FASHION FOR GOOD

CIRCULAR APPAREL INNOVATION FACTORY
AN INTELLECAP INITIATIVE

THE STATE OF CIRCULAR INNOVATIONS IN THE INDIAN FASHION AND TEXTILE INDUSTRIES

OCTOBER 2020

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About the Authors

FASHION FOR GOOD

Fashion for Good is the global initiative that is here to make all fashion good. It's a global platform for innovation, made possible through collaboration and community. With an open invitation to the entire apparel industry, Fashion for Good convenes brands, producers, retailers, suppliers, non-profit organisations, innovators and funders united in their shared ambition.

At the core of Fashion for Good is our innovation platform. Based in the Amsterdam headquarters and recently expanding the programme to South Asia, the global Fashion for Good accelerator programme gives promising start-up innovators the expertise and access to funding they need in order to grow. Our scaling programme and our foundational projects support innovations that have passed the proof-of-concept phase, initiating pilot projects with partner organisations and guided by our dedicated team that offers bespoke support and access to expertise, customers and capital. Our Good Fashion Fund catalyses access to finance to shift at scale to more sustainable production methods.

Fashion for Good also acts as a convener for change, with the world's first interactive museum dedicated to sustainable fashion and innovation. In our headquarters, Fashion for Good houses a Circular Apparel Community co-working space, creates open-source resources like its Good Fashion Guide that provides practical advice to implement cradle-to-cradle™ certified apparel as well as white papers and reports investigating industry practices and developments.

Fashion for Good's programmes are supported by founding partner Laudes Foundation (formerly C&A Foundation), co-founder William McDonough and corporate partners adidas, C&A, CHANEL, BESTSELLER, Galeries Lafayette Group, Kering, Otto Group, PVH Corp., Stella McCartney, Target and Zalando and affiliate partners Archroma, Arvind, HSBC, Norrøna, vivobarefoot and Welspun.

CIRCULAR APPAREL INNOVATION FACTORY

Intellecap, supported by the DOEN Foundation, and with Aditya Birla Fashion and Retail Ltd. as an anchor partner, launched the Circular Apparel Innovation Factory (CAIF) in 2018, an industry-led platform with the vision to build a circular apparel and textile industry. Our mission is to build capabilities and the ecosystem needed for a transition towards the circular textile and apparel industry. And we leverage the Aavishkaar approach of creating impact at scale through providing access to capital, knowledge, and networks throughout an innovator's journey.

We do this as:

- An innovation engine: We identify opportunities, discover and test new solutions, and broker high impact partnerships for brands and value chain stakeholders.
- Facilitators of action: We drive experimentation and action on the ground through pilots, prototypes, and the creation of test beds with a view to scale new solutions and innovation.
- Market builders: We remove growth barriers such as access to business support or capital and catalyse the creation of an enabling environment for scaling up circular innovations
- Industry conveners: We accelerate the speed of innovation, create opportunities for collaboration, engage in policy dialogue and shape the conversation around circular apparel and textile

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Executive Summary

The Indian fashion and textile industry contends with challenges that mirror those in the global landscape. The importance of the industry to India's socioeconomic advancement cannot be overemphasised. It currently employs over 45 million people, contributes 15% of the country's export earnings and 7% of the country's industry output.

Unlike other countries where the predominant focus is on consumption, India is taking on dual roles as both a producer and consumer. As India further adapts from being solely a hub of manufacturing to also becoming a key consumption region, there is clear recognition of the opportunity to side-step the challenges faced by consumer-driven economies and propel the industry towards sustainability.

Innovators play a key role in this process as they provide the services, products and system-level solutions that corporate players can invest in and scale. This is most critical as, on the consumer side, there is a comparatively slower but rising consciousness of sustainability in the fashion space. And, of course, as many of the innovators in this report show, sustainability often also makes plain business sense.

While the search for circular innovations to address the critical industry challenges is ongoing in India in tandem with similar efforts in the global landscape, contextualisation factoring in the uniqueness of the local landscape will be crucial. This means exploring opportunities in both directions: top-down in a conventional sense via brands, but also bottom-up via manufacturers.

Our research finds that while circular innovations have the potential to drive efficiencies and enable the industry to transition to sustainability, there exists significant variance in the degree of momentum and level of technical maturity among different supply chain steps. Key takeaways for each of the supply chain steps detailed in this report are provided below:

Key Takeaways

STEP 1: RAW MATERIALS

Natural fibres form a key focus area of innovation in India. However, most of the innovations in the form of new fibres, such as regenerative protein fibres, as well as innovative technologies are currently at the lab level or early stage with limited access to the industry. In contrast, the man-made cellulosic fibres space has witnessed innovations that have secured wide industry adoption and scale. Additionally, this space is experiencing significant activity in the form of process innovations. Moreover, biosynthetics as a new area of raw material innovation is nascent and relatively unexplored in India.

STEP 2: WET AND DRY PROCESSING

This stage of the value chain exhibits significant innovation activity, primarily focused on reducing water usage, driven by an increasing appetite from Indian textile manufacturers for adopting more sustainable pretreatment, dyeing and finishing products and processes. While many of these innovations are still scaling up, some are already commercially available. Maturity in natural dyes and pigments has emerged but use in terms of scale is limited. In general, green chemistry solutions are a top priority within the industry. Besides this, digital printing, which represents a more sustainable alternative to traditional water-heavy dyeing processes, is another growing area.

STEP 3: CUT-MAKE-TRIM

Overall, cut-make-trim innovations are still emerging in the value chain. To date, the focus has been on mass customisation such as digital design and e-commerce solutions. Innovative technologies such as zero-waste manufacturing and additive manufacturing are emerging but are yet to witness accelerated adoption and scale.

STEP 4: RETAIL AND USE

New circular business models such as rental, rework and re-commerce focused on extending the useful life of clothes exhibit significant potential in India. Significant activity is visible in the rental space, albeit limited to luxury wear. Innovators are attempting to leverage India's existing ecosystem of rework service providers to create products. Digital solutions enabled by technologies such as Virtual Reality and Augmented Reality, aimed at increasing efficiencies and enhancing customer experience in both e-commerce and traditional retail, are also emerging in India.

STEP 5: END-OF-USE

This phase is dominated by mechanical recycling in India for managing textile waste. Chemical recycling and automated sorting technologies are yet to find traction. Mature innovations exist in the space of non-textile to textile recycling, primarily in recycling of PET into polyester fibre.

"We are in a transition towards a circular apparel sector and the role of frontrunners who innovate across the value chain cannot be underestimated. By pioneering with circular solutions, they show what's already possible and collaborate with relevant stakeholders to integrate their solutions in the value chain."

Saskia Werther, Programme Manager, DOEN Foundation

Challenges and Opportunities Across The Supply Chain

The fashion industry is valued at $2 trillion[1] and contributes to over 2% of global GDP but the industry's supply chain accounts for 4% of global total greenhouse gas (GHG) emissions[2]. The direct impact of this complex, global, supply chain is most felt in terms of water consumption, energy emissions, waste creation and chemical usage as evident in the supporting graphic:

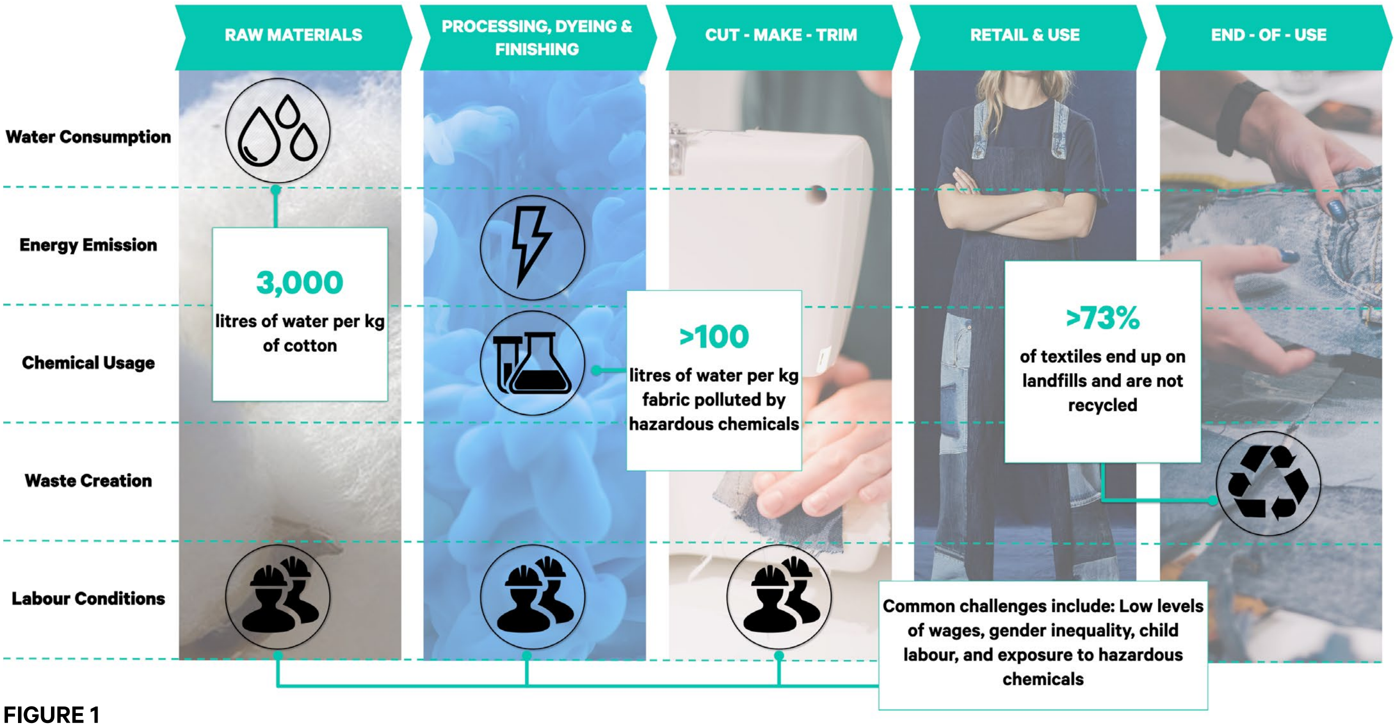


FIGURE 1

> **"Innovators and their innovations have been the bed-rock of human progress and evolution from the very early civilisations. This truly collaborative effort, which maps and surfaces the amazing work already happening, helps reframe our mindset from 'what's not working?' to one that asks 'what's working despite the odds?'**
>
> **The challenges plaguing the industry have been well documented, discussed and debated. Perhaps it's time to shift the narrative to solutions. This work does just that."**

Venkat Kotamaraju, Director, Circular Apparel Innovation Factory (CAIF)

Challenges and Opportunities Across the Supply Chain

In order to address these challenges, the industry must adopt innovative solutions that radically shift the supply chain as we know it. Progress so far has proven to be incremental, efficiency-focused initiatives, rather than implementing fundamentally disruptive solutions.

Ambitious sustainability targets have been set by many industry players and the required shift to a restorative and regenerative industry reflected in their targets is not attainable without innovation. Target setting is not the only activity the industry has undertaken, the “institutionalisation of innovation” across organisations has reflected a desire to integrate sustainability and innovation deeper into core business operations in order to put financial and environmental targets on equal footing.

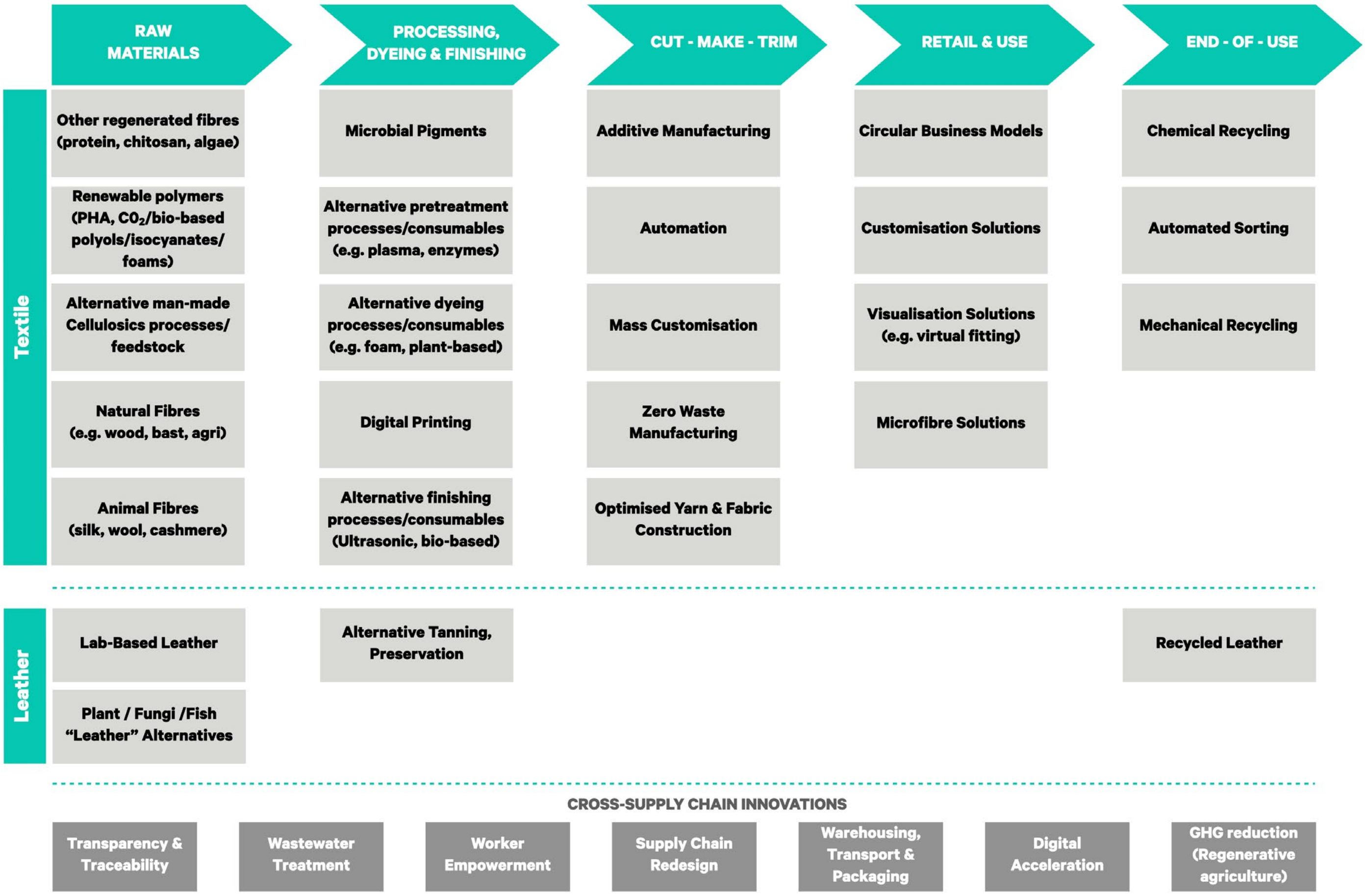
Consumer behaviour and government views have rapidly evolved, as a growing awareness amongst consumers with regards to social and environmental issues tied to apparel and footwear production further accelerates the drive to move the industry forward. Stricter environmental regulation, and policies integrating a circular economy, are increasing pressure on the industry to change.

Innovative solutions, ranging from improvements in resource efficiency to a radical re-thinking of production processes and business models have emerged over the last 10+ years. These solutions have significant impact, not only decreasing the footprint of textile production and distribution, but also changing how we buy and use clothes.

Challenges and Opportunities Across the Supply Chain

The most promising innovation areas on Fashion for Good's watch list are captured below. Each area represents different stages of maturity, different capital requirements, as well as varying, disruptiveness and return profiles.

TECHNOLOGIES WITH THE POTENTIAL TO DISRUPT THE FASHION VALUE CHAIN



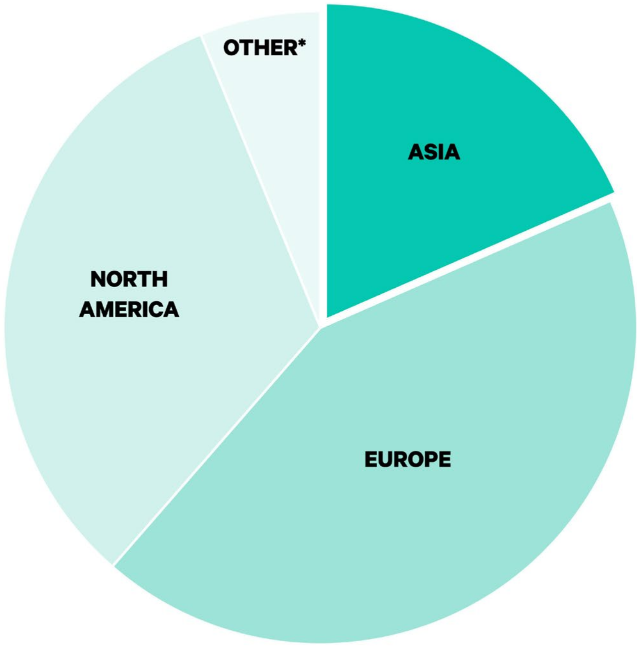
Note: Spinning, knitting & weaving are not listed as separates steps in the value chain. Although they are typically considered as separate steps, innovations in these areas are included in the other steps.

FIGURE 2

Challenges and Opportunities Across the Supply Chain

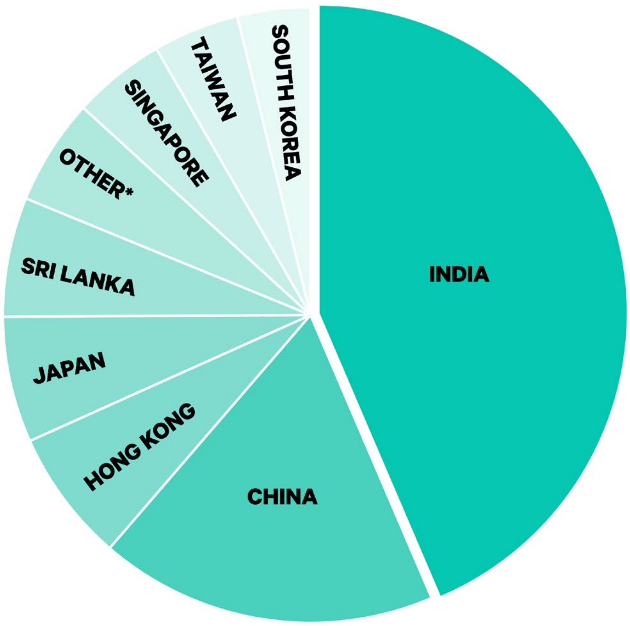
For purposes of this report, the specific focus areas identified in the graphic above have been used as a lens to analyse the innovation landscape in India, highlighting market activity, as well as the most pioneering solutions and white space areas for future innovation.

INNOVATIONS SPLIT ACROSS GEOGRAPHIES



*OTHER covers Africa (0.4%), Oceania (3%), South America (1%) and The Middle East (2%). Percentage of global share.

GEOGRAPHICAL DIVIDE OF INNOVATIONS: ASIA



*OTHER covers multiple countries where less than 10 innovations have been identified by Fashion for Good including Malaysia, Israel and Bangladesh.

FIGURE 3

Challenges and Opportunities Across the Supply Chain

Fashion for Good's innovation database, which houses information on over 2500+ innovators around the world, uncovered promising activities at each stage of the supply chain in the Indian landscape.

INNOVATIONS DISCOVERED IN INDIA ACROSS THE SUPPLY CHAIN

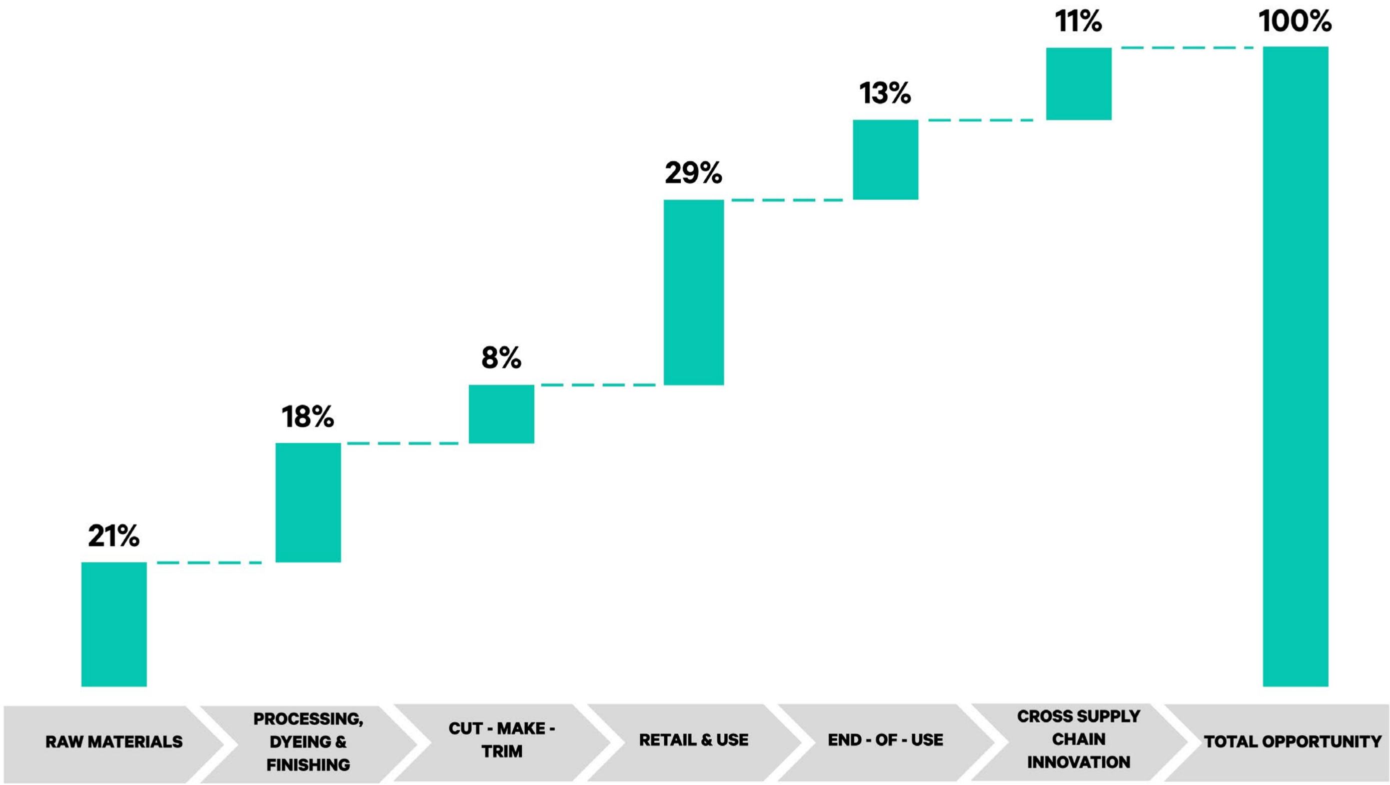


FIGURE 4

Challenges and Opportunities Across the Supply Chain

The following sections of the report highlights innovations according to the supply chain steps above, in both a global and India specific context. Innovations in these key areas will enable major brands, retailers and manufacturers to shift from business as usual to achieving their sustainability goals through a regenerative and restorative approach.

> **“We hope that this research feeds into the growing global movement towards sustainability and circularity. Given India’s importance in the fashion industry, this report mapping innovations and actions the industry can take to enable that circular economy is critical and we hope that it shapes the industry’s transition.”**
>
> Lakshmi Poti, Senior Programme Manager, Materials, Laudes Foundation

Step 1: Raw Materials

The textile supply chain begins with raw materials, which are used as feedstock for the production of fibre, yarns and fabric. It is estimated that more than half[3] of the environmental footprint of the textile and apparel industry is created in this stage. For the most commonly used fibres: polyester (51.5%[4]) and cotton (24.4%[5]), the CO_2 emissions are estimated at 1.7-4.5 kg and 0.5-4.3 kg per T-Shirt of the fibres respectively[6]. This brings about the need for alternative, lower impact new materials or improved manufacturing processes.

KEY FINDINGS FROM THE REGION

- **Low-impact natural fibres have been used extensively in India with traditional production techniques but have not been suitable for industrial scale.**
- **Scaling natural fibres is the mail focus in raw material innovations in India, most technologies being lab scale or early stage with limited industry access.**
- **Man-made cellulosic industry in India is exploring process innovations, with large-scale development of low impact cellulosic fibres by the large players.**

FOCUS AREAS

PLANT BASED NATURAL FIBRES

Known as fibres sourced from plants, bast, fruit and seed fibres, many of these have been in use for centuries. The most widely used natural fibre is cotton, which uses vast amounts of land, pesticides, water and energy during the growing cycle. Many lower-impact natural fibres that use traditional production techniques have historically not been suitable for industrial scale. Innovation opportunities in this space include improving manufacturing processes to enable the scaling up of these fibres, such as bast, leaf and fruit skins, as well as exploring the use of alternative feedstocks such as agricultural or food waste (eg: straw, wheat, coconut husks).

India is one of the largest producers as well as exporters of cotton yarn[7], cotton provides the gold standard by which natural fibres are produced and measured in the country. The majority of production infrastructure in India converts cotton fibre into yarn and fabric. With challenges like water scarcity, sustainable fibre alternatives with similar properties to cotton such as hemp, stinging nettles, lotus stem, agricultural waste and banana fibre present exciting solutions for the textile industry. Historically, there have been challenges around the compatibility of these fibres with the dominant spinning and production infrastructure, originally designed for processing cotton. However, recent technological developments allow for bast fibres like hemp to be processed more efficiently on conventional equipment. This can also improve the material properties and characteristics of these fibres, foreshadowing a future in which these lower footprint fibres might take a more prominent position in the global fibre mix.

Step 1: Raw Materials

The forestry practices followed by man-made cellulosic fibre (MMCF) producers are pivotal in influencing the sustainability of industry. For example, progressive MMCF producers that follow sustainable forestry practices, such as replanting more trees than they are harvesting, can have a net positive environmental impact through increased carbon sequestration. However, irresponsible practices lead to deforestation and thus significant release of carbon dioxide, as previously mentioned. Canopy, through their CanopyStyle initiative, is making huge strides in working with pulp and viscose producers to ensure sustainable forestry practices – having engaged almost 85% of the entire global market of MMCF producers in the initiative. Presently, 42.5% of global market share of MMCF producers achieved a 'green shirt' in the 2019 Hot Button Ranking.

AltMat from Ahmedabad, India has developed a proprietary process to extract usable bast fibre from agricultural produce, sourcing hemp and banana agri-waste directly from organisations and farmers. The fibre is natural, environmentally sustainable and socially inclusive by enhancing farmer's livelihoods. AltMat's fibre, while competitive in price, still needs blending with other materials like cotton, viscose and polyester to make it suitable for use in the apparel industry. The fibres can also be used to make paper, non-wovens and many composites like leather or insulation sheets due to its chemical and acoustic insulation properties.

REGENERATIVE PROTEIN FIBRES

Animal fibres include silk, wool and cashmere and have properties that make them particularly well suited for specific applications, for example, a silk filament has great tensile strength[8]. The durability and strength are performance characteristics that are hard to replace. Moreover, they provide an occupation to local ecosystems. Even with all the benefits, such fibres often have high-water usage and high GHG emissions[9] in most production hubs. Animal fibres make up less than 2%[10] of the total global fibre production however play an important role in the industry due to the characteristics mentioned above. There are opportunities for innovation in both the production process as well as the feedstocks used, for example using algae or spider silk. These are called regenerated fibres which are man-made fibres produced from either animal or vegetable non-fibrous proteins which have been reconfigured to take up a fibrous form to emulate the natural protein fibres of wool or silk[11]. There are also opportunities for innovation in the manufacturing process, for example using water based silk solutions, to mechanically extrude the fibres, reducing water and energy use. Some regenerated sustainable fibres from bio-resources include cupro fibres, casein fibres, groundnut protein fibres, zein fibres, soya bean fibres, silicate fibres and alginate fibres.

Spintex, from the UK, has developed a technology platform that can create bespoke, next generation fibres and materials from a liquid silk solution. The artificially spun silk filaments are produced sustainably and efficiently. Fibres are spun from a water-based silk solution, purely by applying a small pulling force, which forms the solid fibres through self-assembly. Spintex produces this feedstock and spins the resulting fibres at room temperature, representing the main energy saving compared to the conventional silk production process, where up to 50% of the energy input is heat, whilst producing a material that matches or surpasses traditional silks in quality.

Step 1: Raw Materials

MAN-MADE CELLULOSICS

Man-made cellulosic fibres are developed from natural sources by extracting cellulose, processing it into pulp and then extruding into yarn. Cellulosic feedstocks such as wood, food waste or agricultural waste have undergone chemical or mechanical processing to create a new fibre. There are many new processing technologies disrupting the cellulosic industry; for example Lyocell and more recently Eastman's Naia™ fibre. Lyocell's manufacturing process is less chemically intensive than traditional viscose - it does not use toxic compounds as reagents (e.g. carbon disulphide) and operates in a closed-loop process - leading to solvent recovery rates of above 99%. In 2020, Eastman expanded their Naia™ line to include a staple fibre, which utilises feedstock from sustainably managed pine and eucalyptus forests and employs a closed-loop and low impact manufacturing process. India is one of the largest producers of viscose primarily due to the low labour cost and technological expertise[12]. Traditional viscose processing which is dominant in India often incurs high costs related to the effluent treatments that are required as a result of these processes[13].

There are a number of both incremental and disruptive innovations in effluent and wastewater treatments covered in the cross-supply chain innovation section of this report.

Birla Cellulose, a part of the Aditya Birla Group, is among the global leaders in Viscose Staple Fibre (VSF). Birla's product portfolio includes LivaecoTM, Birla ExcelTM, Birla SpunshadesTM, Liva Reviva, Birla Viscose and Birla Modal. Birla Cellulose fibres are of natural origin, moisture absorbent, have a soft feel, are completely biodegradable and are widely used in apparel, home textiles and non-woven applications. Birla has committed to environmentally friendly fashion and its eco range of products are backed with outstanding sustainability credentials. Liva Reviva is RCS certified[14] circular product which uses industrial cotton waste as a raw material. All Birla Cellulose eco products are FSC certified[15], have low water consumption, low greenhouse gas (GHG) emissions, made using a closed loop process and come with complete traceability of the entire value chain. Sustainability is at the core of Birla Cellulose's business strategy and they have set several global benchmarks on sustainable viscose fibres such as sustainable forestry, lowest water consumption and carbon neutrality. Its entire scope 1 and scope 2 GHG emissions[16] are neutralised by carbon sequestered in its managed forest, based on the GHG evaluation done in 2019[17] covering its entire global operations.

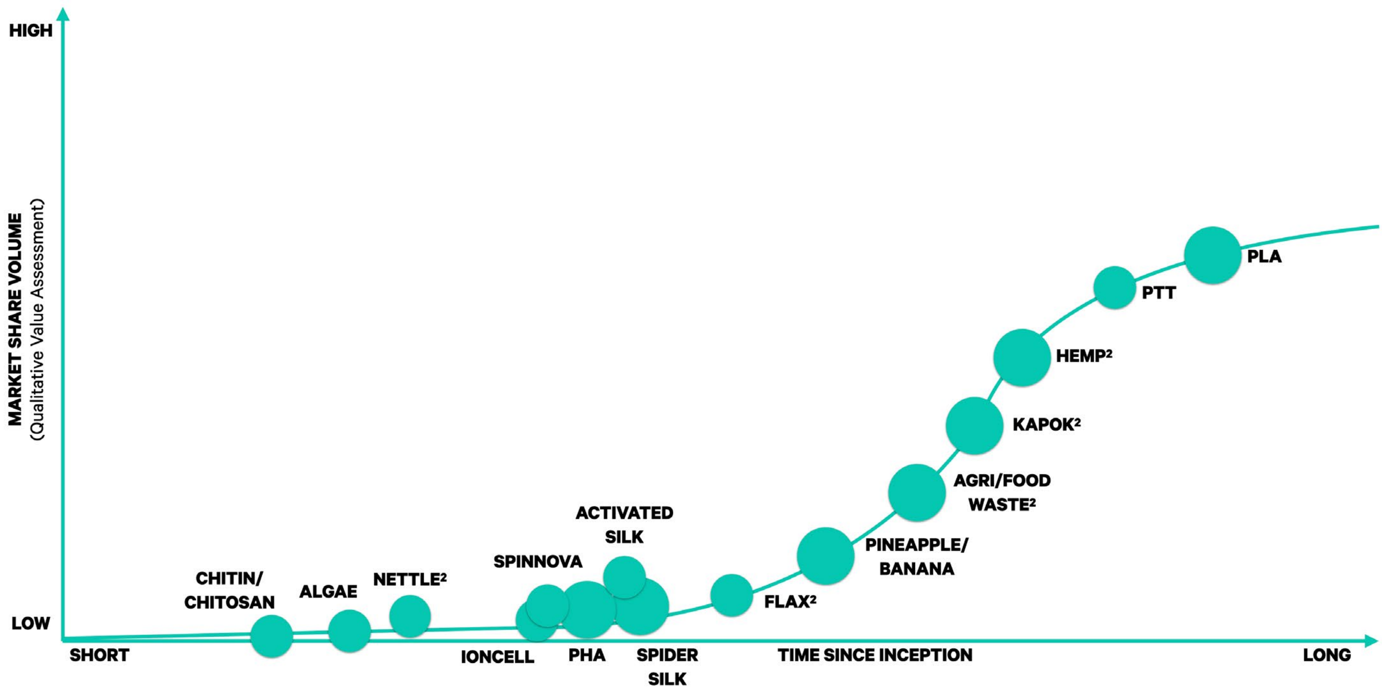
BIOSYNTHETICS

Man-made cellulosic fibres are developed from natural sources by extracting cellulose, processing it into Bio-based and partly biodegradable alternatives to synthetic fibres like polyester and nylon are created by extensive chemical or biological processing of natural feedstock to make biopolymers. Some examples of biosynthetic materials include polylactic acid (PLA), polyhydroxyalkanoates (PHA), and Bio polyethylene terephthalate (BioPET). These can either be a drop-in technology allowing for the use of existing equipment or require a new processing technology such as fermentation or chemical synthesis. Feedstocks can include corn, sugarbeet, agricultural waste as well as greenhouse gases, such as methane

waste gas, and organic waste. Each fibre has different impacts at the end-of-use, some are compostable and marine degradable whilst others are recyclable in existing waste streams. If the fibres are compostable and biodegradable, using them helps address the challenge of microfibre shedding of current fossil-based fibres, however this is not a guarantee for many biosynthetics. As a new area of innovation, at the current scale it is hard for biosynthetic materials to compete with conventional oil-based fibres on price. The manufacturing of biosynthetics is a relatively unexplored application area in India.

Phabio offers bioplastic i.e.biodegradable polymers made from renewable biomass obtained from waste in the beer, dairy and sugar industries, as well as food waste and seaweed. These bioplastics can also be made from agricultural waste, used plastic bottles and other containers using microorganisms.

RAW MATERIAL FIBRES: A SNAPSHOT INTO THE INNOVATION LANDSCAPE



[2] Bast fibres like flax, nettle and hemp, as well as fibres such as kapok and banana have been around for centuries are well established. What is shown here are innovations in quality and efficiency.

FIGURE 5

Step 1: Raw Materials

REGIONAL OPPORTUNITIES

- **Investments and testbeds are required to improve processing technology for alternative low-footprint natural fibres, such as the spinnability and compatibility with the current equipment & infrastructure.**
- **Creating a formal supply chain for agri-waste as feedstock for alternate material innovators can lead to increased farmer income, reduction in agri-waste burning and solving the agri-waste disposal challenges.**
- **Public and private engagement and state-level intervention to develop a local supply chain of alternative low-footprint natural materials and build the conditions for large-scale production.**
- **Building knowledge and human capital for innovations in bio-synthetics and regenerated fibres.**

“ **We are in an era where the fashion industry is aspiring to move to nature based and circular products. Path breaking innovations are enablers of these change; Liva Reviva by Birla Cellulose is one such example where cotton waste can now be up-scaled to fresh fibres. Birla Cellulose is proud to be part of the Full Circle Textiles Project the Fashion for Good consortium project, that aspires to scale the innovations in cellulosic recycling and we believe that co-creating such solutions has the potential to transform the industry into a new, much needed driver of circular and natural fashion.”**

Mukul Agarwal, Head Sustainability and Strategic Projects, Birla Cellulose , Aditya Birla Group

Step 2: Wet and Dry Processing

During the processing stage, the fibres, yarns, fabrics or garments go through multiple steps to achieve the performance and aesthetic properties desired by the brand and its consumers. These steps can be broadly categorised into pretreatment, dyeing, printing and finishing treatments.

Pretreatment is done to prepare for dyeing or printing and can involve removing dirt, bleaching or transforming the materials from a hydrophobic to a hydrophilic state. Hydrophobic is when something repels water whilst hydrophilic is when something can be dissolved in water. Pretreatments account for the highest toxic effluent within wet processing[18].

Modern synthetic dyeing is very effective but highly polluting, regardless of dye type and process: all end with washing out excess colour, which ends up contaminating wastewater. As modern dyes are designed to resist biodegradation, they also accumulate in the environment, especially when wastewater treatment is not done effectively. Dyeing is also a water and energy-intensive process[19].

Finishing treatments give a textile a specific desired effect such as being water repellant or stain resistant. Finishes contain a high amount of hazardous chemicals that have been difficult to replace with lower impact alternatives, as these often face difficulties meeting the same high performance requirements.
The effluent discharge, often hazardous toxic waste, can be full of colour and organic chemicals from dyeing and finishing treatments. To combat the negative health and environmental impact of high effluent discharge, there is increasing traction for safer dyes, pigments and auxiliaries that are biobased and, in some cases, biodegradable, often referred to as "green chemistry".

Overall, wet processing consumes around 5% of the chemicals that are used in apparel manufacturing[20]. Beyond environmental concerns, there are also growing concerns on the impact of these chemicals on human health. Only some of the 80,000 chemicals registered for use have undergone basic human health screening and many of the petrochemical-based products in use today are known to be toxic[21].

KEY FINDINGS FROM THE REGION

- **Given its cultural and environmental context, there is a strong focus in India's innovation landscape on reducing or eliminating the need for water in wet processing, and this space has seen a number of incremental innovations both at R&D as well as commercial application phases.**
- **The abundance of lush flora and fauna as well as its characterisation as mainly an agrarian economy means India shows maturity in innovations using natural dyes and pigments; however, their use at scale is still limited.**
- **Digital printing is a significant area of action in India's dyeing landscape, representing a more sustainable alternative to traditional water-heavy dyeing processes.**

Step 2: Wet and Dry Processing

To address challenges of wet processing, a growing number of innovative, environmentally friendly technologies are emerging in the market, with some of the most promising innovation areas outlined below:

FOCUS AREAS

PLASMA

Plasma, the fourth state of matter, is formed when gas is ionised and becomes more reactive. When this ionised form of gas is applied to a substrate aka surface or material, it is able to alter its properties i.e. activating its surface, removing impurities, depositing a coating. It is a more sustainable alternative to current pretreatment and finishing process as it uses no water, is effluent free and uses significantly less energy and chemicals.

ULTRASONIC & FOAM DYEING

Ultrasonic treatment is a process that utilises acoustic waves to create microscopic bubbles which, when burst, release large amounts of energy that can be used to clean the surface or dye or finish a textile. Using ultrasonic treatment reduces the amount of water, energy, dye and other chemicals required. Besides this, processing time is decreased and the preparatory process in spinning, fabric preparation, dyeing, printing and finishing can be improved. Foam dyeing is another technology applying the pressure of bursting (larger) bubbles, resulting in similar environmental savings.

SUPERCRITICAL CO_2

Another interesting waterless dyeing method is dyeing using supercritical CO_2. This technology involves filling a tank with pressurised gas (instead of water), in which dye can be dissolved. When the fluid gas with the dissolved dye comes into contact with fabric, the dye is deposited onto the fabric. When depressurised, the supercritical gas reverts to its gaseous state, separating from any remaining dye. As a result, this technique leads to a significant reduction in chemicals normally used in the dyeing process and completely eliminates wastewater[22].

Sasmira's Institute of Man-made Textiles (SMMT) has developed a patented technology for waterless dyeing and has built two systems that use supercritical CO_2 technology with a capacity of 3 and 20 litres.

Step 2: Wet and Dry Processing

SPRAY

With spray dyeing and finishing, nozzles spray the exact amount of dyestuff or finishing chemistry required directly onto the fabric. The process is digitally controlled and therefore highly efficient. As a result, large quantities of water, energy and additional chemistry are saved.

CATIONIC AND ENZYMATIC PRE-TREATMENT AND FINISHES

Changing the current pre-treatment methods could significantly decrease water and chemical requirements of further processing steps. Existing innovations include cationic and enzymatic processes.

An example of cationic treatment is when cotton is modified so that it has a permanent cationic, or positive charge, this makes cotton “friendlier” to dye and increases the dye uptake[23]. Cationic treatments have the opportunity to enhance the dyeability of cotton but require advanced effluent treatment as they can cause eutrophication[24]. Eutrophication is when there are too many nutrients in a body of water which can then disrupt the ecosystem[25].

Enzymes can be used to modify the fabric to be more receptive to dyes through processes such as bio scouring, they can be used in both pretreatment and finishing. An enzyme is a substance produced by a living organism which acts as a catalyst to bring about a specific biochemical reaction[26]. By using these treatments, water and chemical usage in these supply chain steps can be reduced.

Nano Dye is a salt free cationic treatment that changes the charge of the cotton molecule to the opposite charge of the dye to enhance the absorption of the dye into the fibre. Resulting in a significant reduction of waste dye, other auxiliaries and water (75%) and energy (90%) usage.

DIGITAL PRINTING

Digital printing is an almost waterless process. Colour fastness depends on different factors such as the colours, layers of printing and fabric type. The current most promising innovation in digital printing is the use of pigments, which has the potential to be suitable for all substrates and improve performance. The fabric however has to be ready-for-dye (RFD) and heat press is required as post-treatment for curing. The growth of digital textile printing technologies is another significant step towards more sustainable textile colourisation. This almost waterless technique can replace traditional dyeing’s intensive water, chemical and energy consuming process. Besides this, it enables near-shoring, on-demand production and customisation. Digital printing can be done both on rolls of fabric as well as garments such as shawls, saris, etc. (known as the “direct to garment” mode[27]). While this technique is also time and colour efficient, our research in India shows that it is currently two or three times more expensive than traditional dyeing, which is a barrier to its full scale implementation.

Step 2: Wet and Dry Processing

NTX - Cooltrans - Cooltrans provides a digitally enabled gravure printing method for both artworks and solids. They distinguish themselves from other printing technologies through their superior fastness, precision and proprietary inks that are manufactured in-house. The technology is applicable to natural, man-made and synthetic fibres.

PLANT BASED DYES AND PIGMENTS

Plant-based dyes and pigments have existed for centuries but have been largely discarded by the fashion industry due to its inferior performance, limited colour palette and higher price than synthetic dyes. However, new cultivation, extraction and application processes have the potential to overcome these barriers and enable the (re)implementation of plant based dyes at scale. As plant based dyes and pigments come from bio-based renewable resources such as wood and algae, they have the potential to significantly decrease the use of chemicals in the dyeing process.

MICROBIAL PIGMENTS

Microbial pigments are produced in natural or genetically modified organisms (GMO), after which they are extracted to be used in traditional dyeing processes.The use of engineered bacteria can scale microbial pigment production, improve dyeing methods as well as performance. The biggest challenges lie in scaling, making mills and dye houses legally compliant to work with genetically modified bacteria.

KB cols use naturally occuring coloured microbes, which are a waste and inexhaustible source, to extract different natural colours, that can be applied in textiles and other applications. They aim to change the landscape of dyeing in the fashion industry by focusing on harnessing the true potential of Biotechnology.

> **“Sustainable innovation in wet processing areas of textile manufacturing can make significant impact in reducing water, dyes and chemical consumption and energy requirements. At the same time it can also bring in new performance attributes to the end products in terms comfort, easy care and health and wellness. I urge industry colleagues to support innovators in this space so that as an industry, we we move away from the `largest polluter’ name tag.”**

Umasankar Mahapatra, Vice President and Group Head – Innovation (Welspun India Ltd.); Business Head – Welspun Health

Step 2: Wet and Dry Processing

REGIONAL OPPORTUNITIES

- **Continued research is needed on identifying new sustainable products and processes such as new dyes which are, for instance, biodegradable, free of halogens and heavy metals in new chemical structures with very high exhaust and fixation values.**
- **Rapid industrial uptake by private sector players is a major gap that needs to be filled to bridge the gap between research and adoption. India's evolving policy landscape sometimes acts as a deterrent, putting researchers in a race to procure private sector investment for continued research.**
- **A significant part of the industry is unorganised[28], with several small dye houses that are unable or unwilling to invest in sustainable solutions. Larger players' adoption would hopefully bring in economies of scale and trickle down this effect to India's unorganised sector.**
- **Sludge treatment and water purification needs to go hand in hand with replacing chemical-based dyes, ensuring that where the industry does not change its input, its output is reduced in toxicity. Policy intervention alongside innovation would enable this.**

Step 3: Cut-Make-Trim

The following innovation areas allow for further process optimisation and elimination of any kind of waste in this supply chain step. Cut, make and trim (CMT) is the process of turning fabric into apparel by cutting the garment from a pattern, sewing it together and finally adding the needed embellishments. The wastage from the cutting itself is normally found in the range of 6 -25 % of the fabric[29]. The cutting waste can be reduced through minimal seam construction and designing for zero-waste. By optimising the processes and eliminating any kind of waste, the environmental footprint can be reduced.

KEY FINDINGS FROM THE REGION

- **CMT is a core step of the value chain in India; a global production hub that employs nearly 40 million people. Innovations in this space can be perceived as a threat to employment.**
- **Innovative technologies for zero-waste manufacturing and additive manufacturing exist but are yet to find mass adoption.**
- **Business model innovations around mass customisation have been a focus of the innovators and the sector as a whole.**

FOCUS AREAS

ADDITIVE MANUFACTURING

This is the process of creating three-dimensional objects, with greater complexity than conventional techniques. Some examples of these processes are flocking and spraying, 3D printing and 3D knitting. Additive manufacturing provides a better business use case by reducing the risk of long lead times and excess stock. With product customisation, customer returns decline which in turn, has a positive impact on the global environmental footprint.

Additive manufacturing is slowly making its way into India's fashion landscape, primarily through jewellery. Largely prevalent in the metal and machinery industry in India, additive manufacturing in the apparel industry has long existed in more low-tech, manual forms of hand and machine knitted and crocheted products.

Step 3: Cut-Make-Trim

Unspun – An on-demand fashion technology company has developed 3D fit algorithms and a 3D weaving machine for intentional and localised manufacturing. With a three-second body scan, unspun creates fully customised garments, perfectly matching supply and demand; by using only the fabric that is needed, no waste is produced. Already at scale, unspun's technology has up to a 24% lower carbon footprint compared with conventional practices. Their production technique eliminates scrap waste and the need for inventory. unspun recently operated multiple denim pilot projects with denim brands, including a publicly announced collaboration with Weekday, under the H&M Group.

ZERO-WASTE MANUFACTURING

These solutions aim to eliminate, reprocess or re-use pre-consumer waste. A key area of innovation in zero-waste manufacturing is garment construction, which refers to a method that eliminates or reduces pre-consumer waste. Zero-waste pattern design is a solution using 100% of the textile, aiming for no waste. Another innovation area is waste mapping which identifies the streams of textiles in the factory and finds alternative uses for this textile waste, minimising the number of textiles that would normally end up in landfills and incineration.

Zero-Waste Manufacturing innovations are at an early stage in India, with a few, select innovators providing solutions that are being used at scale. Typically associated with innovative cutting methods, innovators in this sector are refining processes and technologies enabling the reduction of wastage in garment manufacturing.

One of the most well-established companies in the space of zero-waste manufacturing is Coats Digital (formerly known as Threadsolre and rebranded after being acquired by the Coats Group). One of their products, IntelloCut, provides Artificial Intelligence (AI) driven cut-plans and lay-plans along with periodical reports on cutting performance to reduce fabric wastage and improve profit margins as a result. Coats Digital combines deep industry expertise with the practical application of the latest technology, including Big Data and AI, delivering market-leading software solutions.

Step 3: Cut-Make-Trim

MASS CUSTOMISATION

A hybrid of mass production and customisation — the mass production of individually customised goods and services[30]. It enables personalised, tailored and made-to-measure services for mass production. By analysing collected data of consumer preferences, behaviour and demand, brands and retailers can adjust their productions to better fit the tastes and wants of the consumer. Offering more personalised orders leads to a reduction in dead stock and overproduction. Some examples of these areas of innovation are fit technology, digital design and e-commerce solutions.

Mass customisation is one of the most profitable and mature CMT innovation areas in India. Tailoring custom-made clothes has culturally been the norm in India, replaced in the 90s by ready-to-wear fashion brands. Drawing on the best of both worlds, mass customisation enterprises like Sizenfit, TryNDbuy and Creyate, offer customers the opportunity to customise their clothing in a ready-to-wear, e-commerce environment. Leveraging technologies of sizing, augmented reality, and virtual trials, these retail platforms have templated customisations while reducing over-stocking. Anecdotal evidence also suggests that customised clothing increases the customer's attachment to the garment, thereby ensuring it is worn longer than an impulse purchase[31].

eShakti is a VC-funded mass customisation retailer of clothing originating from Chennai, India, and catering primarily to the American market. eShakti's custom capabilities allow women to tailor any item to their specific tastes such as changing neckline, sleeve or hem, or tweaking the measurements to ensure a flattering fit. Their patented methodology helps them overcome barriers of sizing and fit concerns as clothes are virtually designed and draped. They maintain inventory of fabric only and have grown 60% over the previous year.

AUTOMATION

Automation solutions play an important role with regard to financial viability for on demand, near and onshore production[32], as they reduce the dependency of manual actions within CMT. Examples can be found within picking, handling, conversion and packaging. In India, automation initiatives are largely perceived as a threat to the nearly 40 million people employed by the textile and apparel sector. Particularly in spinning, machines like auto-coners and auto-splicers have reduced human intervention from 20 workers to just two[33]. According to a World Bank report, nearly 70% of the jobs in India are at an elevated risk of being replaced by automation[34]. To adopt automation technologies, upskilling of workers is essential to mitigate unemployment. While automation is an interesting area for manufacturers, there is a lack of innovations in this space in the region.

Step 3: Cut-Make-Trim

Smartex Corp. is a company operating in Europe, USA and China, providing a unique patented system to improve production processes in the Textile Industry. Smartex Corp. integrates advanced Industry 4.0 elements, connects manufacturing processes with Internet of things (IoT) and Artificial Intelligence and enables traceability and sustainability approaches to the textile production lines. Currently, 3-5% of knitted fabrics have faults and need to be discarded. Smartex Corp. installs cameras in circular knitting machines to detect defects in the fabric production. When detected, knitting machines are turned off at the point of fault before continuing to produce an entire fabric roll. The result is a reduction in textile faults to 0.1%.

OPTIMISED YARN AND FABRIC CONSTRUCTION

These are innovations that increase the overall functional performance of yarns and fabrics. In India, this tends to be a space of incremental and iterative innovation — there are not as many outright new innovative solutions, only ongoing improvements on existing machinery and processes used in the industry. Virtual prototyping technologies have also achieved efficiencies from design to product rollout. Some pockets of the regional industry, such as the woollen spinning industry centered in Ludhiana, North India, has long had a closed-loop system where most of the wasted fibres during yarn spinning are collected and re-spun into a “second quality” or slightly inferior quality of yarn with a shorter staple length that has its own market.

Microspin is a Chennai-based yarn spinning enterprise that holds patents for revolutionary spinning machines that make small lots of yarn on IoT-enabled machinery. Operated via proprietary, energy-efficient algorithms, makes them five times more energy efficient than conventional methods. The resultant crafted yarn that is natural and holds dyes better than conventionally spun yarn and therefore requires half the water in their process. It’s easy to produce small lots of blended yarns be it mélange, cotton, silk and any other natural or synthetic fibre.

> **“We see great momentum for sustainable materials and production technologies over the last five years. We have adopted many such technologies in our manufacturing facilities and are committed to creating a circular production system.”**

Abhishek Bansal, Head of Sustainability at Arvind Limited

Step 3: Cut-Make-Trim

REGIONAL OPPORTUNITIES

- There is an opportunity to identify and scale niche innovations in zero-waste manufacturing, optimised yarn and fabric production.
- To grow innovations in CMT, there is a need to upskill garment workers to ensure they are not adversely affected by the growing automation of the apparel industry.
- Additive manufacturing and 3D printing are a huge opportunity in India especially in footwear and garments, an infusion of funding and large scale adoption can help bring economies of scale in these processes.
- Enabling Innovations in cutting and pattern making tools and equipment can reduce wastage at this stage drastically.

Step 4: Retail and Use

While often not at the forefront, the retail and use stage poses challenges that multiply the environmental footprint of the fashion industry. It is estimated that doubling the lifetime of a garment reduces its environmental impact by 49%[35], by saving carbon emissions and water that would be used in the production of new garments. Circular business models aim to keep existing garments in use for a longer period while also changing consumer behaviour. Below details the various types of circular business models as well as where they are on the global maturity curve.

KEY FINDINGS FROM THE REGION

- **Rental models have gained significant success in the luxury and occasion wear segment.**
- **India has a thriving ecosystem of re-workers who lengthen the life cycle of both pre- and post-consumer textile by converting them into new accessories and home decor.**
- **Virtual and Augmented Reality solutions with applications for e-commerce and brick-and-mortar retail are still a niche but growing sector.**

FOCUS AREAS

CIRCULAR BUSINESS MODELS (CBM)

CBMs fall into three main categories: re-commerce, rework and rental. Re-commerce platforms include solutions where consumers can purchase used but good quality garments from either a curated platform, a brand or other consumers. The garments have previously been sorted, cleaned and sometimes restyled or renewed before resale.

Rework innovations create contemporary designs utilising the excess stock by customising, deconstructing and resewing garments. India has a traditional culture of repair and rework through the widespread network of hyper-local tailoring and repair businesses. This cultural inclination to sustainability shifted in the 90s with the advent of ready-to-wear brands, both domestic and international, entering the market[36], leaving a fragmented repair and rework market. Innovators have responded with service-based enterprises aimed at formalising and organising the repair market. All of these innovations rely on a robust logistics network of at-home, pick-up and drop-off services, which help scale these models.

Rental platforms allow consumers to rent garments for one-off occasions or on a monthly basis, allowing consumers access to a wider range of products whilst also extending the life of the clothes. Rental is a burgeoning area of innovation in India and is expected to grow 22% by 2027[37]. For many of these platforms, sourcing of garments utilises dead stock and the focus is primarily on occasion wear.

Step 4: Retail and Use

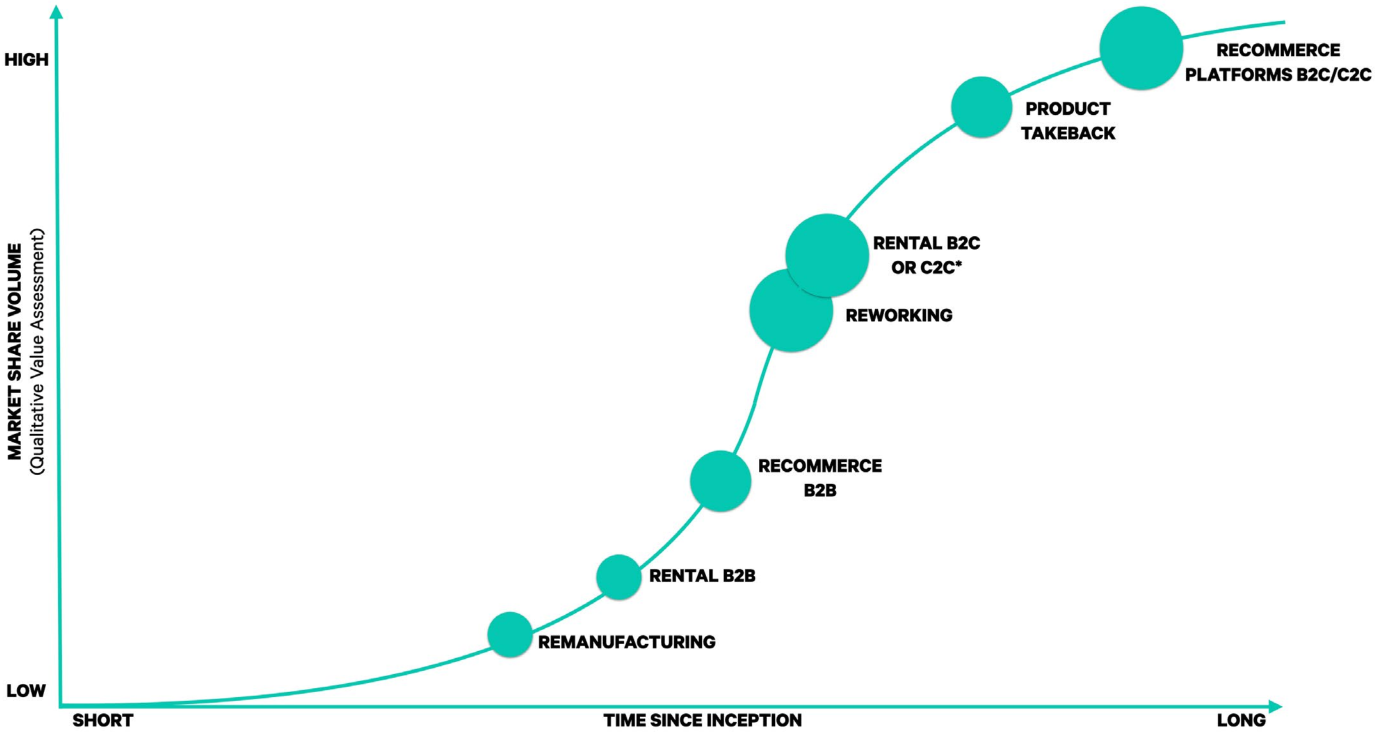
Beyond the environmental benefit of lengthening the life cycle of clothing, there are tangible business benefits of circular business models for the brands. Brands can improve their stock management, increase customer loyalty and revenue potential[38]. It also gives the industry an incentive to invest in high quality materials for long-term use. Consumers get an opportunity to access new styles without needing to buy new products. It also enables them to get value out of their own wardrobe by utilising peer-to-peer re-commerce and rental platforms.

Flyrobe is India's only VC-funded clothing rental platform, which was acquired by Myntra, a popular shopping platform. With a focus on occasion wear, the platform rented out clothing worth over $10 million in retail value in 2017. It offers pick-up and drop-off logistics and also has brick-and-mortar stores in seven cities around the country[39].

Mumbai-based zero-dividend company 'I was a Sari' sources pre-worn saris from informal physical resale markets like Chor Bazaar in Mumbai and employs under-privileged craftswomen to rework them into luxury garments and accessories. I was a Sari received the Green Carpet Ethical Award and the Lakmé Fashion Week Circular Design Challenge in 2019.

Step 4: Retail and Use

CIRCULAR BUSINESS MODELS: A SNAPSHOT INTO THE INNOVATION LANDSCAPE



NOTE: B2B = business to business; B2C = business to consumer; C2C = consumer to consumer

FIGURE 6

REGIONAL OPPORTUNITIES

- **In Rental and Re-commerce, segments other than luxury remain unexplored. Segments with limited time use such as maternity and children's wear offer a significant opportunity.**
- **Re-commerce and repair have long been an inherent part of everyday society, India has a thriving ecosystem of re-workers who lengthen the life cycle of both pre and post-consumer textile by converting them into new accessories and home decor. There is an opportunity for formalisation of these informal sectors leveraging digital innovation.**
- **A consolidated supply chain of dead stock and export surplus would streamline feedstock and enable scaling of circular business models such as rental, re-commerce and rework.**

Step 4: Retail and Use

> **There is a significant need for innovation and collaboration in the Retail Industry. In this COVID-19 pandemic situation, it's imperative to collaborate with stakeholders for business sustenance and bring systematic change towards responsible stewardship. One of the key areas where innovations are unfolding is that of 'New Circular Retail Business Models' pegged on rental, repair and resale which aim to extend the life cycle of garments. The other visible innovation trend is leveraging technology to drive greater efficiencies, design out waste and create superb customer experience in the retail space."**

Naresh Tyagi, Chief Sustainability Officer, Aditya Birla Fashion and Retail

Step 5: End-of-use

At the "end-of-use", the product reaches the end of its lifespan and is no longer in use by its owner. The majority of textiles are not designed for circularity at the end of their use and an overwhelming majority end up in the landfill or incineration. A large percentage of these materials could be reused, recovered and recycled into new materials for the textile industry to use as new feedstock. Today around 25%[40] of global garments are collected for reuse and recycling with only 1%[41] of the recycled garments converted into new materials.

Sorting, which is needed for effective recycling, requires separation of textiles by material type, as well as the removal of embellishments, such as buttons and zippers. Textiles are then recycled through a mechanical or a chemical process to create fibres and yarns, or to be used as material feedstock for a different industry[42]. To date, India has primarily focused on mechanical recycling as a way of managing textile waste, while chemical recycling and automated sorting technologies have yet to become mainstream.

Both pre- and post-consumer textile waste are feedstocks for these recyclers. In India, post-consumer waste is mostly imported from the US and Europe, regions with robust collection systems, and used by the mechanical recycling enterprises to create new yarns, fabric and finished products. Pre-consumer waste is retrieved from domestic and international manufacturing; however, regardless of their origin, the recycled products are mainly exported to other countries through sales to large global retail brands. Various recycling hubs throughout the country process different output; the input for Panipat in North India is mainly pre-consumer waste and the fibre output is downcycled i.e. used in the production of blankets, mop heads and low-cost bedding that finds its way into domestic markets. Tirupur, on the other hand, has a closed loop system, most of the 40 tonnes of daily combustible solid waste[43] generated by the Tirupur textile industry is recycled into textile materials primarily for export.

KEY FINDINGS FROM THE REGION

- **India shows a clear domination of mechanical recycling as a way of managing textile waste.**
- **Chemical recycling and automated sorting technologies are yet to find footing in India.**
- **There exist mature innovations in the space of non-textile to textile recycling, primarily in recycling of PET into polyester fibre.**

Step 5: End-of-Use

Additional details on sorting, mechanical recycling and chemical recycling innovations are provided below.

FOCUS AREAS

SORTING

To enable high value recycling, technologies are required to effectively sort textiles into their various fibre compositions. This is because recyclers have specific feedstock requirements for their process. Today, textile sorting is predominantly done manually, leaving room for innovations in automation. Advanced automated sorting is considered to have a disruptive potential as it enables processing of large textile flows with a high degree of accuracy, thus enabling high value recycling at full capacity and scale.

Located in Chandigarh, Usha Yarns is a two-decade-old recycler that services both the domestic and international market with their 100% recycled content yarns made from pre-consumer cotton waste and post-consumer recycled polyester. Their feedstock of pre-consumer waste comes mainly from garmenting hubs of India and partly sourced from overseas due to the need for a feedstock of 1,000 tonnes per month.

MECHANICAL RECYCLING

Mechanical recycling is a process that involves deconstructing textiles resulting in fibres that can be spun into new yarn and woven into textile. Some natural fibres such as cotton, wool and cashmere respond well to mechanical recycling due to their long fibre length, while other fibres are easily damaged during the process resulting in a reduction of quality. Mechanical recycling is the most common textile recycling method and has been in existence for several decades. India is a global hub for mechanical recycling - its textile recycling sector employs more than one million and registers an annual turnover of around US$ 2 billion in processing about 5 million tonnes of material[44]. An alternative supply chain exists for non-recyclable materials such as zips, buttons and other embellishments as well as domestic post-consumer waste, but it almost entirely relies on an unorganised labour force of itinerant waste workers. Non-recyclable waste, both generated within the country or imported, and waste that does not make its way to recyclers, finds its way into the large and informal economy of waste workers. Commonly known as “chindi-wallas”, and many belonging to the nomadic Waghri community of Gujarat, this is the invisible force behind the recycling of textile and in fact most forms of dry waste in India. They have traditionally done the work of collecting, repairing and re-selling used clothing from households around India, driving product life extension through low-cost, cash-based trading. Attempts have been made to organise this sector with dry waste management companies that find themselves tackling textile waste, amongst others, typically in the form of post-consumer household waste generated domestically.

Post-consumer textile waste generated in India largely does not make its way to recyclers. India is the world’s second largest exporter of textile and fabric, which accounts for about 13% of its total export earnings. Apart from producing a large volume of pre-consumer waste during the production of these exports, as more global brands enter India, it is also becoming a global consumption hub leading to an

increase in post-consumer waste generation. Our research has shown that textile waste is the third largest source of municipal solid waste in India, implying that most of this waste ends up at landfills rather than with recyclers. This gap between textile waste producers and recyclers exists primarily due to the logistical challenges of a large country with far-flung manufacturing setups. Further, there is little to no organisation in the collection and aggregation of domestic textile waste, which explains the recyclers' dependence on imported waste.

Mechanical recycling faces challenges as the process performs best with non-blended input in order to generate pure output; however, a large proportion of textile waste today comes from blended garments - notably polycotton. Additionally, optimal operation of the machinery for mechanical recycling requires hundreds of kilos per fabric per colour to run one cycle of shredding, carding and spinning[45]. While there are multiple established players in mechanical recycling, and the process has a significantly lower environmental footprint as compared to virgin fibres, the impact of mechanical recycling is considered to be sub-optimal, as it cannot support an endless recycling of products.

Geetanjali Woollens, one of the oldest mechanical recyclers based in Baroda, Gujarat, processes 25 tonnes of post-consumer waste a day imported from US, Europe, Australia, Japan etc. using a manual process of segregation by fabric composition and colour, done entirely by skilled women workers. The post consumer waste is then shred into fibre and spun into yarn suitable for knitting and weaving, which today finds its way into many world renowned brands for their sustainable collections. Non-recyclable waste, if any, is sold onwards to small-scale waste collectors.

CHEMICAL RECYCLING

Chemical recycling is a process where modifications in the textile fibre are made on the molecular level to create recycled fibre, yarn and textile. Chemical recycling is considered to have a highly disruptive impact with a potential for true circularity, given it is able to produce output of indistinguishable quality to virgin production. Today, most chemical recyclers need a high purity textile feedstock to process; however, the majority of garments on the market consist of some sort of poly-cotton blend. Blend recycling is thus an area of significant opportunity. Chemical recycling solutions for blends are highly complex and capital intensive, with most technologies only in the lab or early pilot stage. As the technological and investment challenges are overcome, chemical recycling has the potential to play an important role in reducing the environmental footprint of the industry. While the conversations around chemical recycling are nascent in the Indian landscape, the pioneers of the industry are testing out these technologies recognising chemical recycling as a key investment for securing the future of the Indian textile industry.

Step 5: End-of-Use

One such example is the "Full Circle Textiles Project: Scaling Innovations in Cellulosic Recycling" – a first-of-its-kind consortium of brands, manufacturers, innovators and India based Birla Cellulose as key supply chain partner. The Project's overall aim is to investigate economically viable and scalable solutions for cellulosic chemical recycling to enable a closed loop system converting textile waste – of cotton and cotton-blend materials, to produce new man-made cellulosic fibres[46].

PerPETual has developed a unique chemical recycling process which transforms waste PET bottles into high quality esters, exhibiting the same quality as virgin equivalents and can be used in the production of PET-based fibres and yarns. PerPETual already produces esters from PET bottles at scale and is continuously innovating and piloting to scale their textile-to-textile operations. They are currently operating at a scale of recovering over 200 million PET bottles daily, therefore making them one of the largest PET chemical recyclers globally.

Founded in 2018, Australia-based Blocktexx has developed a patent pending process that combines chemical recovery technology and advanced manufacturing to separate and recycle polyester and cotton blends. The company raised seed funding of over $500k in mid-2019, which enabled the optimisation of their technology in a pilot plant alongside trial projects with supply and demand partners.

> **"While the linear system today is damaging both society and the environment, climate crisis and resource depletion are two of the biggest challenges around the end-of-use phase of the value chain. Integrating circularity into each key stage from design to reuse and recycling will help close the loop, maximise resources and minimise waste."**
>
> Komal Arora, Head - Sustainability & CSR, H&M India

Step 5: End-of-Use

REGIONAL OPPORTUNITIES

- **Investment is required in chemical recycling technologies for polyester and blended fibres, especially to handle domestic post-consumer waste.**
- **Automated sorting technology is a clear innovation whitespace which can significantly enhance the speed and scale of recycling. However, its impact on local employment would be significant and must therefore be coupled with upskilling and training interventions.**
- **Chemical Recycling technologies could use existing mechanical recycling supply chains for reaching faster implementation.**
- **Building a new value chain for pre- and post-consumer domestic textile waste would help hedge against possible regulatory restrictions on waste imports.**
- **Organising waste workers and enabling aggregation of waste collected by them could help create a robust and socially impactful model of end-of-use textile management.**

Step 6: Overarching Supply Chain

There are quite a few topics that are overarching, with impact across the supply chain. This section covers said topics, looking at traceability and transparency, worker empowerment, supply chain redesign and logistics and packaging. Below is a short overview of opportunities in each of these areas.

FOCUS AREAS

SUPPLY CHAIN REDESIGN

Changing the current system of large scale productions in low-cost regions to a system of locally situated micro manufacturers also provides an area of opportunity for innovation. The current supply chain system has, to a large extent, served the consumer well - economies of scale have driven costs down and increased accessibility. However, it has contributed to labour exhaustion, an increased environmental footprint and production delays[47].

Alternative solutions have emerged, such as operating a network of small and flexible factories located close to customers. Micro factories operating on a regional level enable production, process and logistics networks to interact in a much more flexible, faster and customised manner. An important part of micro factories is automation, which allows for localisation with lower costs and higher efficiency[48]. Investing in redesigning the supply chain has a large potential impact on both innovation and sustainability.

Nimbly is an on-demand 3D knitting platform that powers the one-off manufacturing of standard-size garments. Nimbly matches supply with demand, making products in less than an hour – with no order minimums. Nimbly partners with brands, retailers and designers to produce standardised and customised knit creating clothes that are ethically sourced and responsibly produced. Nimbly has the potential to reduce inventory waste with on-demand production. Additionally, true-sizing technology can reduce reverse logistic burdens and waste generated from returns.

Step 6: Overarching Supply Chain

WORKER EMPOWERMENT

Workers play a crucial role in the supply chain, it is estimated that a hundred human hands touch a garment during its creation process[49]. The fashion industry employs around 300 million people across the supply chain[50] of which 80% are women[51]. As a production hub and a labour-intensive geography, worker empowerment is a critical area of innovation in India.

Technological innovations in worker welfare can empower workers. Through various software solutions workers are now able to engage with their employer, report with anonymity, as well as receive training. These solutions become viable alternatives to traditional and manual auditing by giving the workers a medium to engage with others, share opinions and learn about their rights, as a result the workplace can become safer and more efficient

&Wider has created a cloud platform which enables buyers and employers to hear about workers' everyday lives and working conditions directly from the workers themselves. The cost-effective diagnostic tools offered by &Wider use mobile phones to track and encourage improvement in labour practices along the supply chain. By using &Wider's tool, brands and suppliers include workers directly in ethical trade conversations.

LOGISTICS AND PACKAGING

Global supply chains demand long distance transportation and the increasing market share of e-commerce with high return rates requires increased frequency of transportation. Throughout the supply chain there is a high consumption of single use packaging which is primarily made of plastic and cardboard. This contributes significantly to the carbon emissions of the industry, an estimated 5%[52] of the total emissions.

If every garment produced per year was shipped in a polybag, there would be more than 180 billion polybags generated each year[53]. New packaging solutions such as bioplastics, compostable and recycled materials and reusable packaging solutions exist, however no one solution has proven to be a replacement for the traditional materials. This creates an underserved innovation opportunity for the industry.

The Ganges river in India is the second biggest contributor to plastic pollution in the oceans by way of streaming discarded plastic into the open ocean. Additionally, some of the key water bodies in India near Mumbai, Kerala and the Andaman and Nicobar Islands are among the most polluted in the world. Despite these dire environmental consequences, more than half of all the plastic produced is designed to be used only once. In order to improve the current situation, innovative solutions in environment-friendly packaging materials, recycling of packaging materials into new feedstock and circular logistics are required.
Fashion for Good for example launched a multi-stakeholder pilot project, The Circular Polybag Pilot, which explores solutions that aim to reduce the use and impact of virgin polybags in the fashion industry.

Step 6: Overarching Supply Chain

Bio-based and biodegradable plastics are often made from feedstocks such as corn or sugarcane and have been adopted for short-term use in product packaging such as the food industry. These can be either 'drop in' solutions i.e. direct replacements for existing plastics or require changes in infrastructure to be produced. These bioplastics have the potential to be a good replacement for plastic used in the apparel industry. India is an established market for bioplastics with several manufacturing plants in Bengaluru and Chennai. However there is often confusion between 'bio-based' and 'biodegradable'; not everything bio-based is biodegradable and not everything biodegradable is bio-based. This can lead to challenges around understanding end of life impacts once the bioplastics reach landfill.

Phabio offers biodegradable non-toxic polyhydroxyalkanoates (PHA) as a sustainable alternative to existing polyesters. Phabio's innovation lies in making biodegradable polymers from renewable biomass obtained as wastage in industries including beer, sugar industry, food waste and seaweed. Phabio uses less water and no chemicals to produce PHA, making it greener than the conventional polyester production. These bioplastics are biocompatible, causing no harm to marine aquatic life or to the environment.

Capturing existing packaging and recycling it back to virgin grade is another prime area for innovation. The Central Pollution Control Board of India estimated the collection efficiency of plastic waste to be 80.28% in 2014, out of which only 28.4% was treated and the remaining quantities were disposed of in landfills or open dumps[54]. There is a visible uptick in innovations that are redesigning systems and where post-use materials and collected components are being put to other uses. These models aim to incentivise and improve collection and build mechanical and chemical infrastructure to recycle plastic waste.

Lucro is an Indian recycling company that harnesses the possibilities of flexible plastic to produce high quality, innovative and recycled-content products. Lucro specialises in recycling local flexible plastic waste to manufacture recycled-content products. Their Plast-E-CycleTM model helps collect discarded plastic waste through their network of rag-pickers. This waste is further sorted and washed, extruded and granulated to close the loop by producing recycled products. Lucro assists brand owners to redesign and manufacture packaging material to help them shift from virgin material to recycled materials.

Step 6: Overarching Supply Chain

WASTEWATER TREATMENT

The dyeing and finishing of textiles represents 20% of global industrial wastewater[55], and around 280 000 tonnes per year of dye end up in freshwater[56], making treatment of wastewater a priority area for the industry. Conventional treatments, while reducing effluent, generate toxic sludge with chemical discharge and greenhouse gas emissions. Not only is there a high environmental cost but the current systems are also very expensive. Current innovations can be found in the form of microbial fuel cell (MFC) technologies that treat the effluent and convert it into a source of energy.

JSP has developed a microbial fuel cell that generates electricity from the decomposition of textile effluent. Bacteria within the fuel cell breakdown energy rich dissolved solids, releasing energy into a self contained unit that powers itself. JSP recovers water completely while reducing the extensive need of external electricity. The technology is affordable for small and mid scale dyeing units that don't have common effluent treatment plants.

Another disruptive solution for wastewater treatment is provided by SeaChange Technologies, which separates and oxidises unwanted materials, microplastics and other non-biodegradable components from the water with the help of a powerful jet turbine, releasing only a small amount of CO_2 and water vapour. In 2019, Fashion for Good corporate partners Arvind Limited, BESTSELLER, C&A and PVH Corp., came together with support, funding and expertise for a pioneering pilot project with SeaChange technologies. Arvind Limited provided access to their Effluent Treatment Plant near Gujarat, India, one the world's largest textile manufacturing operations, to conduct a field evaluation. The SeaChange system was implemented over a period of three months to test and evaluate the feasibility of wide scale implementation of the system[57]. Following this successful pilot, SeaChange Technologies is now planning and preparing for its commercial launch.

DIGITAL ACCELERATION

Digital solutions can streamline production processes creating efficiencies in design, merchandising and planning, B2B buy-in, sourcing and production as well as in consumer engagement. Some examples include the use of 3D design, digital sampling, AI trend forecasting, digital showrooms, on demand manufacturing as well as enhanced selling.

There are a number of other benefits that come with digitisation throughout the supply chain, including:

- More accurate designs and better communication between designers and manufacturers that can potentially lead to products that are more effectively designed for their purpose;
- Fewer samples, which means less waste;
- The elimination of unnecessary (air)travel;
- Dramatically shorter lead times, which could contribute to limiting overproduction and facilitate on-demand manufacturing;
- And fewer returned items through e-commerce (in the case of digital fitting and virtual try-on).

Step 6: Overarching Supply Chain

We have explored the opportunities for digital acceleration throughout the fashion value chain highlighting the innovations that are driving the transformation.

DIGITAL ACCELERATION

FIGURE 7

3D DESIGN

Historically prototypes and samples would go through multiple iterations and physical prototypes before the final product is signed off. 3D design means designers can see the garment instantly. In addition to this, it also allows for real-time feedback on the cost and in the near future also the impact of the garment. It enables more effective communication between teams and between brands and manufacturers. Solutions also exist that enable the digitisation of real fabrics, that can then be saved and uploaded into 3D design software. The 3D design process can be implemented internally or outsourced to third party companies. Whilst the latter might be quicker in the short-term, the advantages of digitising one's own internal workflow allows brands and manufacturers to reap the benefits.

Swatchbook is a cloud platform revolutionising the exploration, visualisation and sharing of materials. The platform enables suppliers to upload their materials along with other metadata and pricing details for brands to further explore, discover and visualise materials, sharing them with other stakeholders for further use.

Step 6: Overarching Supply Chain

MERCHANDISING AND PLANNING

Following the design phase, merchandisers can then compile the final collection using these digital samples. They can be more easily distributed throughout the company and reduce lead times. This in turn allows for better trend forecasting. In addition, many start-ups and established players are developing advanced AI trend prediction solutions that help brands to better understand their consumers and their needs.

B2B SELL IN

Digital showrooms enable brands and manufacturers to showcase their digital collections in a virtual space. With reduced travel in a post COVID-19 world, this enables both brands and manufacturers to continue to drive customer relationships. These showrooms actually allow stakeholders to go above and beyond the usual experience bringing the garments to life through different platforms and technologies such as Virtual Reality (VR) or using 3D assets.

SOURCING AND PRODUCTION

As mentioned before, brands as well as manufacturers work with 3D software which can be used as a real-time feedback and communication platform. As such, it's important for brands to onboard their manufacturing partners to ensure they are achieving consistent quality together. The ultimate goal is to create 3D models that remove the need for tech packs, where manufacturers could cut and sew products using only these 3D models.

Digital samples also help facilitate on demand manufacturing as customers can see photo-real images early on in the process.

CUSTOMER ENGAGEMENT

Alongside supply chain solutions there are many technologies that allow brands to engage with consumers in new ways. Some examples of these include AI style and fit solutions, virtual fashion try on, Extended Reality (XR) shopping and live selling.

AI style and fit advisors allow brands to provide better recommendations to consumers, reduce e-commerce returns and drive conversion. Virtual fashion try-on uses Augmented Reality (AR) to allow consumers to virtually try on garments before they buy. Whilst XR shopping means they can shop virtually from wherever they are in the world. Finally, live selling allows brands and retailers to reach new markets or audiences using store associates or celebrities.
While still a niche space, the application of VR and AR technologies for e-commerce and retail appears to be the "next big thing" in the world of sustainable shopping.

TRANSPARENCY AND TRACEABILITY

Transparency in the supply chain means the standardised disclosure of relevant information at each step creating a common understanding, accessibility, clarity and comparison[58]. Traceability on the other hand, is defined as the process by which materials and products are tracked as well as the conditions in which they

were produced throughout the entire supply chain[59]. Traceability is an indispensable prerequisite leading to increased transparency and ultimately accountability by enabling brands to address environmental and social sustainability impacts through identification of such pain points along the supply chain.

Transparency and traceability solutions are challenged by the complexity of global textile supply chains which are characterised by a lack of integration among the numerous actors. This is made more acute by the growing number of standards without a unified, industry-wide solution that is easily implementable. Furthermore, the ambiguous link of traceability to firm performance, perceived risk of disclosing certain data and the unclear business case gives companies limited incentives to incorporate traceability into their strategy. Currently, only a third of the industry traces the supply chain beyond Tier 2[60]. While significant environmental impact takes place in Tier 1 and 2, there is an increased consumer and stakeholder demand as well as evolving laws and regulations forcing companies to re-evaluate their efforts.

The Indian textile and apparel industry is notoriously opaque as garment supply chains are highly fragmented, difficult to trace and environmentally inefficient. In a crowded marketplace like India which is also one of the top garment exporters in the world, transparency is required in order to stay competitive.

The most interesting traceability projects combine blockchain technologies, tracers and communication platforms. Blockchain technology is a type of distributed ledger system for maintaining a permanent digital and tamper-proof record of transactional data. Tracers are product marking and identification tools. There are various types of tracers that can be integrated with blockchain technology to enable traceability. DNA, fluorescent particles and microparticle analysis are some of the new tracers being applied in the textile industry; for more details see the Organic Cotton Traceability Pilot, convened by Fashion for Good and Organic Cotton Accelerator[61]. To communicate the information stored in a blockchain, tools such as hang-tags including QR codes, benchmarking and auditing platforms are used. Beyond ensuring security and authenticity of data, blockchain-based innovations are also aiming to ensure data exchange by enhancing compatibility and the ability to integrate with existing systems used by stakeholders across the supply chain.

TrusTrace provides brands such as Filippa K, Decathlon and the Fenix Group, with a blockchain-based software platform for tracing their supply chain from fibre to garment. Through TrusTrace, users have been able to seamlessly identify the raw materials at a LOT level, collect and validate product and facility certifications, compute the product footprint and communicate the product story to the end customers. The information is used by brands to communicate this information to their customers, perform internal risk analysis and manage their supply chain better.

Conclusion

We believe that accelerated dynamism in the circular innovation landscape will drive efficiencies across the Indian fashion and textile supply chain, enabling the industry to leap-frog to sustainability. Innovators developing products, processes and service offerings or combinations thereof at critical points in the supply chain as well as systems level solutions, can usher in necessary disruptions through accelerated adoption and scale.

However, our research identified a variance in the level of innovation momentum observed in different phases of the industry supply chain. While significant innovation momentum is visible in the “Retail and Use” phase, given the relative ease of developing solutions and proving underlying business cases, there is very little innovation activity unfolding in the “Cut-Make-Trim” phase of the supply chain. On the other hand, while there are a number of innovations emerging in phases like “Raw Material”, they exhibit low maturity in terms of scalability and technology usage.

Key insights emerging from our analysis of the current state of innovations at different points in the Indian fashion and textile supply chain as well as opportunities and whitespaces at each of these points can be classified into following themes:

- The need for the region is to develop new feedstocks for the textile industry. New feedstocks sources could include alternative raw materials such as new natural fibres, regenerated fibres and cellulosics, or fibres from existing materials that have been recycled to create virgin grade output.

- The challenges around wet processing have been evident for a few decades. The country is buzzing with new research in this space, with many research institutions and innovators pursuing sustainable solutions around waterless dyeing, low impact pre-treatment and finishing processes. Research and development (R&D) needs further support to scale their research; this support can be enabled through involving industry stakeholders, government and funding institutions at the onset of these innovations.

- Cut-make-trim innovations pose a larger question to the ecosystem in India, impact for cut-make-trim innovations on the workers/livelihoods needs to be assessed. There needs to be a purposeful approach towards marrying technological innovations in cut-make-trim with worker wellbeing, upskilling and alternate job creation. This too needs a collaborative effort of the government, industry and innovations.

- Circular business models are making waves as SMEs are pushing forward to change the consumer mindset and create a viable business with rentals, re-commerce and rework. Larger players have already started identifying this as an opportunity in the region and it’s only a matter of time until larger retail players in the industry will integrate the existing SMEs or create their own models.

Conclusion

- Disclosure in the supply chain in India has been another evident area of innovation, which has attracted multiple technological solutions. The focus needs to be on material transparency along with process transparency. It is essential to develop transparency for newer feedstocks, including transparency for recycled materials and potentially build a common industry standard for transparency. Currently transparency solutions appear to be optional solutions driven by the buyers, these solutions require standardisation and incentives for incorporation with buyer and supplier buy-in.

Here we highlight the key enablers that will enable the circular transition in the fashion industry in India.

1. **A sustained focus on R&D will be essential to promote upstream innovations**. In case of "Raw Materials", R&D efforts need to focus on developing new natural fibres, bio-synthetics, regenerated fibres and processes that consume fewer chemicals, less water and energy. Such efforts also need to be directed towards enhancing compatibility of such products with existing equipment and infrastructure available in India. This would temper the need for substantial investments towards complete infrastructure overhaul in the mid-stream phases, allowing for phased equipment upgrades. Similarly in the "Wet and Dry Processing" phase, significant focus on R&D is required to identify new alternative dyes and finishing products like biodegradable dyes that are free of halogens and hence, more sustainable. R&D is also required to develop new processes that reduce water usage and harmful effluent discharged during this phase.

2. **Public-private engagement and appropriate policy incentives will be necessary for establishing and strengthening local supply chains (supply side interventions) to ensure availability of, and access to, innovative circular products**. This will be particularly relevant for ensuring production and seamless availability of alternative products, particularly in the "Raw Materials" and "Wet and Dry Processing" phases of the supply chain. In case of "Raw Materials", sufficient incentives for labs, farmers, manufacturers and entrepreneurs will need to be deployed to create a supply chain for large-scale production of new alternative materials. The same holds true in the "Dyeing and Finishing" for ensuring production and distribution of products such as new sustainable dyes.

3. **Investing in innovations and simultaneously building supply chain capabilities will be critical for faster innovation adoption and scale-up**. This requirement holds true across the supply chain phases to spur demand for innovative products and processes. In case of "Raw Materials", this translates to the need for investing in new alternative material production and building capacities of supply chain players to adopt such alternative materials. Similar efforts are needed in "Dyeing and Finishing" to drive adoption of alternative products like biodegradable dyes as well as processes like waterless dyeing. In "Cut-Make-Trim", capacities need to be built for innovations around zero-waste manufacturing and optimised yarn and fabric production. In "End-of-Use", investment is required in technologies for chemical recycling of polyester and blended fibres and for automated sorting. To tackle this issue, Fashion for Good created The Good Fashion Fund. It provides funding (in the form of debt financing) to the most promising high impact and disruptive technologies in the fashion industry. Its focus is on textile and apparel production in Asia (India, Bangladesh and Vietnam). There is a need for more such funding tools to enable the scale-up of these disruptive innovations.

Conclusion

4. **Up-skilling of workers in the supply chain will facilitate easier innovation adoption and job protection**. This flows naturally from the earlier point on developing supply chain capabilities and is also applicable throughout the supply chain, especially in phases where innovation unfolds in the form of mechanisation. Efforts to accelerate circular transition through innovation adoption needs to factor in the human aspect of the fashion and textile supply chain. Most innovations will entail enhanced adoption of automation and/or a change in processes or mechanisms. Either way, this implies that innovations will make certain existing jobs/skills redundant and create new/altered jobs that call for new skills. This in turn, implies that up-skilling of workers will be crucial to ensure the availability of skilled resources and also to ensure protection of jobs and livelihoods of workers.

> **“There is a perfect storm of innovation and opportunity brewing in the Indian fashion industry. With action and all industry actors coming together to capitalise on these innovations, India is positioned to transform the fashion industry towards circularity.”**
>
> Katrin Ley, Managing Director, Fashion for Good

Definitions and References

DEFINITIONS

1. **Hydrophobic state and Hydrophilic state**: A hydrophilic surface has a strong affinity to water and spreading of water on such a surface is preferred. Hydrophobic materials are known as non-polar materials with a low affinity to water, which makes them water repelling[62].
2. **Substrate**: In chemistry, a substrate is typically the chemical species being observed in a chemical reaction, which reacts with a reagent to generate a product. It can also refer to a surface on which other chemical reactions are performed, or play a supporting role in a variety of spectroscopic and microscopic techniques[63].
3. **Supercritical CO2**: is a fluid state of carbon dioxide where it is held at or above its critical temperature and critical pressure. Carbon dioxide usually behaves as a gas in the air at standard temperature and pressure (STP), or as a solid called dry ice when frozen. If the temperature and pressure are both increased from STP to be at or above the critical point for carbon dioxide, it can adopt properties midway between a gas and a liquid[64].
4. **Cationic and Enzymatic process**: Cationic polymerisation is a type of chain growth polymerisation in which a cationic initiator transfers a proton to a monomer which then becomes reactive toward chain growth. The cationic polymerisation usually proceeds at very high rates both at high and low temperatures. Both the rate of reaction and the molecular weight decreases with increasing temperature[65]. **Enzymatic process:** enzymes help in accelerating the biochemical reaction which converts a substrate into a product.
5. **Eutrophication**: Harmful algal blooms, dead zones, and fish kills are the results of a process called eutrophication — which occurs when the environment becomes enriched with nutrients, increasing the amount of plant and algae growth to estuaries and coastal waters[66].
6. **SALT (for dyeing process)**: Salt plays this crucial role of catalyst. Salt has an extremely high affinity for water. Broadly speaking, Salt is necessary in three ways, firstly, to drive dye into textile during the dyeing process in textile. Secondly, use of salt leads to maximum exhaustion of dye molecules during the dyeing process in textiles. Thirdly it is used as an electrolyte for migration, adsorption, and fixation of the dyestuff to the cellulose material[67].
7. **Industry 4.0**: is the information-intensive transformation of manufacturing (and related industries) in a connected environment of big data, people, processes, services, systems and IoT-enabled industrial assets with the generation, leverage and use of actionable data and information as a way and means to realise smart industry and ecosystems of industrial innovation and collaboration[68].
8. **Polyethylene terephthalate (PET)** is a general-purpose thermoplastic polymer which belongs to the polyester family of polymers. Polyester resins are known for their excellent combination of properties such as mechanical, thermal, chemical resistance as well as dimensional stability. PET is one of the most recycled thermoplastic and has the number "1" as its recycling symbol. Recycled PET can be converted to fibres, fabrics, sheets for packaging and manufacturing automotive parts[69].
9. **Single use plastics/polybag**: Single-use plastics are goods that are made primarily from fossil fuel–based chemicals (petrochemicals) and are meant to be disposed of right after use—often, in mere minutes. Single-use plastics are most used for packaging and service ware, such as bottles, wrappers, straws, and bags[70].

Definitions and References

10. **Biobased and biodegradable**: Biobased plastics are made from renewable resources instead of non-renewable petroleum based resources. These renewable resources can include corn, potatoes, rice, soy, sugarcane, wheat and vegetable oil. Biobased plastics are made by creating plastic polymers from these materials, through either chemical or biological processes. Examples of these types of plastics are polylactic acid (PLA) – derived from starch, polyhydroxybutyrate (PHB) – derived through microbial synthesis, and biobased polyethylene (bioPE) – produced from sugar cane. Biodegradable plastic degrades through exposure to naturally occurring microorganisms. When classifying a plastic as a biodegradable, the environment and timeframe must be specified; otherwise the claim is rendered pointless due to an array of variations. All organic matter will eventually biodegrade. This includes traditional petroleum-based plastics. However, the rate of biodegradation of different organic materials can vary on an exponential scale[71].
11. **Tier 1, 2 and 3**: Tier 1 cities include the top metropolitan cities of India. These cities are densely populated and have higher living expenses. Major international airports, industries, top multi-specialty hospitals, education, and research institutes are located in tier 1 cities. For example Bengaluru, Delhi, Mumbai, Chennai. Tier 2 cities include developing cities with a rapid growth rate in industrial and allied sectors. These cities are the most convenient destination for foreigners, especially medical travelers, to get the best services at affordable costs. For example Agra, Dehradun, Coimbatore, Lucknow. All the other cities of the country except the tier 1 and tier 2 cities come under Tier 3 category. It includes cities having lower population density and cost of living. The tier 3 cities have poor air connectivity and other infrastructure facilities[72].

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