comprehensive solution to the environmental problems caused by textile waste. This involves aligning the intended lifespan of a garment with the longevity of its constituent materials - a process referred to as “matching speed cycles”.

12. Ellen MacArthur Foundation, 2017, A new textiles economy: Redesigning fashion’s future. See: https://www.ellenmacarthurfoundation.org/a-new-textiles-economy (accessed 7 November 2023).

Case study: the paper dress

Popular in the 1960s, the paper dress is an example of a garment with a well-matched speed cycle. An output of emerging fast fashion culture, the dresses were designed to be fashionable, short-lived, and easily disposed of after two to three wears. They were made from a variety of cellulose-based materials and strengthened with nylon or rayon to make them water-repellent, fire-retardant, durable and resemble traditional textiles. The fibres were pulped and calendared into rolls onto which the pattern was printed. Bonding the seams with glue and dispensing with hems enabled speedy and cost-effective manufacturing.

Learnings that can be applied in the modern-day

By the 1970s, paper was outcompeted by the functionality of more traditional textiles and by the decreasing cost of synthetic fibres. Whilst paper dresses ultimately failed to satisfy consumer standards, learnings from their short-lived popularity can be applied in a contemporary context to inform more sustainable approaches to fast fashion.

Manufacture learnings

The time, funds and resources used to manufacture disposable garments should align to their short lifespan. Techniques used in manufacturing paper dresses, such as digital printing to replace dying, and bonding instead of stitching, might better match the speed cycle of disposable garments.

Material learnings

Although designed to be disposable, paper dresses contained plastics and synthetic dyes. To mitigate the impact of the throwaway culture in 21st century fast fashion, any material waste generated must be circular or compostable. One approach could be to use agricultural waste to develop fully compostable textiles.

Design learnings

Purposeful design decisions can help to keep manufacturing costs low by minimising the material and skilled time required to construct a garment. Paper dresses typically did not include fastenings and used few materials per garment. Today, this would have the added advantage of simplifying any separation and recycling processes.

Extrapolating from the use-case of 1960s paper dresses, garments that are purposefully designed to be disposed of quickly and recycled easily could be an effective way to enable the customer to remain abreast of rapidly changing fashion trends while causing minimal environmental damage. However, existing recycling infrastructure is largely insufficient to allow garments to be sustainably disposed of as quickly as they are created. To make disposable garments truly sustainable, adequate end-of-life infrastructure must be in place.

> "Museums are a storehouse of cumulative knowledge and material culture. Historical approaches can be learned from to inspire a multi-faceted approach to garments that can meet the diversity we demand from our clothing."
>
> Hannah Auerbach George, Business of Fashion Textiles and Technology Research Fellow at the Victoria and Albert Museum.

> "Paper dresses are relevant to today's desire for perpetual newness and culture where aesthetic value trumps material longevity and quality. These garments were designed to be fashionable, short-lived and then disposed of."
>
> Dr Liz Tregenza, Lecturer in Cultural and Historical Studies at UAL, London College of Fashion.

Environmentally driven design: transdisciplinary approaches to circular and sustainable innovation

Professor Kate Goldsworthy, Chair of Circular Design and Innovation at University of the Arts London (UAL) discussed the importance of environmentally driven design. She presented a series of case studies to showcase a range of transdisciplinary approaches to sustainable innovation.

Image: Professor Kate Goldsworthy, Chair of Circular Design and Innovation at UAL.

"More work is needed to determine how fashion, textiles, design, materials and environmental science research can be integrated. These disciplines have clear synergies but there are challenges associated with combining them into a singular and integrated approach that can learn fast and support change at scale."

Professor Kate Goldsworthy, Chair of Circular Design and Innovation at UAL.

Good material choice does not guarantee sustainability. A key priority for the next decade will be to incorporate circular design into a garment from the outset to ensure that products can be created, used, and recovered sustainably. Designers must also work with other disciplines to minimise the whole-life environmental impact of garments. Integrating environmental science research into the earliest possible stages of product development is essential to this ambition.

Case study: Designing for end of life

The Circular Design Speeds project, developed as part of the Mistra Future Fashion programme[13], sought to understand the consequences of different circular fashion models, by developing design prototypes for different speeds of use. For example, the ultrafast prototype focussed on designing a short-life, compostable paper garment made from cellulose that could be produced in a contemporary paper mill.

Every stage of the project was guided by experts. Recycling specialists identified that composting or paper re-slushing was the most effective end-of-life approach. Material scientists then developed a paper-based material according to this end-of-life specification. Business innovation experts identified future scenarios that could impact the supply chain, and social scientists assessed user perception of the material to maximise the potential for customer acceptance. All these findings were then embedded into the garment's design process from the outset.

13. Mistra Future Fashion (online), See: http://mistrafuturefashion.com/ (accessed 7 November 2023).

This interdisciplinary approach successfully identified and connected environmental impacts across the garment's lifecycle that would likely otherwise have been overlooked. For example, the finishing process that was developed to improve the wearability and aesthetics of the paper material not only improved its durability and handling, but also increased the speed of degradation when composted.

Case study: Environmental impact analysis

Recycling and composting technologies are only effective if products are designed to suit them. Ananas Anam is a UK-based company and part of the B-corporation movement, creating plant-based textiles. Their R&D project in collaboration with University of the Arts London (UAL) was to create a biodegradable yarn[14] from the same pineapple harvest waste as its signature Piñatex textile. The project exemplified the importance of incorporating 'product perspective' at the R&D stage of a new material.

While the material used to create a garment may be sustainable, the blends used, fixings, finishings or stitching can significantly affect its whole-life impact. For example, textile blends can improve a material's performance or durability, but often reduce the composite material recovery potential. When selecting a fibre with which to blend its Piñatex fibre, Ananas Anam ranked the available options considering their impact on global warming, eutrophication, water depletion and scarcity, and fossil fuel use. The recyclability and compostability of each material within the constraints of existing infrastructure was also considered. Tencel's Refibra fibre was selected based on its blending compatibility and environmental credentials.

Caste study: Closing the loop

Brands often report that they have little insight into or influence over the raw materials in a given supply chain. However, the partnership between Kukri Sports and researchers in the Business of Fashion, Textiles and Technology research programme highlights the positive influence that retailers can have on their suppliers.

The goal of the partnership was to increase the circularity of the synthetic polyester used in their sportswear, focusing on two garments from their collection. A group of 19 stakeholders were engaged across the value chain and barriers to circularity and sustainability were analysed and designed out. The project illustrates how open dialogue between retailers, designers, environmental scientists, manufacturers, policy makers, recyclers and other parties is essential to understand current barriers to circularity, identify leakage points in the supply chain, and improve fibre-to-fibre recovery within the boundaries of the current system through circular design[15].

Conclusion

By consulting stakeholders at every stage of a garment's value chain, the fashion and textiles industry can better pre-empt and prevent any unintended environmental harm associated with emerging solutions before they occur. A comprehensive, united and interdisciplinary approach can also communicate necessary interventions more coherently to inform decision-makers and influence customer behaviour.

14. Ananas Anam, 2017, Piñayarn. See: https://www.ananas-anam.com/pinayarn/ (accessed 7 November 2023).
15. Business of Fashion, Textiles and Technology, Challenge 5: Circular Materials. See: https://bftt.org.uk/challenges/challenge-5/ (accessed 7 November 2023).

CASE STUDY 1

The next generation of sustainable antimicrobial textile coatings

Dr Joseph Houghton, Senior R&D project manager at Virustatic and R&D Fellow at University of Leeds and UAL, outlined their protein-based alternatives to metal-based biocides to reduce environmental impact across a range of sectors.

The problem

Biocides, such as disinfectants, are chemical substances or micro-organisms intended to control harmful organisms. When used on textiles, the biocides employed are often metal-based chemicals, for example silver chloride, and are highly toxic to aquatic life. Without adequate wastewater treatment plans, the leaching of these metal-based biocides through domestic washing and end-of-life processing can have lasting impacts upon the environment.

The antimicrobial textiles market is growing rapidly following the COVID-19 pandemic and is expected to reach $13.63 Bn by 2028[16]. Demand for metal-based chemicals in textiles is projected to increase in the fashion and athleisurewear sectors where their biocidal activity is utilised to control odour. This is expected to result in much higher levels of these toxic compounds entering wastewater streams.

Virustatic's solution

Founded in 2009, Virustatic is an SME (small to medium sized enterprise) undertaking research and development of protein-based antimicrobial and antiviral products. Their Viruferrin® coating is bio-based, environmentally benign and renewable with antiviral and antimicrobial efficacy that meets the international ISO 18184:2019 and ISO 20743:2021 antiviral and antibacterial textiles standards. Their Virustatic Shield® is a reusable face covering launched in March 2020 in response to the COVID-19 pandemic. It utilises the Viruferrin® coating to reduce the inhalation of pathogenic aerosols while conserving the natural microbiome of human skin and offering a more sustainable alternative to the popular single-use polypropylene face masks, which are often treated with per- and poly- fluoroalkyl substances (PFASs) and metal-based biocides.

Next steps

Current biocide regulations set by the UK Health and Safety Executive (HSE) do not distinguish between toxic metal-based biocides used regularly in textiles and environmentally benign and sustainable alternatives. Existing policies surrounding the permitted use of terms such as "antiviral" and "antibacterial" to define a product means that its environmental impact is not taken into account. In settings such as hospitals, the use of conventional biocides is unlikely to change in the near future. However, in the fashion and non-medical textile sector, Virustatic maintains that more environmentally friendly, bio-based products for use in anti-odour textiles and antimicrobial textiles are sufficient and should be classified under a separate policy to the traditional biocidal product registry (BPR).

A more open dialogue between regulatory bodies and SMEs could help to identify innovation gaps and areas where products with a better environmental impact can, and should, be encouraged.

> "SMEs are in this unique situation where they are flexible enough that they can come up with these really interesting innovations, but they don't have, necessarily, the influence to push innovative products through regulation."
>
> Dr Joseph Houghton, Senior R&D project manager at Virustatic and R&D Fellow at University of Leeds and UAL.

16. Fortune Business Insights, 2021, Antimicrobial Textiles Market Size, Share & COVID-19 Impact Analysis, By Active Agents (Synthetic Organic Compounds, Bio-Based Compounds, Metal & Metallic Salts and Others), By Fabric (Cotton, Polyester, and Others), By Application (Home, Commercial, Medical, Apparel, Industrial, and Others) and Regional Forecasts, 2021 – 2028. See: https://www.fortunebusinessinsights.com/antimicrobial-textiles-market-102307 (accessed 7 November 2023).

CASE STUDY 2

Climate-responsible leather-inspired biomaterials from collagen

Dr Yudi Ding, CEO and Co-founder of Hide Biotech, discussed their flagship biomaterial produced from collagen and its use as a sustainable and responsibly sourced leather alternative in the fashion industry.

"We cannot just focus on what is vegan or not. Assessing whether a material is sustainable requires a more comprehensive and sophisticated approach."

Dr Yudi Ding, CEO and Co-founder of Hide Biotech.

The problem

Of the raw materials used in the fashion industry, the environmental impact of leather is far greater than that of other materials such as animal fibres and plant fibres[17]. CO_2 emissions associated with leather production are estimated at over 100 tonnes per year.

In recent years, vegan products have become associated with sustainable choices, resulting in a surge in demand for vegan, plastic-based leather. The typical manufacturing process of vegan leather mixes a biomass with non-renewable polyvinyl chloride (PVC) or polyurethane (PU) to create 'pleather'. However, a holistic sustainability assessment of pleather – accounting for water consumption, embedded carbon, and generated waste streams - has yet to be conducted. Non-plastic and sustainable leather alternatives are required.

Hide Biotech's solution

Hide Biotech specialises in extracting collagen from existing waste streams to produce novel materials for the fashion industry.

Hide Biotech identified an opportunity to utilise waste collagen from the fishing industry to develop a sustainable biomaterial alternative to mimic the chemical composition of leather. Hide Biotech extracts and uses collagen, sourced from fish scales and skin in the rapidly growing sustainable fishing industry, to create its Hide bioleather crust. Tanning reagents, pigment dyes and fat liquors are then used to recreate the aesthetic and texture of natural leather. Creating Hide Bioleather requires 20 times less water than traditional leather.

Next steps

Hide Biotech is working with fashion brands and manufacturers to feed its bioleather into existing supply chains to help brands meet their sustainability goals. Collaboration from the design stage through to scaling-up production is crucial to ensure the material is a viable replacement for the natural leather. Policymakers, investors, and academia will continue to inform their environmental targets.

"We want to leverage natural resources and source them responsibly so that, at the end of the life, our product can go back to nature."

Dr Yudi Ding, CEO and Co-founder of Hide Biotech.

17. Kerring, 2021, Environmental Profit & Loss (EP&L): 2021 Group Results. See: https://keringcorporate.dam.kering.com/m/5edba9133d460b06/original/Kering-Environmental-Profit-and-Loss-Report-2021-EN-Only.pdf%20pg%207 (accessed 7 November 2023).

CASE STUDY 3

Low carbon polyester recycling

Tim Cross, Director of Project Plan B, discussed how textile polyester can be recycled using thermomechanical processes, resulting in polyethylene terephthalate (rPET) to be supplied back into the fashion industry.

Image: Tim Cross, Director of Project Plan B.

The problem

Many garments are made from polyester and cannot be recycled. At end-of-life they become landfill waste or are incinerated.

Project Plan B's solution

Project Plan B have developed a system to recycle polyester waste. The textile is passed through a shredder and then undergoes thermomechanical extrusion where it is heated and pressurised. After filtering and cooling, the polyester is pelletised and ready for reuse. Trials have been executed to demonstrate that the resultant recycled polyester (rPET) can be re-spun into yarn polyester and fed back into the fashion industry. Where rPET cannot be recycled into textiles, it can be used elsewhere to create accessories such as buttons.

Infrastructure for processing polyester at a commercial scale is currently in its early stages of development. Project Plan B's first recycling plant is expected to open in the UK in September 2023. It is estimated that the system will be capable of processing up to 3,000 tonnes of post-consumer textile polyester in its first year of production.

Project Plan B's rPET also has a lower carbon footprint than PET from virgin mateirals. Producing rPET requires 598kg of CO_2 per tonne of clothing compared to 5,180kg of CO_2 per ton for newly manufactured polyester.

Challenges

The technology behind Project Plan B's mechanical recycling process is proven. However, how clothing is constructed and designed majorly impacts its recyclability meaning that a lot of polyester clothing is unsuitable for mechanical recycling. Environmentally friendly design can help to tackle this problem if garment designers consider end-of-life options when selecting feedstocks. In many cases, unrecyclable materials can be easily replaced with recyclable alternatives without affecting garment functionality or cost.

Lack of clarity surrounding the definition of 'waste' and complex regulation concerning treatment of post-consumer garments makes the collection and transportation of recyclable textiles at scale a challenge.

Finally, recycled rPET will match the colour of the source polyester. This limits its capacity for redyeing and therefore its potential re-use applications.

> "Simple changes in design make all the difference: if you know how to design the clothing, you know how to design it for the system that will recycle it."
>
> Tim Cross, Director of Project Plan B.

CASE STUDY 4

Sustainable technologies for chemical and fibre circularity

Dr Aida Rafat, CEO and Founder of DyeRecycle, discussed how their circular chemical technologies can improve the sustainability of synthetic dyes by providing a scalable recycling solution.

The problem

Colour schemes are deeply rooted in the identity of many brands and strongly influence desirability. As such, the fashion and textiles industry demands a highly precise dying capability, resulting in widespread popularity of synthetic dyes.

Since their inception and industrialisation in the 19th century, synthetic dyes have been used similarly to natural dyes, from the dying process to the disposal of wastewater and chemicals. While many natural dyes that are released back into the environment are biodegradable, synthetic dyes are produced from petroleum-based products. These are toxic to both terrestrial and aquatic life, and thus require adequate wastewater treatment processes.

DyeRecycle's solution

DyeRecycle offers a circular solution within the synthetic dye industry. Their innovation uses a non-volatile, non-toxic liquid solvent on synthetically-dyed fabric waste, which selectively and non-destructively separates the dye and the fibre. This separation process enables the respective entities to return to the supply chain.

DyeRecycle's dye extraction and recycling process uses less carbon, energy and water than traditional dying processes.The extracted dyes can be converted back into dyestuff powder or liquid drop-in product for re-use in textile mills and dyehouses. They have no loss in performance or vibrancy compared to virgin synthetic dyes.

The textile fibres left behind after dye extraction are dye-free, uniform and up to three times more valuable to mechanical recyclers than coloured textile waste. This is because colourless fibres can be re-dyed more precisely, making them significantly more desirable to manufactures.

Next steps

DyeRecycle's current palette of dyes consists of 30 unique colours, with the capacity to increase considerably due to the range of synthetic dyes currently in circulation within the fashion industry.

A significant challenge faced by DyeRecycle derives from the range of regulatory approaches towards post-consumer versus pre-consumer textile waste. As recycling infrastructure scales up, it will become increasingly difficult to identify the origin of a given textile and establish if it has encountered any restricted substances. One effective solution would be to better regulate garment design processes to limit or preclude the use of non-recyclable or toxic materials such as elastane or Bisphenol A (BPA).

> "When developing new circular processes and a circular product, it's important to focus not only upon the engineering or setting up the supply chain but also upon changing mindsets, which is something more easily said than done."
>
> Dr Aida Rafat, CEO and Founder of DyeRecycle.

PANEL DISCUSSION

Innovation and entrepreneurship

Entrepreneurs from the case study session considered what they had learned from their experience of building a sustainable business in this sector.

Image: (Left to right) Dr Joseph Houghton, Senior R&D project manager at Virustatic and R&D Fellow at University of Leeds and UAL; Dr Yudi Ding, CEO and Co-founder of Hide Biotech; Dr Aida Rafat, CEO and Founder of DyeRecycle Tim Cross, Director of Project Plan B and Andrew Yip, Head of Materials & Process innovation at PANGAIA.

The panel was chaired by Andrew Yip, Head of Materials & Process innovation at PANGAIA. Panellists were Dr Aida Rafat, CEO and Founder of DyeRecycle, Tim Cross, Director of Project Plan B, Dr Yudi Ding, CEO and Co-founder of Hide Biotech and Dr Joseph Houghton, Senior R&D project manager at Virustatic and R&D Fellow at University of Leeds and UAL. Their advice for other innovators in the space included:

- **Align expectations**
  Innovators need to explore why unsustainable design decisions are made, and then offer more sustainable solutions at an equivalent price. This will require innovators to first understand designers' specifications and prioritise scalable approaches to make their sustainable alternatives widely affordable.
  Current market specifications are based on outputs from an established, linear and optimised economy. As the circular economy matures, and end-of-life considerations become increasingly important, designers might have to adapt their expectations to accommodate the sustainable options available to them.
- **Close the language gaps**
  Confusion occurs when stakeholders use different terminology. Establishing a common communication method will make collaboration between different disciplines more effective.
- **Draw upon networks of expertise**
  This approach will help start-ups to acquire complex skills that they otherwise would have to learn themselves. For example, Project Plan B have partnered with the Salvation Army who have extensive experience in transporting post-consumer textile waste across borders.
- **Convince decision-makers**
  Systemic change can occur only when budget- holders and other senior decision-makers commit to sustainability. Identifying decision-makers should be a priority.

- **Monetise sustainability**

  There are compelling economic incentives to achieve circularity in a sector with significant price sensitivity. For example, the Circular Textiles Foundation[18] analysed a batch of 1.2 million uniform garments (equivalent to 400 tonnes of plastic) and calculated that circular design could save 13p per garment, reducing production costs by £15,000 in total.

"Everybody in the value chain has some incentive, so individuals must work out how to integrate theirs. That's how innovation moves from concept to realisation. You need to either find common ground or force it into the relationship."

Andrew Yip, Head of Materials & Process innovation at PANGAIA.

18. Circular Textiles Foundation. See: https://circulartextilesfoundation.co.uk/ (online). See: https://circulartextilesfoundation.co.uk/ (accessed 7 November 2023).

PANEL DISCUSSION

Business-level action and system-level change

Discussion on how businesses could support the transition to a circular fashion economy and also identified necessary system-level intervention.

Image: (Left to right) Professor James Busfield FREng, Queen Mary University of London; Mart Drake-Knight, Co-founder of Teemill; Lucy Hope, Virustatic; Professor Jane Harris, Director of UAL, Fashion, Textiles and Technology Institute, and Sarah Gray, Lead Analyst at Waste and Resources Action Programme (WRAP) .

The panel discussion was chaired by Professor Jane Harris, Director of UAL, Fashion, Textiles and Technology Institute. Panelists consisted of Professor James Busfield FREng, Head of the Soft Matter Group at Queen Mary University of London, Mart Drake-Knight, Co-founder of Teemill, Sarah Gray, Lead Analyst at WRAP and Lucy Hope, Development Director at Virustatic.

> "It doesn't matter how slowly we start or how ineffective our initial steps are. Do something, make a difference, get moving. Don't just wait for legislation to come along and smack you round the face. That will cost you a fortune."
>
> Tim Cross, Project Plan B.

Defining sustainability

The term 'sustainable' can be elusive and easily misused. A clear, consistent definition for the fashion and textiles industry would help distil goals, make it easier to monitor business and wider industry progress and help the public to recognise greenwashing. Consumer demand could then be used more effectively to drive change.

Business-level action

- **Create an open dialogue with the customer**
  In some cases, companies avoid taking the first steps towards sustainability because they fear public backlash. A balance needs to be struck between holding businesses accountable for their actions and recognising that the path towards sustainability is iterative. Companies can help to build trust with their customers by clearly communicating the sustainability gaps in their business models and their immediate and long term strategy to address these. Values-driven leadership can help ensure that a company's financial decisions align with its sustainability mission. Visible targets from larger brands can stimulate demand for sustainability-driven start-ups.
- **Prepare for the future**
  Companies will inevitably have to comply with increasingly stringent sustainability regulations. Making measured and voluntary changes at an early stage will ease the transition.
- **Make use of technology**
  For example, algorithms used in drip marketing can support incentivised material recovery and automating production lines can help to tackle the waste from speculative mass production models.
- **Establish supply chain loops**
  Most businesses are based on linear principles. An intermediate step in developing a circular economy could be to establish a 'triangular economy', where three linear businesses trade to form supply chain loops, although ensuring mutual profitability would be important.

"We shouldn't strive for a simplistic model of circularity; we want maximum material utilisation. This can come in many forms."

Mart Drake-Knight, Co-founder of Teemill.

"We will need to attend to policy, skills and education simultaneously if we are to address the fashion industry's sustainability problem at the rate required."

Professor Jane Harris, Director of UAL, Fashion, Textiles and Technology Institute.

Regulation and policy intervention

Priorities for policy intervention and regulation changes in the UK could include:

- **Aligning with the international policy landscape**
  A consistent approach to regulations will be more impactful and make it easier for emerging innovations to expand globally. For example, adopting the Extended Producer Responsibility (EPR) policies forthcoming in Europe might increase their impact while being an 'easy win' for the UK.
- **Improving end-of-life infrastructure**
  Establishing the distinction between 'waste' versus 'resource' globally would help to solve existing issues surrounding the movement of post-consumer textile across borders, and would help recycling infrastructure to reach the scale needed to support the circular economy.
- **Stabilise the end-of-life market**
  Funding for textile waste collection and pricing of disposed textiles needs to be stable to encourage companies to implement circular practices.
- **Adapt**
  Despite the UK being third globally for investment in innovation[19], it is proportionally weak in generating scale up at 13th in the world[20]. To better support and accelerate sustainable innovation, the UK regulatory landscape needs to be adaptive and responsive.
- **Monitor progress**
  Implementing circular practices does not automatically lead to sustainability improvements at all levels. Environmental impacts must be monitored, and policies updated accordingly.

19. Council for Science and Technology, Increasing the availability of scale-up investment for domestic innovative science and technology companies: evidence pack (online). See: https://www.gov.uk/government/publications/letter-to-the-prime-minister-on-investment-in-innovative-science-and-technology-companies/innovation-finance-evidence-pack-html (accessed 7 November 2023).
20. ScaleUp Institute, 2020, Call for Greater Coordination between Private and Public sector to address Growth Capital Gap. See: https://www.scaleupinstitute.org.uk/news/call-for-greater-coordination-between-private-and-public-sector-to-address-growth-capital-gap/#:~:text=Although%20it%20ranks%20third%20in,peers%20have%20developed%20for%20scaleups (accessed 7 November 2023).

- **Set standards**
  Sustainability certifications can influence customers and reduce greenwashing. However, certifications should be carefully constructed and managed, with well-defined benchmarked and affordable accreditation fees so that smaller or nascent organisations are not disadvantaged. As the many facets of 'sustainability' evolve, certifications should adapt to monitor appropriate industry benchmarks.
- **Supply chain structure**
  Simplifying the complex, fragmented and opaque supply chains often associated with the fashion industry and working to incentivise inter-sector communication would facilitate a more holistic approach to sustainability.

"This is a systemic problem, so we need a systemic solution. A lot of people are working on point-to-point solutions for what is an end-to-end problem. But we're driving towards a cliff, we can't just slow down, we need to change direction"

Mart Drake-Knight, Co-founder of Teemill.

"We need systemic change. We need innovation but we also need a market that makes sense. That is where policy initiatives can add value"

Sarah Gray, Lead Analyst at Waste and Resources Action Programme (WRAP)..

Skills and education:

Transitioning and operating a circular fashion industry demands particular skills. It will be important to:

- **Retrain the workforce**
  For example, designers will need to understand novel recycling technologies so that they can ensure appropriate end-of-life considerations are incorporated when identifying materials and feedstocks.
- **Attract new talent**
  Many disciplines such as material science and economics will play a vital role in tackling the fashion industry's environmental challenges. Companies and educational institutions have an opportunity to engage current and prospective students by better advertising the impact that can have.
- **Exploit existing opportunities**
  The fashion industry should take advantage of the UK's apprenticeship levy to offer training and re-training. Government-funded institutions, such as the London City Institute of Technology, can work with employers to develop curricula focussed on solving specific industry challenges.

"Increasing the value of our waste streams is a vital challenge for this industry. If you talk to any textile recycler or circular fashion expert, the problem is that our feedstocks aren't worth the cost of collecting, sorting and recycling."

Andrew Yip, Head of Materials & Process innovation at PANGAIA.

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