Safer Chemistry Innovation in the Textile and Apparel Industry

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FASHION FOR GOOD

SAFER MADE

About this Report

This report was commissioned by Fashion for Good to accelerate the adoption of new technologies that reduce or eliminate the use of hazardous chemicals by:

- Creating the language to facilitate conversations about textile and apparel safer chemistry innovation

- Bridging the gap between sustainability in a broad sense and the detailed safer chemistry challenges of the textile and apparel industry

- Identifying the main safer chemistry innovation areas based on the functions delivered by the chemicals of concern, and showcasing innovative companies active within each innovation area.

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About Safer Made

Safer Made is a venture capital fund that invests in safer products and technologies. Our investment premise is that people prefer safer products. The technologies we invest in enable brands and retailers to tell a differentiated story of safety and sustainability that resonates with consumers. Safer Made works with brand manufacturers and retailers that lead in safety and sustainability to invest in technologies that address their safer chemistry needs. Safer Made's General Partners are Adrian Horotan and Marty Mulvihill.

About Fashion for Good

Fashion for Good is a global initiative to make all fashion good. It is 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 organizations, innovators and funders.

At the core of Fashion for Good is its innovation platform. Fashion for Good's Plug and Play Accelerator gives promising start-up innovators the expertise and access to funding they need in order to grow. The Scaling Program supports innovations that have passed the proof-of-concept phase, with a dedicated team that offers bespoke support and access to expertise, customers and capital. Finally, the Good Fashion Fund (in development) will catalyze access to finance where this is required to shift at scale to more sustainable production methods.

Additionally, Fashion for Good acts as a convener for change. From its first hub in Amsterdam, it houses a Circular Apparel Community co-working space; creates open-source resources like its Good Fashion Guide; and welcomes visitors to join a collective movement to make fashion a force for good.

Fashion for Good was launched in 2017 with C&A Foundation as a founding partner. Its programs are supported by corporate partners Adidas, C&A, Galeries Lafayette Group, Kering, Target and Zalando, as well as organizations including the Cradle to Cradle Products Innovation Institute, the Ellen MacArthur Foundation, IDH—the Sustainable Trade Initiative, Impact Hub Amsterdam, McDonough Innovation, Plug and Play and the Sustainable Apparel Coalition.

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Executive Summary

Few people know about the complex chemistry embedded in our clothes, and the hazardous nature of some of the chemicals involved. As investors in safer chemistry and materials, we often find ourselves describing the opportunity to people who are not familiar with the need for safer chemicals. Finding the right level for this conversation is important. Talking about specific chemicals is often too detailed. Talking about sustainability and market needs in high-level terms fails to grasp what the innovation opportunity is about.

This report provides an overview of the safer chemistry innovation opportunity in the textile and apparel sector. We describe key drivers, evaluate the role different chemicals of concern have in the production of textiles and apparel, identify five key areas of innovation, and provide insights to accelerate the adoption of new technologies that reduce or eliminate the use of hazardous chemicals.

Safer Made invests in companies and technologies that bring safer products to market. We come across new technologies and materials every day. Having a clear picture of what the industry needs, what the big impacts are, and how these new technologies and materials can address them gives us an indication of the potential value creation, and allows us to compare new technologies and materials with other approaches addressing the same challenges.

Eliminating hazardous chemicals from the textile and apparel industry requires action from a broad group of actors, both within and outside the industry. Articulating the safer chemistry innovation opportunity helps conversations among industry actors such as brands, retailers, chemical suppliers and mills. A clear picture of the safer chemistry innovation need would also help innovators attract financial support including investment capital, and would help actors outside the industry, such as investors, governments and the advocacy community, grasp the opportunity and get involved.

Chemicals deliver certain functions to final garments. For example, fluorocarbon chemicals make rain jackets water repellent. Other chemicals are used to deliver functions to the manufacturing process; for example, sizing agents reduce the abrasiveness of yarns during fabric construction. Hazardous chemicals often end up discharged into the environment, and high-profile examples of river and surface water pollution have been a liability for the sector. Brands are realizing that in the eyes of consumers they have a responsibility for both the chemicals on their garments and the process chemicals that are used in their manufacturing.

The textile and apparel industry is facing increased pressure and scrutiny from consumers, advocacy groups and regulatory agencies to address the use of hazardous chemicals. They are being called to address labor and human rights concerns in their supply chain—but this is not the subject of this report.

So far, leading global brands have been addressing their supply chain liabilities with regards to the use of potentially hazardous chemicals by adopting proactive policies such as:

1) Increasing transparency

Gather and provide information about chemicals and materials used in their products and manufacturing processes.

2) Reducing the use of hazardous chemicals

Create Restricted Substances Lists (RSLs) and Manufacturing Restricted Substance Lists (M/RSLs) as tools to work with their supply chain partners to manage the chemicals used in both their products and manufacturing processes.

In addition to transparency and lists of restricted chemicals, which we regard as established policies, some brands have taken their chemicals management further by:

i) Implementing safer chemistry tools at the design phase

Adopt safer chemistry and circular economy concepts at the product design stage.

ii) Telling the story

Incorporate their work on safer materials into their brand story, demonstrate leadership, differentiate, and create a positive vision for the future.

3) Partnering with innovators and participate in the innovation ecosystem

Develop capabilities and structures to collaborate with innovators, and also become active participants in the innovation ecosystem.

In this report we evaluate the role of different chemicals of concern in the production of textiles, apparel and footwear, and provide insights to accelerate the adoption of new technologies that reduce or eliminate the use of hazardous chemicals.

A key finding is the map we created of the five key innovation areas for safer chemistry in textiles and apparel, shown in Figure 1 ***(next page)***.

FIGURE 1
Safer Chemistry Innovation Areas and Sub-Areas
Source: Safer Made, 2018

The report is organized as follows:

In **Section 1** we describe the main drivers of safer chemistry and materials adoption in the textile and apparel space with emphasis on transparency, consumer awareness and circularity.

In **Section 2** we identify the classes of chemicals of concern found in the most common industry M/RSLs* and outline the functionality of different classes and the stage of the supply chain they are used in.

In **Section 3** we define the "Innovation Areas" in textile and apparel that describe the industry's innovation needs to help brands, suppliers, innovators, investors and startup companies collaborate to bring safer chemistry innovation to commercial reality.

In **Section 4** we offer some insights into strategies brands and retailers can use to accelerate the adoption of new, safer chemistry technologies.

In **Section 5** we provide some final thoughts.

* Within the textile, apparel and footwear industry restricted substance lists (RSLs) address chemicals potentially found in the finished article, while manufacturing restricted substance lists (MRSLs) address chemicals used during the manufacturing process. Most companies are adopting both RSLs and MRSLs and they both signal the need for safer chemistry so we use M/RSLs to refer to both types of lists throughout the report.

We expect this report to stimulate conversations and catalyze innovation that brings safer and more sustainable textiles and apparel to market.

Throughout this report we use the term “textile industry” to mean the sector of economic activity concerned with the production of fibers, yarns and fabrics which are then used for a wide variety of applications. We use the term “apparel industry” to mean the sector of economic activity concerned with the production of apparel, clothing and garments. The apparel industry is downstream from the textile industry, but we use the term “textile and apparel industry” to mean the combination of both the textile and the apparel sectors. ■

SECTION 1

Safer Chemistry Drivers: Transparency, Awareness and Circularity

Introduction to Safer Chemistry

Before the industrial revolution, people used naturally occurring materials such as natural fibers, wood, clay, sand, stone and iron ore—and did not alter them very much. Most of the materials people used for textiles and apparel were safe: clothes made of cotton, hemp, linen, wool and animal skins were made without the use of chemical treatments.

The industrial revolution brought to the world tens of thousands of new chemicals, mostly without considering their potential harmful effects on human health and the natural world. The textile sector was one of the first industries to embrace the synthetic chemistry revolution which could produce high-performance dyes at a much lower cost than natural dyes.[1] We are still catching up with the potential impacts of new chemicals and materials.

Initially most man-made new chemicals were deemed safe, including those used for textile apparel, under a default assumption that these new chemicals are more or less similar to the naturally occurring materials people used before the industrial revolution. But evidence has been accumulating that some of these chemicals are harmful to human health and to the natural world.

Chemical pollution has more recently been linked to increases in chronic health conditions including infertility, asthma, obesity, cancer and neurodevelopmental diseases. For example, a recent study published in 2017 by The Lancet's Commission on pollution and health found that pollution is the world's greatest environmental threat to health. Diseases caused by pollution were responsible for an estimated 9 million premature deaths in 2015—16% of all deaths worldwide—three times more deaths than from AIDS, tuberculosis and malaria combined, and 15 times more than from wars and other forms of violence.[2]

> ***People's awareness and attitude toward chemical safety has changed.***

People's awareness and attitude toward chemical safety has changed. The 1960s were a turning point for the public perception of chemicals, and since then work to remove many of the most harmful chemicals such as lead, mercury or asbestos from our products has progressed. However, many hazardous chemicals are still used. Recent examples include fluorocarbon chemicals in textiles and food contact packaging;

[1] Anthony S. Travis (1990). "Perkin's Mauve: Ancestor of the Organic Chemical Industry". Technology and Culture. 31 (1): 51–82. DOI: doi.org /10.2307/3105760

[2] Philip J Landrigan, et. al. (2018) "The Lancet Commission on pollution and health". The Lancet, 391 (10119): 462–512. DOI: doi.org/10.1016/ S0140-6736(17)32345-0

Bisphenol A, Bisphenol S and other endocrine disrupting compounds in baby bottles and canned food; volatile chemicals in paints and coatings; formaldehyde in textiles, building products and baby shampoo. These hazardous chemicals and others can be removed or reduced by developing safer chemistry.

> ***40% of American adults… "are socially responsible, driven to protect the environment and are avid users of green products."***

People want to live healthier and more secure lives, and demand products that are safe for their families and the natural world. According to the Natural Marketing Institute, a marketing research organization, in 2008 about 40% of American adults were either consumers who "are socially responsible, driven to protect the environment and are avid users of green products. They take action to ensure personal and planetary health and influence others to do the same;" or they are consumers who "make most purchase decisions based on benefits to their personal health."[3]

Many consumers become sensitized to chemical and material safety issues when they have children. This is a time of significant lifestyle changes when people are open to new information, switching brands and creating new habits. This is also a time when many people attain relatively high purchasing power and make other significant life decisions, such as buying a house.

Once aware of the hazardous chemicals issue, people approach their purchasing decisions with increasing scrutiny. Many read labels and seek safer products. Consumers usually start with food, move to personal care products and then to other products they bring into their homes or have on their body, including apparel, packaging, furniture and building products.

Consumers enjoy more choices and power than ever before, and they are looking for brands and products that reflect their values. Brands need to be proactive in their management of the chemicals and materials incorporated in their products or used in their manufacturing processes, or they risk losing people's trust.

[3] Connecting Values with Consumers, 2008. LOHAS Journal. The Natural Marketing Institute.

Retailers are well positioned to understand the needs of their consumers. In 2017 we saw new or updated chemical policies from Target,[4] Walmart,[5] CVS,[6] Costco,[7] Home Depot[8] and Best Buy.[9] These chemicals management policies usually ban certain chemicals; set goals and targets for other chemicals; and hold the retailers and their suppliers to higher transparency standards. For example, Jennifer Silberman, Chief Sustainability Officer at Target, shared details when announcing Target's renewed chemicals policy in 2017.

> ***"Over the next three to five years Target aims to achieve transparency of all product ingredients, remove several classes of chemicals of concern from beauty, baby, and other formulated household products, remove fluorinated chemicals and flame retardants from textile products.***
>
> ***Our chemical strategy will be one of the most comprehensive in the U.S. retail industry, including all Target-owned and national brand products and operations, not just formulated products. It's ambitious, but using our size, scale and expertise, we think we'll be able to make significant progress.***
>
> ***We hope our robust approach will accelerate similar efforts across the industry. Ultimately, we want to bring all stakeholders together to innovate and champion a consistent, industry-wide approach to greener chemistry."***

Brands and retailers within the apparel industry have supported greater chemical oversight through both the adoption of restricted substance lists and industry wide support for voluntary chemical management and tracking systems. Organizations including Zero Discharge of Hazardous Chemicals (ZDHC), the Sustainable Apparel Coalition (SAC), American Apparel and Footwear Association (AAFA), AFIRM group and Cradle to Cradle (C2C), provide important resources for brands to develop their chemical management policies.

Many brands supplement participation and adoption of industry standards with chemical management and sustainability programs that highlight the ways they are leading in sustainability. For example, Levi's is a member of AFIRM, AAFA, ZDHC and SAC, and they have developed their own approach to chemicals management that has been a catalyst for adopting new technologies, such as a new water and chemical-free finishing process.[10] Another example is Patagonia, a brand that supports innovation through their Tin Shed Ventures arm and has backed companies like Beyond Surface Technologies that makes safe, bio-based finishing chemistries. Other examples are H&M supporting the Global Change Award, and the C&A Foundation supporting Fashion for Good, an accelerator for sustainable innovation in the apparel supply chain. The Boston Consulting Group has worked with the Global Fashion Agenda to summarize how brands have been working toward more

[4] Target: corporate.target.com/article/2017/01/chemical-policy-and-goals (retrieved 4/11/2018)
[5] Walmart: walmartsustainabilityhub.com/sustainable-chemistry (retrieved 4/11/2018)
[6] CVS: cvshealth.com/social-responsibility/corporate-social-responsibility/planet-in-balance-environmental-sustainability/removing-chemicals-of-consumer-concern (retrieved 4/11/2018)
[7] Costco: costco.com/sustainability-environment.html (retrieved 4/11/2018)
[8] Home Depot: corporate.homedepot.com/sites/default/files/image_gallery/PDFs/Chemical%20Strategy%2010_2017.pdf (retrieved 4/11/2018)
[9] Best Buy: corporate.bestbuy.com/wp-content/uploads/2017/08/BBY-Chemicals-Mgmt-Statement-FINAL_2.pdf (retrieved 4/11/2018)
[10] Marc Bain, "Levi's Jeans will be Broken in with Lasers," Quartz online, February 27, 2018, quartzy.qz.com/1215862/levis-jeans-will-be-broken-in-with-lasers/

environmentally and socially responsible practices. The resulting Pulse of Fashion Industry report captures many of the key trends in the sector and ranks brands on their performance.[11]

The Drivers of Safer Chemistry Adoption: Transparency, Awareness and Circular Economy

We have identified three major factors driving the adoption of safer chemistry in the textile apparel sector.

- The call for **transparency** from consumers, retailers and the advocacy community.
- The increasing public **awareness** of the environmental pollution associated with the manufacturing of textiles apparel products.
- The adoption by many brands and retailers in the textile apparel space of the **circular** economy language, concepts and frameworks.

The Call for Transparency

The clothes we wear tell our story, whether we want it or not. People weave brand stories into their own personal stories, and brands need to support and represent their values. The transparency trend in apparel started as a way to address dangerous and illegal working conditions, including forced and child labor practices. It is now a broad movement to improve the safety and sustainability of the whole textile and apparel supply chain.

According to a report by the Fashion Transparency Index, the number of brands that are disclosing information about their immediate suppliers increased from 5 in 2016 to 32 in 2017. According to the same report, 68% of the brands surveyed disclosed their chemical management policy, and 58% disclosed their supply chain guidelines for chemicals in 2017.[12]

These transparency initiatives are voluntary and the oversight is limited. Most companies have little additional regulatory mandates beyond compliance with local regulations and import rules. This may change, however, with European chemical regulations increasingly requiring disclosure. The European Chemicals Agency (ECHA) requires companies to disclose the presence of chemicals of concern present in apparel products at a weight greater than 0.1% of the total product weight.[13] Similar to California's Prop 65 regulation[14], this EU regulation could require point of sale disclosure of the chemicals of concern present in the apparel products, as defined by EU's REACH SVHC framework.

[11] Pulse of the Fashion Industry Report, 2018. (May 2018) Published by Global Fashion Agenda at globalfashionagenda.com/pulse/ (retrieved 5/11/2018)
[12] Fashion Revolution "Fashion Transparency Index 2017" full report can be accessed at fashionrevolution.org/about/transparency/ (retrieved 4/11/2018)
[13] European Chemicals Agency, "Use Your Right to Ask," chemicalsinourlife.echa.europa.eu/use-your-right-to-know (retrieved 4/11/2018)
[14] California Environmental Protection Agency, "Proposition 65 in Plan Language," oehha.ca.gov/proposition-65/general-info/proposition-65-plain-language (retrieved 4/11/2018)

As of the first quarter of 2018, companies in selling into the European Union are only required to disclose chemicals of concern when asked by consumers or large institutional buyers. We believe that the potential shift toward consumer labeling and disclosure requirements will drive the sector to remove chemicals of concern from products faster than regulatory action. The companies already ahead of the curve on transparency and safer chemistry will benefit when regulations catch up.

Increasing Awareness

Global production of apparel and footwear in 2016 exceeded 62 million tons.[15] The environmental impact of this production is significant. For example, it takes 700 gallons of water to produce a single t-shirt.[16] Water is used in large quantities in both the production of natural and synthetic fibers, and the chemical processing of yarn and fabric. Chemical dyes and finishing agents are applied to yarn and/or fabric by soaking them in water with chemicals. These processes take large qualities of water and chemicals as inputs, and generate large volumes of polluted water that is often discharged.

About 8,000 chemicals are used in the manufacturing of the 400 billion square meters of fabric sold globally every year.[16] Chemicals are used at every step in the textile manufacturing process, and many are potentially hazardous to human health and the natural world. Figure 2 shows a few examples of potentially harmful chemicals used in textile and apparel manufacturing.

FIGURE 2
Potentially Harmful Chemicals Used in Textile and Apparel Manufacturing
Source: C&E News

[15] Pulse of the Fashion Industry Report. (May 2017) Published by Global Fashion Agenda globalfashionagenda.com/pulse/ (retrieved 7/19/2018)

[16] Alex Scott, "Cutting Out Textile Pollution," Chemical and Engineering News, (93) 41: 18-19, Oct. 19, 2015, cen.acs.org/articles/93/i41/Cutting-Textile-Pollution.html

The advocacy community has brought attention to human health and environmental impacts of the textile apparel sector. For example, the Greenpeace Detox Campaign was launched in 2013 to address the impact of water pollution in textile producing regions of China.[17] This campaign led to the creation of the Zero Discharge of Hazardous Chemicals (ZDHC)[18] group, and to increasing pressure on brands to do more to ensure the protection of human health and the environment. The ZDHC group worked with brands and suppliers to identify chemicals of concern used in the manufacturing of textiles, apparel and footwear. The resulting ZDHC manufacturing restricted substance list (MRSL) satisfied the demands of Greenpeace and has rapidly become one of the most widely used standards in the industry. ZDHC is continues to catalyze the adoption of safer chemistry by working with the industry to identify and scale safer alternatives to the chemicals found on their MRSL.

The textile and apparel sector has also faced increased scrutiny of the labor conditions in textile production facilities. While outside the scope of this report, disasters such as the Rana Plaza building collapse in Bangladesh in 2013 have brought public attention to the apparel sector, and where and how clothes are made.

Many consumers have also become aware of the impacts of the textile apparel sector, starting with outdoor enthusiasts, and including sports and fashion. Social media and online shopping have accelerated this awareness, and consumers are increasingly looking for brands and products that reflect their values. For example, Patagonia's Ryan Gellert explains in an interview with Fashion Network: "Customers are more engaged with making conscious purchase decisions and are demanding more from the brands they support in the way of sustainability and fair labor. Social media and digital communication help to facilitate this."[19]

Circular Economy

Brands and retailers in the textile and apparel sector have been adopting the language and frameworks of circular economy in response to concerns about the environmental impacts of the textile sector.

In the United States and Europe, large quantities of apparel are discarded every year. According to the U.S. EPA, the average American consumer disposes of around 30 kilograms of clothing every year, with more than 85% headed for the landfill.[20] In Europe the average consumer discards about 12 kilograms of clothing, with about 75% estimated to be recycled or reused.[21]

[17] Greenpeace Campaign website greenpeace.org/archive-international/en/campaigns/detox/ (retrieved 4/11/2018)
[18] roadmaptozero.com/ (retrieved 4/11/2018)
[19] Fredericke Winkler, Patagonia's Ryan Gellert: "Customers are more engaged with making conscious purchase decisions", Fashion Network, March 15, 2018
[20] United States Environmental Protection Agency, "Advancing Sustainable Materials Management: Facts and Figures" 2014. Report Accessed online at: epa.gov/smm/advancing-sustainable-materials-management-facts-and-figures#Materials (retrieved 4/11/2018)
[21] Friends of the Earth Europe, "Less is more: resource efficiency through waste collection, recycling and reuse." February 14, 2013. foeeurope.org/less-more-140213

In a circular economy, manufacturing and use are regenerative processes. Circular economy seeks to minimize pollution, waste, energy and water use by designing products that are long-lived, reusable, recyclable or biodegradable.

Today, many of our products, including apparel, rely on materials and chemistries that are not easily reused, recycled or degradable. They are often produced using manufacturing techniques that rely on the consumption of large quantities energy, water and chemicals that can cause pollution.

Moving to a circular economy creates demand for safe materials designed to be recycled or degraded into nutrients. The notion of an inherently safer chemical and materials system has been articulated by several leading thinkers, and goes by different names that all tie into the concept of the circular economy, including cradle -to-cradle design, green chemistry, sustainable chemistry and biomimicry.

People want products that are safer for their families and the environment. What are brands and retailers really doing about advancing safer chemistry? Section 2 goes into more details. ■

SECTION 2

What Brands and Retailers Do About Advancing Safer Chemistry

What Brands and Retailers Do About Advancing Safer Chemsitry

Many people, especially young parents, actively seek brands and products that lead with a message of health, wellness and sustainability. Retailers and brands got the message. How are they responding to this need? We identify several strategies brands and retailers use to manage chemicals of concern and advance safer chemistry. These strategies stand by themselves, but they also build upon each other in an increasing maturity scale.

The first step is to find out what chemicals are used within the supply chain. Brands and retailers have spent considerable resources on finding what's in their products and how they are made.

Next, brands and retailers often create restricted substance lists (M/RSLs)* aiming to use safer ingredients in the manufacturing processes when solutions are available. In implementing the M/RSLs, most brands and retailers initially rely on working with their existing suppliers, and focus on innovation to current processes.

Brands and retailers often turn these efforts into a competitive advantage by telling the story to their customers and differentiating from their competitors. Safer chemistry innovation and new materials provide positive narratives that resonate with consumers and build brand loyalty.

Responding to Chemicals of Concern

Stage 1: Awareness and Transparency

Internal or external stakeholders raise issues related to chemicals and pollution in the supply chain. At this stage companies often adopt transparency initiatives to determine what chemicals are being used in their supply chains.

Stage 2: Restricted Substance Lists

After finding out what chemicals and materials are in their products or used in their supply chains, companies adopt restricted substance lists (M/RSLs) which serve as a way to communicate chemical management goals with supply chain partners, ensure compliance with regulations, and track progress. While every brand will often maintain their own M/RSLs there are a number of industry standards gaining widespread acceptance.

Stage 3: Preferred Lists and Upfront Screening

As brands and their suppliers look for ways to differentiate and drive innovation, many have adopted preferred substance lists that incentivize the screening of chemicals at the design phase and the development of safer chemicals in the supply chain. These initiatives are relatively new and companies are still optimizing their communication and incentive systems.

Stage 4: Product Redesign

Brands use new materials, designs or manufacturing processes that highlight their efforts on sustainability. This is often one of the most effective ways to communicate brand values and drive systemic change.

* Within the textile, apparel and footwear industry restricted substance lists (RSLs) address chemicals potentially found in the finished article, while manufacturing restricted substance lists (MRSLs) address chemicals used during the manufacturing process. Most companies are adopting both RSLs and MRSLs and they both signal the need for safer chemistry so we use M/RSLs to refer to both types of lists throughout the report.

Developing new products that differentiate on safety and sustainability may sometimes require a fundamental redesign of existing products or processes. To do this, brands and retailers often turn to inventors, innovators and start-up companies in search of new partnerships to develop safer products with new performance characteristics.

M/RSLs are a core component of the chemicals management policy. In the rest of this section we delve deeper into the classes of chemicals of concern included in M/RSLs.

What Makes Some Chemicals Hazardous?

Hazardous chemicals damage human health and the natural world. We distinguish four categories of hazardous chemicals based on the intrinsic properties that make them harmful. Both government and non-government organizations in the field of environmental health use these or similar definitions to identify chemicals of concern in manufacturing or consumer products, and certain chemicals may fall into more than one category.

- **Acutely toxic or hazardous:** These are the chemicals that people naturally associate with danger, like explosives or flammable liquids. This category also includes acute toxicants and chemicals that do immediate and lasting damage to tissues, including strong acids or bases. These chemicals are rarely found in finished goods, but they are often used in the manufacturing process and can pose a danger to workers. They are usually known, regulated and labeled.

- **Carcinogenic, mutagenic and toxic for reproduction (CMR):** Heavy metals like lead and mercury fall into this category because they have long lasting health effects, even if they are not immediately dangerous. Chlorinated solvents and azo-dyes with the potential to release aryl-amines are well known examples of CMR chemicals found in the textile sector.

- **Persistent, bio-accumulative and toxic (PBT):** These chemicals stay in the environment and living tissues for long periods of time. They may be relatively safe in small amounts, but because they do not break down there is a potential for them to accumulate in our bodies and the environment, leading to long-term health impacts. The poly and perfluorinated alkyl substances (PFAS) used in durable water repellants are an example of a class of compounds that fall into this category.

- **Endocrine disruptors (ED):** Endocrine disruptors like bisphenol-A and phthalates are used in many products and have been showed to interfere with hormonal signaling mechanisms in ways that may contribute to chronic disease and infertility. The science related to the identification and impact of endocrine disrupting chemicals is still evolving, and as a result data and guidance are less available for these chemicals.

Creating and Applying Restricted Substance Lists (M/RSLs)

Until recently, the chemicals management practices and policies focused on specific chemicals banned or expected to be banned by governments. For chemicals of concern that are not yet banned, multiple collaborative mechanisms for self-regulation have emerged, such as shared guidelines and certifications.

Brands are increasingly adopting M/RSLs as the foundation of their chemical management policy. Most brands build their M/RSLs starting from the standard M/RSLs developed and maintained by bodies including Zero Discharge of Hazardous Chemicals (ZDHC), American Apparel and Footwear Association (AAFA), Bluesign, Global Organic Textile Standard (GOTS) and Cradle to Cradle (C2C). These programs provide lists of restricted chemicals based on regulatory requirements (like those found under the European REACH chemical regulation), as well as volunteer restrictions adopted as a part of certification and other oversight initiatives.

The many chemicals on these M/RSLs provide a wide range of functions and performance characteristics. Often these chemicals are not present in the final garments, but are essential in the manufacturing process. Until recently, the selection and management of chemicals used in production processes occurred at mills and manufacturers, not at the brand level. M/RSLs have become an essential tool for brands to work with mills and manufacturers in their supply chain as they become proactive about chemicals management.

We evaluated the thousand or so individual chemicals on the five major industry restricted substance lists mentioned above, and organized them into 46 classes of chemicals that capture the majority of the chemicals found on M/RSLs, as shown in Table 1 (next page). We further map these 46 classes on to six broader groups of chemicals of concern, color coded in the table: Amines (yellow), Dyes (cyan), Halogenated Chemicals (purple), Metals (green), Monomers (red) and Solvents (blue). New chemicals that fall into one of these broad chemical groups should be viewed with greater scrutiny. ***See Table 1 on the following pages.***

CHEMICAL CLASSES	USE	WHERE IT IS USED	BROAD CHEMICAL GROUP
Amines	Auxiliaries including surfactants, dispersants and softeners, or as process chemicals or precursors for other materials	Various manufacturing processes	Amines
Aryl amines	In polyurethanes and as decomposition products of azo colorants	Mills	Amines
Quaternary ammonium compounds (DTDMAC, DSDMAC, DHTDMAC)	Disinfectants, cleaners, antimicrobial treatments	Finishing	Amines
Azo-dyes (Aryl-amine releasers)	Dyes	Dye houses	Dyes and residuals
Hypochlorite	Bleaching	Dye houses, denim finishing	Dyes and residuals
Naphthalene	Common residual found in synthetic leather tannins, and in dye dispersing agents that use naphthalene sulfonate derivatives.	Leather production, dye houses	Dyes and residuals
Poly aromatic hydrocarbons (PAHs)	Residual in carbon black, dyes, rubber and other petrochemical products	Dye houses	Dyes and residuals
Sensitizing disperse dyes (ZDHC for subset of known sensitiz-ers, or GHS codes H317, H334, R43, R42)	Dyes for synthetic fibers including polyester, acetate, polyamide	Dye houses	Dyes and residuals
Titanium dioxide	Pigments	Dye houses	Dyes and residuals
Chlorinated and non-chlorinated (MIT/CMIT)	Antimicrobial and preservative for formulated products	Chemical manufacturers	Halogenated chemicals
Chlorinated benzenes	Solvents and fiber swelling agents in dying process	Dye houses	Halogenated chemicals
Chlorophenols	Hide preservation	Leather processing	Halogenated chemicals
Halogenated flame retardants	Flame retardants	Fabric finishing	Halogenated chemicals
Per- and poly-fluorinated compounds	Durable water repellency and stain repellency	Fabric finishing	Halogenated chemicals
Short chai chlorinated paraffin	Leather conditioners	Leather production	Halogenated chemicals
Triclosan and triclocarban	Antimicrobial fabric treatment	Fabric finishing	Halogenated chemicals
Arsenic	Some pesticides/defoliants for cotton; can be a contaminant in other materials and dyes	Cotton farms	Metals
Cadmium	Some pigments and coating	Many parts of the supply chain based on function	Metals
Cadmium (PVC stabilizer)	Stabilizer in PVC		Metals

TABLE CONTINUED ON NEXT PAGE...

CHEMICAL CLASSES	USE	WHERE IT IS USED	BROAD CHEMICAL GROUP
Catalysts (Sb)	PET catalyst	Various manufacturing processes	Metals
Chromium (Leather)	Tanning agent	Mills	Metals
Chromium (Wool)	Mordant for mordant dyes used for dark shades of wool	Dye houses	Amines
Lead	Plastics, paints, inks, pigments, surface coatings	Mills	Metals
Mercury	Present in pesticides; can be found as a contaminant in caustic soda Mercury compounds may be used in paints (e.g., surface paints on zippers and buttons)	Many parts of the supply chain based on function	Metals
Nano silver	Antimicrobial fabric treatment	Fabric finishing	Metals
Organotin compounds	Plastics/rubbers (polyurethane), inks, glitter, some adhesives, heat transfer materials	Rubber production, shoe manufacturing, printing	Metals
Acrylamides	Manufacture of resins, sealants, binders, thickeners, fibers	Various manufacturing processes	Monomers
Acrylonitrile, Acrylates and Methacrylates	Production of acrylic yarns (85% acrylonitrile, with the balance often being acrylates/methacrylates)	Acrylic yarn manufacturing	Monomers
Bisphenols including BPA, halogenated bisphenols, epoxy resins	Residual in epoxy resins or polycarbonates	Shoe manufacturing, outdoor equipment manufacturing	Monomers
Butadiene and styrene	Synthetic rubbers, monomers for ABS	Shoe manufacturing, outdoor equipment manufacturing	Monomers
Epoxide and epoxide precursors like ethylene oxide, propylene oxide, epichlorohydrin	Epoxy resins and adhesives	Shoe manufacturing, outdoor equipment manufacturing	Monomers
Formaldehyde and other short-chain aldehydes	Wrinkle-free coatings	Fabric finishing	Monomers
Isocyanates	Monomers in polyurethane production and as cross-linkers in fabric finishing	Polyurethane production, shoe production, finishing	Monomers
Ortho-phthalates	PVC plasticizers for screen printing and coatings	Non-woven manufacturing and printing	Monomers
Vinyl chloride and vinylidene chloride	Waterproof plastic impregnated fabrics, artificial leathers	Non-woven manufacturing and printing	Monomers
Alkyl-phenol Ethoxylates	Cleaners and detergents	Mills	Solvents and process aids
Aromatic solvents	Synthetic leather and manufacturing and can be found in cleaners and ink solvents	Leather and dye houses	Solvents and process aids
Benzene and o-, p-, or m- cresol	Solvents used in processing and/or adhesives	Shoe manufacturing, outdoor equipment manufacturing	Solvents and process aids
Carbon disulfide	Rayon and other cellulosic manufacturing	Rayon fiber production	Solvents and process aids

TABLE CONTINUED ON NEXT PAGE...

CHEMICAL CLASSES	USE	WHERE IT IS USED	BROAD CHEMICAL GROUP
Chlorinated cleaning solvents	Dry cleaning, spot cleaning, scouring	Garment manufacturing	Halogenated chemicals
DMF	Swelling/foaming for polyurethane non-woven	Materials and chemical suppliers	Solvents and process aids
Glycols	Solvents in finishing, cleaning, printing and adhesive processes	Fabric finishing, garment manufacture	Solvents and process aids
N, N-dimethylacetamide (DMAC)	Solvent for elastane and polyurethane coatings; adhesives	Materials and chemical suppliers	Solvents and process aids

TABLE 1
Classes of Chemicals of Concern in M/RSLs
Source: Safer Made, 2018

Organizing chemicals of concern by class can prevent a cycle of "regrettable substitution," which occurs when a phased-out, harmful chemical is replaced with a closely related chemical which may cause similar harm. This approach helps identify potential chemicals of concern before they show up on restricted substance lists. Once a chemical has been identified as belonging to one of these classes, it is easier to determine what sort of data will be needed to ensure that it is safe.

Amines are a broad class of nitrogen containing compounds that perform many different functions within the textiles supply chain. They can be used as building blocks for dyes, polymers and surfactants (quaternary ammonia compounds). Amines are often contaminants or released during the breakdown of materials. Amines can be a health concern because of corrosive and reductive potential activity (usually low molecular weight amines), as well as their biological activity (higher molecular weight and aromatic amines), including carcinogenicity of aryl amines.

Dyes and residuals include some dyes that are harmful and should be avoided. Among the more harmful are aryl amine releasers (azo and benzidine dyes) and sensitizing disperse dyes. Because many dyes are designed to bind fibers, they can also react with biological tissues and should be treated with caution even if they are "natural dyes." ChemSec has developed their Textile Guide in collaboration with ZDHC Group to help identify safer dyes and other textile chemicals.[22]

Halogenated chemicals contain one or more of the halogen group elements Fluorine (F), Chlorine (Cl), Bromine (Br) or Iodine (I) covalently bonded to carbon. They have a tendency to persist in the environment, and some of them are biologically active. Halogenated chemicals including perfluorinated surfactants and brominated flame retardants are regulated and/or included on M/RSLs.

[22] textileguide.chemsec.org/ (retrieved 4/11/2018).

Heavy metals are used in dyes and as catalysts or formulation aids in resins and synthetic fibers. Many of the most dangerous heavy metals like lead and cadmium are regulated, while others like organotin compounds can be found in a wide variety of formulations. Some functions, such as catalyzing polymerization, can only be accomplished with metals. For other functions, such as leather tanning, the alternatives to heavy metals are more expensive or do not perform as well.

Monomers are the building blocks of synthetic fibers and resins. They must be reactive to perform their function, and are hazardous to human and environmental health before they have been polymerized or cured. The final polymers and fibers made from these monomers are usually biologically inert and do not pose an immediate hazard beyond their tendency to persist in the environment. Since monomers are the buildings blocks of synthetic fibers and resins, they cannot be avoided without changing basic materials.

Solvents are widely used to transfer chemistry onto fabric and/or remove residuals. Solvents and process aids are used in large quantities and often affect workers. Some solvents fulfill specific functions, such as DMF used in foaming polyurethane, while others are used for many applications, such as the aromatic solvents used for cleaning or dispersion of dyes. In most cases there are multiple solvents that can be used for the same function. Cost and availability are significant factors in safer solvent adoption, since solvents are used in large volumes several steps upstream from brands in the supply chain.

We further distinguish two groups of classes of chemicals based on how easy it is to find alternatives, as shown in Table 2 ***(next page)***. The first group includes classes of chemicals for which safer alternatives are available, and the second group includes classes of chemicals that either do not have available alternatives or have emerging alternatives that need more development.

Alternatives Currently Available	Alternatives Requiring Development and/or Not Available
Alkyl phenol ethoxylates	Amine auxiliaries
Chlorophenols	Halogenated flame retardants
Triclosan and triclocarban	Chlorinated solvents
Arsenic	DMF
Cadmium	Glycols
Mercury	Nano silver
Lead	Isothiazolinone-derivatives
Organotin compounds	Antimony catalysts
Ortho-phthalates	Titanium dioxide
Azo-dyes (Aryl-amine releasers)	Fluorinated compounds
Sensitizing disperse dyes	Formaldehyde and other short-chain aldehydes
Poly aromatic hydrocarbons	Hypochlorite
Benzene and o-,p-, or m- cresol	Bisphenols including BPA
Chlorinated benzenes	Vinyl chloride and vinylidene chloride
	Acrylamides
	Butadiene and styrene
	Epoxide and dioxane precursors
	Chlorinated paraffin
	Aryl amines
	Naphthalene
	Carbon Disulfide
	Chromium
	Aromatic solvents
	N,N-dimethylacetamide (DMAC)
	Quaternary ammonium compounds
	Acrylonitrile, acrylates and methacrylates

TABLE 2
Chemical Classes Grouped Based on Availability of Solutions
Source: Safer Made, 2018

Chemicals that have been banned or may be banned in certain jurisdictions often already have available alternatives that work. Brands should be able to rely on supply chain partners to find substitutes for these classes of chemicals.

Chemicals in the second group may require brands, mills and chemical suppliers to work together to find alternatives. Note that an “alternative” may be a substitution with a new chemical, or may be a change in process or material design that mitigate the need for the chemical. In some cases alternatives are in development but may have drawbacks, and more process development work may be required to integrate the new solutions into the manufacturing processes.

There are also chemical classes that have no current satisfactory alternatives and require significant chemistry and/or process innovation to eliminate. Removing these chemical classes may require brands to support more systemic innovation and bring new technologies into the textile supply chain.

Plastic Pollution in the Textile and Apparel Industry

In addition to the classes of chemicals of concern described above, there are emerging concerns related to plastic pollution caused by the textile and apparel industry.

Synthetic fibers like polyester and nylons now dominate apparel. A recent report published by Textile Exchange in 2016 shows polyester fibers having 55% of all textile mill fiber volume.[23] Synthetic polymers tend to persist in the environment and can end up acting as chemical pollutants as well as substrates that magnify the accumulation of other harmful chemicals within ecosystems.

A recent article published in Environmental Science & Technology connects plastic microfiber pollution in marine environments with emissions from washing apparel made from synthetic fibers.[24] Media and consumer interest and awareness of the marine pollution problem has been growing, and awareness of the connection to synthetic textile apparel has raised the concern about marine plastic pollution within the apparel industry, especially in the outdoor apparel industry which has the closest ties to the problem due to its high use of synthetic fibers.

A number of organizations including the Leitat Mermaids project in Europe and the Outdoor Industry Association in the US support research and industry collaborations looking to address microfiber pollution.[25] New materials that would displace synthetic fibers (polyester, polypropylene and nylon) could be designed to degrade in the marine environment and therefore eliminate plastic microfiber pollution. Another approach, taken by a few innovative companies including Guppyfriend, Coraball, Planet Care Solutions and Lint LUV-R, is to use wash bags, washing balls and/or filters that prevent micro particles from apparel from being released into wastewater when washing clothes.[26]

The apparel industry also uses significant amounts of plastic for hangers, and to package and ship its products. All of these synthetic materials have the potential to contribute to plastics pollution. The typical approach to this challenge has been to look for plastics that are recyclable, reusable or compostable. However, the reality is a little complicated for a variety of reasons.

[23] textileexchange.org/wp-content/uploads/2017/02/TE-Preferred-Fiber-Market-Report-Oct2016-1.pdf (retrieved 4/8/2018)

[24] Mark Anthony Browne, et. al. (2011) "Accumulation of Microplastic on Shorelines Woldwide: Sources and Sink" (45) 9175–9179. DOI: dx.doi.org/10.1021/es201811s

[25] Nikki Hodgson (2017) "Microfibers and the Outdoor Industry: Issue Update" Published online: outdoorindustry.org/article/microfibers-and-the-outdoor-industry-issue-update/#articles (retrieved 4/11/2018) and projects.leitat.org/mermaids-projects-preparatory-actions-have-been-completed/ (retrieved 5/14/2018)

[26] Guppyfriend: guppyfriend.com/en/, Coraball: coraball.com/, Planet Care: planetcare.org/, and Lint LUV-R: environmentalenhancements.com/Lint-LUV-R-links.html (retrieved 4/11/2018)

Bio-based plastics such as polylactic acid (PLA) and polyhydroxy alkonates (PHAs) are compostable but have no recycling infrastructure, have low heat resistance, and are more expensive. PLA is not marine degradable but is compostable, while PHA is both compostable and marine degradable. These plastics are still relatively uncommon in the textile supply chain, but are growing in popularity within the packaged food sector.

Petroleum-derived safe plastics such as polyethylene (PE), polypropylene (PP) and polyethylene terephthalate (PET) are recyclable but not compostable. These are the most common plastics in the textile industry and are used for packaging and to make yarns and fabrics.

There are potentially harmful chemicals used in some resins and plastics found in hard-goods and footwear including polystyrene; bisphenols (BPA, BPS, BPF) in epoxy resins; phthalates in polyvinyl chloride (PVC); isocyanates in polyurethane; and polyfluorinated (PF) coatings.

Many brands are looking for alternatives to the plastic "poly bags" used to ship apparel. AFIRM[27] is an industry group that has developed a packaging-specific restricted substance list. We have also seen young companies such as NORMN Hangers[28] proposing alternatives to the plastic hangers in transportation and display.

[27] afirm-group.com/ (retrieved 4/11/2018)
[28] normanhangers.com/ (retrieved 4/11/2018)

SECTION 3

Innovation Areas in Safer Chemistry and Materials

Innovation Areas in Safer Chemistry and Materials

The Innovation Landscape

We discussed the main factors driving the need for safer chemistry innovation in Section 1, and the industry's use of M/RSLs as the foundation of chemicals management in Section 2. In Section 3, we explore how to help advance safer chemistry innovation beyond implementing M/RSLs; and how to bring new investors and innovators into the textile apparel space.

We define "Innovation Areas" in textile apparel to describe the innovation needs and to facilitate conversations between multiple stakeholders including brands, mills, ingredient suppliers, investors, innovators and start-up companies.

> ***In defining the innovation areas, we focus on the relationships between function and material performance needs on the one side, and the universe of potential solutions and alternatives on the other.***

Function and performance define the innovation need. We often ask people responsible for product design and materials research at leading brands and retailers, "What are your top challenges regarding safer chemistry and sustainability?" The answers quite often come in the form of "a way to make x without using y" or "a material that delivers z," rather than "a drop-in alternative to chemical c." Even if chemicals and chemical classes are the culprits in terms of safety and sustainability, function and material performance are what matters for designers and material experts.

In defining the innovation areas, we focus on the relationships between function and material performance needs on the one side, and the universe of potential solutions and alternatives on the other.

We start with the function and take a broad perspective on what could be used to deliver that function.[29] This approach is in contrast to one that tries to characterize and manage

[29] Joel Tickner, et.al (2015), "Advancing Safer Alternatives Through Functional Substitution" Environmental Science and Technology, (49), 742–749. DOI: dx.doi.org/10.1021/es503328m

particular chemicals and find specific substitutes. It offers an efficient means to reorient chemicals management—from the risk management focus on single chemicals, to evaluating the best options to deliver specific functions.

We believe that the solutions to safer chemistry challenges are quite often new materials and processes that deliver new performance characteristics. These new materials and processes do not emerge from a search for one-to-one substitutes to chemicals of concern. Our approach to defining the Innovation Areas is shown in Figure 3.

Taking a functional approach helps avoid instances when one harmful chemical is replaced with another chemical, less known but also harmful. These kinds of "regrettable substitutions" happen more often than we would like; when chemists or engineers are asked for alternatives, they will likely find compounds that are similar in structure and likely to have similar impact. The sidebar highlights a recent example of such a regrettable substitution.

Regrettable Substitution The BPA Example

Searching for alternatives to bisphenol-a (BPA), a known endocrine disruptor, certain manufacturers used similar compounds, such as bisphenol-s (BPS) in certain applications. Unfortunately, both BPA and BPS are endocrine disruptors with estrogenic activity of comparable potency, even though only BPA was called out initially. Many products labeled BPA-free contained the endocrine-disrupting chemical BPS. One application of BPA is electronic receipts, where the chemical is used as a dye transfer agent. In that application, the approach to eliminating BPA included transitioning to ink printing the receipts, eliminating the need for dye transfer agents altogether. This type of "platform change" approach to eliminating a chemical of concern may often be missed in discussions of safer chemistry, because they do not have a one-to-one correspondence with a chemical of concern.

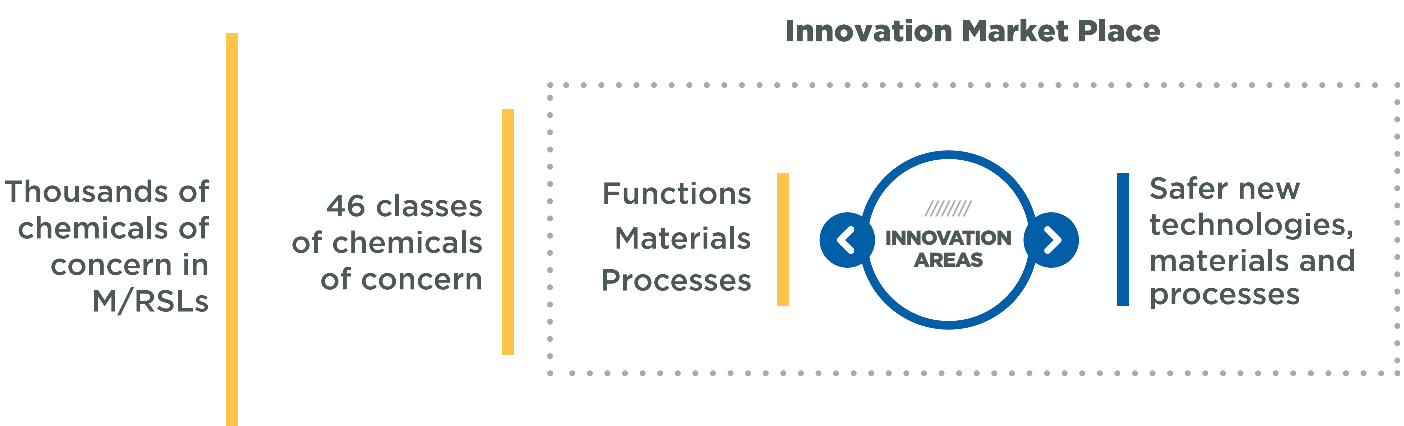


FIGURE 3:
Innovation Areas Defined at the Function, Material or Process Level
Source: Safer Made 2018

Eliminating chemicals of concern through process and material changes during the design phase adds to chemical management strategies based on M/RSLs. Materials and system-level changes may allow brands and retailers to address additional sustainability goals, including the reduction of energy and water use, and the microfiber and plastics pollution problem described previously.

In the following portion of this section, we define five safer chemistry Innovation Areas within the textile and apparel sector: New Materials, New Safer Chemistries, Waterless Processing, Fiber Recycling and Supply Chain Information Management Tools.

We also identify and group current examples of young companies working on safer chemistry, materials and technologies for each innovation area. We do not claim to comprehensively record all the innovation activities and mention all companies active, but we do think it is useful to highlight the extent of current activity, and to showcase examples. We expect the Innovation Areas and the innovation activity to continue to evolve and change with the needs of the textile and apparel sector.

Innovation Area #1: New Materials

Fibers and yarns are the building blocks of the textile industry. Figure 4 shows the current share of volume for the main types of fiber used in the textile industry.

Of the 46 classes of chemicals of concern identified in Section 2, 22 are associated with the production of basic input materials for the industry such as leather, polyester or polyurethane. Table 3 organizes these classes of chemicals with the fibers and materials where they are used in the textile and apparel industry.

MATERIAL/PRODUCT	FUNCTION/PRECURSOR	SPECIFIC CHEMICAL/S
Acrylic yarn	Monomers used in the production of acrylic yarns	Acrylonitrile, acrylates, methacrylates
Elastane and polyurethane	Solvent for elastane and polyurethane	N,N-dimethylacetamide (DMAC)
Flame retardant fabrics	Flame suppression	Halogenated flame retardants
Hard goods	Epoxy resins or polycarbonates for glues	Residual BPA, halogenated bisphenols, epoxy resins
Leather	Leather conditioners	Short chain chlorinated paraffin
Leather	Solvents used in synthetic leather manufacturing and leather dyeing	Aromatic solvents
Leather	Synthetic leather tanning	Residual naphthalene
Leather	Tanning	Chromium
Polyacrylamide fiber and resin	Manufacturing of resins, sealants, binders, thickeners, fibers	Acrylamides
Polyester	Polymerization catalyst	Antimony

TABLE CONTINUED ON NEXT PAGE...

Polyester	Antimicrobial fabric treatment for odor control	Nano silver
Polyester	Antimicrobial fabric treatment for odor control	Quaternary ammonium compounds (DTDMAC, DSDMAC and DHTDMAC)
Polyurethane	Swelling/foaming agent	DMF
Polyurethane	Monomers for polyurethane production	Isocyanates
Polyurethane	Polyurethane breakdown product	Aryl amines
PVC impregnated fabrics and synthetic leathers	Stabilizer	Cadmium
PVC impregnated fabrics and synthetic leathers	Plasticizers	Di-(2-ethylhexyl) adipate (DEHA) and ortho-phthalates
PVC impregnated fabrics and synthetic leathers	Basic material	PVC and PVDC
Rayon	Process chemical used in rayon and other cellulosic fiber manufacturing	Carbon disulfide
Rubber	Plastics/rubbers, inks, glitter, some adhesives, heat transfer material	Organotin compounds
Rubber	Rubber and carbon black manufacturing process chemicals	Residual poly aromatic hydrocarbons (PAHs)
Shoes and outdoor equipment	Synthetic rubbers, and monomers for ABS	Butadiene and styrene
Shoes and outdoor equipment	Epoxy resins and other adhesives	Epoxide and epoxide precursors like ethylene oxide, propylene oxide, epichlorohydrin
Cotton apparel	Wrinkle-free textile finishing	Formaldehyde and other short-chain aldehydes
Synthetic fabrics	Yarns and fabrics made from PET, PP, nylon, etc. that do not break down in the environment	Microfiber pollution

TABLE 3

Classes of Chemicals of Concern Associated with the Production of Common Yarns and Materials in the Textile and Apparel Industry

Source: Safer Made 2018.

The choice of materials drives the choice of process chemistry used to produce and finish a garment. Materials can be designed to minimize the use of harmful chemistry. Materials derived from renewable sources or from recycled feedstocks have the potential to lower the lifecycle carbon, water and chemistry impacts when compared to traditional materials.

Textile industry insiders like to point out that no significant new materials have been introduced since polyester in the 1950s. The industry is hungry for new materials with new performance characteristics, and there are several companies aiming to bring them to market. The need for materials innovation provides the opportunity to adopt new materials that perform better and are safer, and to design safer manufacturing processes. Addressing chemicals of concern and resource use associated with fiber production in the supply chain could be the catalyst for developing more sustainable fibers, yarns and fabrics.

Leather and its polyurethane substitute can serve as good examples. Leather processing is associated with the use of chlorophenols (preservation), chromium (tanning) and short chain chlorinated paraffin (conditioning). Polyurethane is a synthetic leather substitute, linked to isocyanates (chemical feedstock), DMF (process solvent) and arylamines (byproducts or breakdown products). Switching to a performant, safe and economic alternative to leather would eliminate both the need for chemicals of concern associated with the production of leather, and its polyurethane-based substitute.

Consumers show a growing preference for natural materials. The natural trend started in food and is now a driving force in cosmetics and personal care products market. While this trend is still nascent within the apparel industry, we see a number of young brands focusing on natural materials and dyes as a key differentiator. Coyuchi (bed linens),[30] Allbirds (shoes),[31] and PACT (clothing)[32] are examples of new brands that lead with messages that highlight their choices of natural materials.

Within the New Materials Innovation Area we distinguish three sub-areas ripe for innovation: New Synthetic Fibers, Leather Alternatives and New Cellulosic Fibers. Each are described in turn.

New Synthetic Fibers

Our clothes are increasingly made of plastic. Polyester made up 55% of the total fiber market in 2015 according to a Textile Exchange Preferred Fiber Market Report.[33] Most of the polyester used by the industry is from virgin feedstock; and a small percentage of polyester is sourced from recycled PET drink bottles. One of the safer chemistry challenges related to polyester—both recycled and virgin—is the use of antimony for the PET polymerization process.

As the chart shows, polyester consumption in 2015 is more than double that of its nearest rival - cotton. Polyester is the only fiber that has gained market share since 1990.

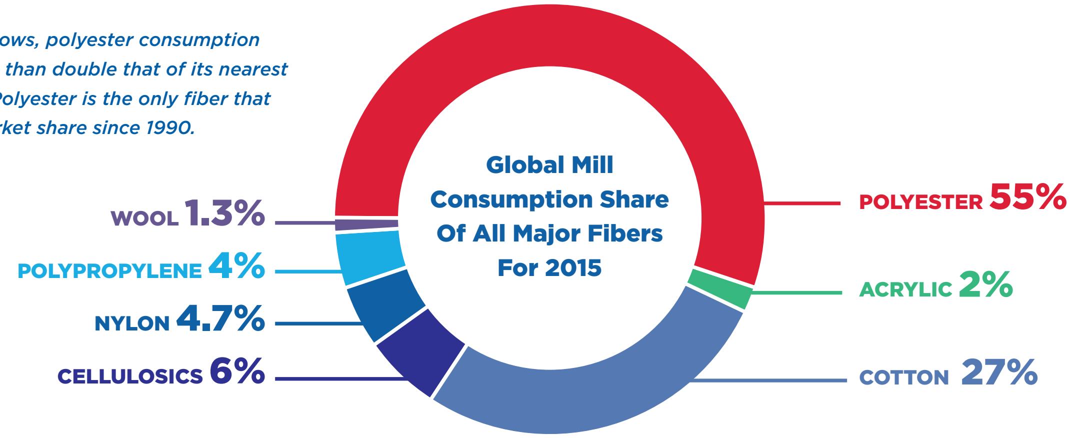


FIGURE 4

Global Share of Textile Fibers

Source: Textile Exchange, Preferred Fiber Market Report, 2016

[30] coyuchi.com/ (retrieved 4/11/2018)
[31] allbirds.com/ (retrieved 4/11/2018)
[32] wearpact.com/ (retrieved 4/11/2018)
[33] Textile Exchange, (2017) "Preferred Fiber and Materials Market Report 2017" Published online at: textileexchange.org/2017-market-reports/ (retrieved 4/11/2018)

Microfibers and the environmental persistence of polyester fibers is a significant environmental challenge. Large polyester producers, like the Poole Company, have been working to develop new types of polyester that are biodegradable, so it can be blended with natural fibers and degrade in the environment at the end of the product's life.[34] Ciclo is producing a polyester yarn additive that allows garments to degrade in anaerobic and marine environments at the end of life.[35]

Other companies have innovated by adding bio-sourced additives to PET to boost bio-based content and eliminate the need for additional odor control finishings, which are oftentimes biocides. For example, Sundried,[36] a UK-based sportswear brand, has designed apparel made from recycled PET that includes coffee grounds processed into yarn, making it antibacterial. These coffee ground-infused fibers eliminate the use of additional biocides including quaternary ammonium compounds, nano silver, and isothiazolinone-derivatives. Virent, has been working with major chemical and yarn supplier Toray to produce the first 100% bio-based polyester t-shirt.[37]

> ***The industry is hungry for new materials with new performance characteristics... The need for materials innovation provides the opportunity to adopt new materials that perform better and are safer, and to design safer manufacturing processes.***

There is emerging interest in polyester-like fibers that degrade in a marine environment. The leading polymer candidate replacement at the moment is polyhydroxyalkanoates (PHAs). Mango Materials[38] plans to make a PHA-based yarn that can degrade in the marine environment. Other companies have been looking to PHAs to eliminate another source of plastic pollution, the plastic "poly bags" used to ship garments. Existing poly bags are not degradable and are rarely recycled, so some brands would like to replace them with a compostable bag, likely made from PHAs, starch or another degradable bioplastic.

We also see significant interest in new synthetic fibers made of proteins similar to the ones in spider silk, from companies like Bolt Threads and Spiber.[39] As of late 2017, both companies raised significant capital and partnered with existing leading brands (Bolt Threads with Stella McCartney, and Spiber with The North Face). Like other synthetic fibers, these polymers are extruded to make filament that can be spun into yarn. The difference is that the polymers are protein-based and made through fermentation. These fibers will be both biodegradable and sourced from biological feedstocks. Similarly, Algiknit[40] is extruding biopolymers isolated from seaweed into fiber and yarn that can be used by the apparel industry.

[34] rivetandjeans.com/denim-north-america-tackles-biodegradable-performance-denim/ (retrieved 4/11/2018)
[35] ciclotextiles.com/ (retrieved 4/11/2018)
[36] sundried.com/ (retrieved 4/11/2018)
[37] virent.com/ (retrieved 5/14/2018)
[38] mangomaterials.com/ (retrieved 4/11/2018)
[39] boltthreads.com/ and Spiber: spiber.jp/en (retrieved 4/11/2018)
[40] algiknit.com/ (retrieved 5/14/2018)

Sheerly Genius[41] uses ultra-high molecular weight polyethylene (UHMWPE) to create a new yarn. UHMWPE is an extremely strong material originally used as a light alternative to Kevlar. Sheerly Genius aims to bring it to the apparel space, focusing initially on pantyhose. The extreme resistance of this new yarn ensures it will last through wear, and reduces the need to buy new pairs of pantyhose. The very high value of the material also makes takeback and recycling a likely element of the business model. Table 4 shows current examples of companies working on new synthetic fibers innovation.

COMPANY	TECHNOLOGY	WEBSITE
Algiknit	Fibers made from seaweed extract	algiknit.com
AMSilk	Production of synthetic silk biopolymers (Biosteel®)	amsilk.com
Beaulieu Yarns	Sustainable versions of polyamide yarns (PA6) yarns	beaulieuyarns.com
Bionic	Materials made from plastic recovered from marine and coastal environments	bionic.is
Bolt Threads	Synthetic spider silk	boltthreads.com
Ciclo	Additive to promote the degradation of PET and other synthetics yarns	ciclotextiles.com
Cocona Inc. / 37.5® Technology	Fabric enhancer derived from coconuts	thirtysevenfive.com
Danimer	PHA producer relying on the fermentation of sugar	danimerscientific.com
Fulgar	Castor oil-based fibers	fulgar.com
Full Cycle Bioplastics	PHA flexible film producer, which relies on fermentation of waste biomass	fullcyclebioplastics.com
Green Banana Paper	Banana byproduct-based fibers	greenbananapaper.com
Mango Materials	PHA-based marine degradable fiber, produced from methane captured at waste water treatment facilities	mangomaterials.com
Offset Warehouse	Banana byproduct-based fibers	offsetwarehouse.com
Orange Fiber	Citrus byproduct-based fibers	orangefiber.it/en
Pinatex	Pineapple leaf-based fiber alternative	ananas-anam.com
Qmilk	Milk-based fibers	qmilkfiber.eu
Samatoa Lotus Textiles	Lotus-based fibers	samatoa.lotus-flower-fabric.com
Sheerly Genius	Ultra-high molecular weight polyethylene-based new yarn for pantyhose, athletic and leisure apparel	sheerlygenius.com
Singtex / S.Cafe	Coffee grounds-based polyester fiber additive and enhancer	singtex.com/en-global/technology/fabrics_info/scafe
Smartfiber AG	Patented process to embed seaweed within natural cellulose fiber	smartfiber.de
Spiber	Production of synthetic silk biopolymers	spiber.jp/en
Tjeerd Veenhoven	Renewable textiles made from algae	tjeerdveenhoven.com
Virent	Biobased PET producer working with Toray to produce Bio-PET	virent.com

TABLE 4
New Synthetic Fiber Companies
Source: Safer Made 2018.

[41] sheerlygenius.com/ (retrieved 4/11/2018)

Leather Alternatives

New leather alternatives have the potential to eliminate several classes of chemicals of concern. Table 5 shows the function these chemicals play in leather production.

CHEMICALS OF CONCERN USED IN LEATHER PRODUCTION	FUNCTIONS
Chlorinated aromatics	Solvent
Pentachlorophenol	Preservative
Chromium	Tanning agent
Chlorinated paraffin	Softener
Naphthalene	Contaminant in tanning and dyeing
Sodium sulfide	Tanning agent
Acrylic and Isocyanate monomers	Cross-linkers and finishing agents

TABLE 5
Classes of Chemicals of Concern Associated with Leather Production
Source: Safer Made 2018

Luxury, fashion and sports brands are interested to differentiate by bringing to market animal free products. Existing animal free leather is based on synthetic vinyl or polyurethane polymers, which rely on phthalates (vinyl) and/or DMF (polyurethane) to provide a texture similar to leather. Both Phthalates and DMF are chemicals of concern included in most M/RSLs.

Several innovative companies are exploring ways to bring new leather alternatives to market including the companies highlighted in Table 6.

COMPANY	TECHNOLOGY/SOURCE MATERIAL	WEBSITE
Amadou	Mushroom	amadouleather.com
Atlantic Leather	Fish	atlanticleather.is
bleed clothing GmbH	Cork	bleed-clothing.com/english
E-Leather	Recycled leather fibers with synthetic fiber support	eleathergroup.com
Ecovative / Bolt Threads	Mushroom	ecovativedesign.com
Fruitleather	Fruit waste	fruitleather.nl
Geltor	Bio-fabricated leather made from fermentation produced collagen	geltor.com
Grado Zero Espace - Muskin	Fungus (Phellinus ellipsoideus)	gradozero.eu

TABLE CONTINUED ON NEXT PAGE...

COMPANY	TECHNOLOGY/SOURCE MATERIAL	WEBSITE
Modern Meadow	Bio-fabricated leather made from fermentation produced collagen	modernmeadow.com
MycoWorks	Fungal mycelium	mycoworks.com
Noani	Eucalyptus fiber	noanifashion.de/en
Okinawa	Plant and wood	okinawa.it
Pinatex	Pineapple leaf	ananas-anam.com
Provenance	Bio-fabricated leather made from fermentation-produced collagen	provenance.bio/technology
Thamon	Sal leaf	thamon.co.uk
Vegea	Grape waste	vegeacompany.com/en

TABLE 6
Innovative Companies Working on Leather Alternatives
Source: Safer Made 2018.

New Cellulosic Fibers

Cotton is the second most used fiber in the textile and apparel industry after polyester, despite its high costs and heavy environmental footprint. Cotton can use as much as 20,000 liters of water to produce one kilogram of fiber, according to the World Wildlife Fund.[42] Conventional cotton farming also accounts for 16% of all insecticides and 6.8% of all herbicides used worldwide.[42] Awareness of the significant impact of cotton production has been growing, and increasingly brands are looking for more sustainable natural fiber options, ranging from organic cotton to new cellulosic fibers.

Other cellulosic fibers in the same class as cotton such as linen, hemp, rayon and Tencel are gaining popularity as natural fibers with potentially less environmental impact and different performance properties.

Rayon and Tencel fibers are created from woody biomass, which is pulped and chemically extruded to create new cellulose filament. These alternative cellulose fibers have their own environmental impact. Canopy, an NGO focused on sustainable forestry, recently released a third-party audit of a global viscose and rayon producer, assessing their risk of sourcing their feedstock from endangered forests.[43] Lenzing, a large cellulosic fiber producer, has launched EcoVero, a product line using sustainable wood feedstock and a cleaner production process with supply-chain transparency.[44] Stella McCartney also recently released a life cycle assessment report comparing the environmental performance of ten raw material sources of alternative cellulose fibers.[45] This report underscores the importance of understanding the fiber supply chain, since even nearly identical yarns can have different environmental impacts.

[42] worldwildlife.org/industries/cotton (retrieved 4/11/2018)
[43] canopyplanet.org/canopy-media/announcing-the-canopystyle-audit/ (retrieved 4/11/2018)
[44] uk.fashionnetwork.com/news/Lenzing-unleashes-new-eco-friendly-fibre,832288.html#.WS5HuOt97IU (retrieved 4/11/2018)
[45] scsglobalservices.com/resource/lca-comparing-ten-sources-of-manmade-cellulose-fiber (retrieved 4/11/2018)

Researchers are also exploring new cellulosic fibers. For example, a team of researchers at the University of Cambridge have created a fiber that has the strength and flexibility of spider silk and is made from a material called hydrogel, containing silica and cellulose.[46] Examples of innovative companies exploring new cellulosic fibers are highlighted in Table 7.

COMPANY	TECHNOLOGY	WEBSITE
9Fiber	Greener method for processing hemp fibers	9fiber.com
Agraloop	Conversion of agricultural waste to cellulosic fiber	circular-systems.com/agraloop
CRAiLAR	Flax fiber that drastically reduces chemical and water usage	crailar-fti.com
Ioncell-F	Converting wood into textiles using ionic liquids	ioncell.fi
Nanollose	Conversion of industrial organic waste to plant-free cellulose	nanollose.com
Spinnova	Wood fiber-based yarns	spinnova.fi
Tyton Bio	Conversion of agricultural or post-consumer fabric into cellulosic fiber feedstock	tytonbio.com

TABLE 7

Innovative Companies Working on New Cellulosic Fibers

Source: Safer Made 2018.

There are several young companies developing ways to use post-industrial and post-consumer apparel waste as feedstocks to create regenerated cellulose fibers. These startups are highlighted in the Fiber Recycling Innovation Area #4.

Innovation Area #2: New Safer Chemistries

Significant amounts of chemicals are applied to yarns and fabrics during the dyeing and finishing steps in order to color fabrics and to provide various functions such as water repellency, stain resistance, flame resistance, moisture wicking, wrinkle resistance, and antibacterial and odor resistance. Table 8 includes some of the classes of chemicals of concern in M/RSLs that could be eliminated by switching to safer finishing and dyeing chemistries.

CHEMICAL CLASSES	USE	WHERE USED IN THE SUPPLY CHAIN
Amines	Auxiliaries including surfactants, dispersants and softeners, or as process chemicals or precursors for other materials	All parts of the supply chain
Chlorinated and non-chlorinated (MIT/CMIT) Isothiazolinone-derivatives	Antimicrobial and preservative for formulated products	Chemical manufacturers
Poly aromatic hydrocarbons (PAHs)	Residual in dyes, rubber, carbon black, other petrochemical products	Dye houses

TABLE CONTINUED ON NEXT PAGE...

[46] sustainablebrands.com/news_and_views/chemistry_materials_packaging/sustainable_brands/trending_biomimicry_changing_attitud (retrieved 4/11/2018)

CHEMICAL CLASSES	USE	WHERE USED IN THE SUPPLY CHAIN
Sensitizing disperse dyes (ZDHC for subset of known sensitizers, or GHS codes H317, H334, R43, R42)	Dyes used with synthetic fibers including polyester, acetate, polyamide	Dye houses
Titanium dioxide	Known as Titanium white and used in many pigments in the textile industry	Dye houses
Azo-dyes (Aryl-amine releasers)	Dyes	Dye houses
Chlorinated benzenes	Solvents, fiber swelling agents in dying process	Dye houses
Chromium Wool	Mordant for mordant dyes used for dark shades of wool	Dye houses
Hypochlorite	Bleaching	Dye houses, denim finishing
Arsenic	Some pesticides/defoliants for cotton, as well as a contaminant in other materials and dyes	Farms
Formaldehyde and other short-chain aldehydes	Wrinkle-free coatings	Finishing
Halogenated Flame Retardants	Flame retardants	Finishing
Nano silver	Antimicrobial fabric treatment	Finishing
Per- and poly-fluorinated compoundS	Durable water repellency	Finishing
Per- and poly-fluorinated compounds	Stain resistant	Finishing
Triclosan and triclocarban	Antimicrobial fabric treatment	Finishing
Glycols	Solvents in finishing, cleaning, printing, adhesive processes	Finishing, and garment manufacture
Chlorinated cleaning solvents	Dry cleaning, spot cleaning, scouring	Garment manufacture
Chlorophenols	Hide preservation in the leather industry	Leather processing
Short chain chlorinated paraffin	Leather conditioners	Leather production
Aromatic solvents	Used in synthetic leather manufacturing, and can be found in cleaners and ink solvents	Leather production and dye houses
Naphthalene	A common residual in synthetic leather tannins, and in dye dispersing agents that use naphthalene sulfonate derivatives	Leather production and dye houses
Chromium (Leather)	Tanning agent for leather	Leather Tanning
Alkyl phenol Ethoxylates	Cleaners and detergents	Mills
Aryl amines	Found in polyurethanes and as decomposition products of azo colorants	Mills
Lead	Plastics, paints, inks, pigments, surface coatings	Mills
Ortho-phthalates	Plasticizer in PVC for screen printing and coatings	Non-woven manufacturing and printing
Vinyl chloride and vinylidene chloride	These polymers form the basis of some waterproof plastic-impregnated fabrics and artificial leathers	Non-woven manufacturing and printing

TABLE 8

Classes of Chemicals of Concern Associated with Dyeing and Finishing Textiles

Source: Safer Made 2018.

Finishing mills and dye-houses typically source their own chemistry and design their own manufacturing processes. Bringing new production methods or technologies to market requires working together with the mills and dye houses. They are often reluctant to invest capital upfront when demand for the new process or technology may be uncertain. When developing chemical and manufacturing innovation in dyeing and finishing, it is critical to understand how these technologies will be used within the supply chain, and how the costs and benefits of the new technologies will be split among the various supply chain partners.

Within the New Safer Chemistries Innovation Area we distinguish two sub-areas: Safer Finishing Chemistries and Bio-based Dyes.

Safer Finishing Chemistries

Finishing refers to the processes performed after dyeing the yarn or fabric to improve the look, performance or "hand" (feel) of the finished textile or clothing. Additional chemicals are often added to yarns or fabrics to provide performance attributes including water repellency, stain resistance, flame resistance, moisture wicking, wrinkle resistance, anti-bacterial and odor resistance properties.

Safer durable water repellency, antimicrobial and wrinkle-free finishing chemistries are active innovation needs, as the end-use function relies on applying chemicals of concern to fabric. We have seen examples of established chemical suppliers and young companies working on potential solutions.

In the durable water repellency (DWR) space, many outdoor and fashion brands have pledged to remove fluorinated finishes from their apparel, which has spurred the development alternative DWR coatings from a wide range of suppliers. The solutions that come from existing suppliers (such as Chemours or Huntsman) or from young companies rely on the same set of chemical alternatives: silicones, palm oil derivatives and polymer coatings such as polyurethane or paraffin. Suppliers have proprietary formulations that change the application and durability of these finishes, but so far many struggle with performance issues such as inferior water repellency to the existing fluorocarbon-based solutions, loss of performance when exposed to oils and dirt, and inferior wash durability.

Among the young companies developing durable water repellency solutions, Green Theme International[47] stands out; they are developing a way to deliver highly durable water repellency performance without using fluorocarbons. Another innovative company in this space, Dropel,[48] is adapting existing processes and formulations to deliver fluorocarbon-free durable water repellency for cotton fabrics.

[47] greenthemeint.com/ (retrieved 4/11/2018)
[48] dropelfabrics.com/ (retrieved 4/11/2018)

Bio-based Dyes

Synthetic dyes have been at the heart of the chemical industry since its beginning. BASF's first commercial products were aniline dyes, and after producing the first synthetic indigo in 1897, dyes made up almost 80% of BASF's revenue. Today there are many other chemical suppliers of dyes, and most are have launched more sustainable product lines: Archroma (Earthcolors), Huntsman (Avitera), Garmon (Nimbus) and DyStar (Cadira and Lava). Most existing chemistry suppliers have focused their innovation efforts on improving dyeing efficiency and reducing labor, energy and water use during the resource intensive dyeing process.

Industry is interested in natural and bio-based dyes, and several companies are addressing this need. Stony Creek Colors and The Colours of Nature are producing natural indigo.[49] PiliBio and Colorfix are making new dyes and modifying existing ones with fermentation processes and renewable feedstocks.[50] Nature Coatings[51] is using waste from the wood industry to create a carbon black alternative that is more effective and better for the environment. Examples of innovative companies active in the New Safer Chemistries Innovation Area are included in Table 9.

COMPANY	TECHNOLOGY	WEBSITE
Acticell	Denim bleaching agent to replace KMNO4	acticell.at
APJet	Atmospherically stable plasma for chemical deposition	apjet.com
Beyond Surface Technologies	Bio-based textile finishing chemistries	beyondst.com
Colorifix	Bio-based dyes expressed and applied with bacteria	colorifix.com
ColorZen	Efficient and safe cationization of cotton	colorzen.com
The Colours of Nature	Natural indigo and other dye production and dyeing	thecoloursofnature.com
Dropel	Durable water repellency for cotton	dropelfabrics.com
eDye	Melt dyeing of polyester	e-dye.com
Green Theme International	Waterless chemistry platform providing high performance durable water repellency	greenthemeint.com
Hygratek	Bio-based (corn husk and silica powder) omniphobic coating for fabric	hygratek.com
Nature Coatings	Wood waste-based carbon black alternative	naturecoatings.net
Nano Textile	Ultrasonic finishing processes that eliminate chemical binders	nano-textile.com
PiliBio	Fungus dyes and pigments made by fermentation	pili.bio
Recycrom	Pigments made from textile waste	recycrom.com
SpinDye	Melt dyeing processes using recycled polyester	spindye.com
Stony Creek Colors	Natural indigo dye production from plants grown in the U.S.	stonycreekcolors.com

TABLE CONTINUED ON NEXT PAGE...

[49] Stony Creek Colors: stonycreekcolors.com and Colours of Nature: thecoloursofnature.com/ (retrieved 4/11/2018)
[50] PiliBio: pili.bio/ and Colorfix: colorifix.com/Colorifix/page.php (retrieved 4/11/2018)
[51] naturecoatings.net/ (retrieved 4/11/2018)

Wet-Green	Leather tanning chemicals derived from olives	wet-green.com
Life Materials	Antimicrobial finishing based on peppermint oil	life-materials.com

TABLE 9
Examples of Innovative Companies Working on Safer Finishing Chemistries and Bio-based Dyes
Source: Safer Made 2018.

Innovation Area #3: Waterless Processing

Large quantities of water are used at almost every step of the textiles and apparel manufacturing process in apparel textiles, including applying dyes and finishing chemicals to fabrics. Water is also used to clean yarn, fabric and apparel through the production process. Water-based processing and waste-water is one of the main sources of chemical emissions into the environment from the textile industry.

Waterless chemical application processes would reduce chemical pollution and enable the removal of auxiliary chemistries, such as dispersants and salts, added to the water base during the dyeing and finishing processes. Switching to waterless processes may also enable the use of new chemistries, which could be optimized to minimize the use of chemicals of concern. Table 10 shows some of the classes of chemicals of concern in M/RSLs that could be reduced by waterless processing.

CHEMICAL CLASSES	USE	WHERE USED IN THE SUPPLY CHAIN
Alkyl phenol ethoxylates	Cleaners and detergents	Mills
Amines	Auxiliaries including surfactants, dispersants, softeners	Across the supply chain
Azo-dyes (Aryl-amine releasers)	Dyes	Dye houses
Chromium	Mordant for mordant dyes used for dark shades of wool	Dye houses
Formaldehyde and other short-chain aldehydes	Wrinkle-free coatings	Fabric finishing
Hypochlorite	Bleaching	Dye houses, denim finishing
Mercury/caustic soda	Found as contamination in caustic soda (NaOH) used in water-based processes	Across supply chain
Per- and poly-fluorinated compounds	Durable water repellant and stain resistant finishing	Fabric finishing
Quaternary ammonium compounds	Disinfectants, cleaners, antimicrobial treatment	Across supply chain
Sensitizing disperse dyes (ZDHC for subset of known sensitizers, or GHS codes H317, H334, R43, R42)	Dyes used with synthetic fibers including polyester, acetate, polyamide	Dye houses

TABLE 10
Classes of Chemicals of Concern that Could Be Reduced by Moving to Waterless Processing
Source: Safer Made 2018.

Within the Waterless Processing Innovation Area we distinguish two sub-areas: Waterless Dyeing and Waterless Finishing.

Waterless Dyeing

Dyeing fabric is one of the most water-intensive steps in the production of textiles, and many innovations in waterless textile processing aim to reduce or eliminate water use from the dyeing process.

Existing manufacturers like Thies,[52] Benninger,[53] Fong's,[54] Suntex[55] and others have developed dyeing equipment optimized to reduce water use by more efficiently circulating the fluids and controlling or increasing the dyestuff-to-water ratios. These approaches save water, but don't change the underlying chemistry.

Another way to reduce the amount of water used during the dyeing process is chemically modifying the fibers so the dyestuff binds better. One of the approaches is the cationization of cotton, which means treating the cotton fibers, yarn or fabric with a caustic amination agent. The treated cotton has a positively charged surface that binds better to dye, which is commonly negatively charged. A company implementing this approach is ColorZen.[56]

Solution pigmenting or dope dyeing for synthetic fibers is another water-saving process. In dope dyeing, the dye is added to the bulk polymer or polymer solution before it is extruded to make synthetic filaments. This process can be used for both petroleum-based synthetic fibers such as polyester and synthetic cellulosic fibers such as rayon. This approach is illustrated by companies such as e.Dye and We aRe SpinDye working to bring dope dying of polyester to wide adoption.[57]

Using liquid or supercritical carbon dioxide as the solvent would eliminate the need for water and other potentially harmful chlorinated solvents, and can be relatively easily cleaned and re-used by letting it go into gas phase and then re-compressing it. Companies like DyeCoo[58] have shown that carbon dioxide can be used instead of water for the dying of synthetic yarns and fabrics.

Waterless Finishing

Like dyeing, the application of finishing chemicals often relies on using water as the solvent, and often uses similar equipment. Companies like APJet or MTI-X have developed alternative ways to

[52] thiestextilmaschinen.com/ (retrieved 4/11/2018)
[53] benningergroup.com/en/ (retrieved 4/11/2018)
[54] fongs.eu/ (retrieved 4/11/2018)
[55] suntextextiles.com/ (retrieved 4/11/2018)
[56] colorzen.com/ (retrieved 4/11/2018)
[57] e.dye: e-dye.com/ and We aRe SpinDye: spindye.com/ (retrieved 4/11/2018)
[58] dyecoo.com/ (retrieved 4/11/2018)

apply chemistry to textiles without using water.[59] They both rely on the generation of atmospheric plasma near the surface of fabric to bond finishing chemicals. Plasma coating has been used in the electronics industry for many years, and is being explored for use in textile finishing.

In another approach, Green Theme International[60] is developing a new waterless finishing platform that uses a pressure vessel to bind its chemistry to fibers. Table 11 includes examples of companies working on waterless dyeing and finishing technologies.

COMPANY NAME	PRODUCT/TECHNOLOGY	TEXTILE PROCESS	WEBSITE
APJet	Atmospherically stable plasma for chemical deposition	Fabric finishing	apjet.com
Applied Separations	Super critical CO2 technology	Dyeing	appliedseparations.com
ColorZen	Efficient and safe cationization of cotton	Dyeing	colorzen.com
DyeCoo	Super critical CO2 for dyeing synthetics	Dyeing	dyecoo.com
eDye	Dope dyeing of polyester	Dyeing	e-dye.com
Green Theme International	Waterless chemistry platform providing high performance durable water repellency	Finishing/dyeing	greenthemeint.com
MTI-X	Plasma processing for textile dyeing and finishing	Finishing/dyeing	mti-x.com
SpinDye	Dope dyeing processes using recycled polyester	Dyeing	spindye.com
Xeros	Polymer bead-based cleaning system that eliminates water use and microfiber pollution in commercial laundry	Finishing/dyeing	xeroscleaning.com

TABLE 11
Examples of Innovative Companies Working on Waterless Dyeing and Finishing
Source: Safer Made 2018.

Innovation Area #4: Fiber Recycling

Recycling fiber has the potential to save the chemicals, energy and water expended to create the virgin fibers, as well as to reduce the amount of textiles in landfills and incinerators. Consumers respond positively to the recycling message. Advocacy groups focused on the circular economy are asking brands to look for fiber recycling solutions. As a result, leading brands are looking for ways to source more materials from recycled products, collecting used apparel for recycling at stores, and telling their customers about the sustainability benefits of recycled materials.

Within the Fiber Recycling Innovation Area we distinguish four sub-areas: Recycled Cotton, Recycled Polyester, Recycled Nylon and Recycled Blends.

[59] APJet: apjet.com/ and MTI-X: mti-x.com/ (retrieved 4/11/2018)
[60] greenthemeint.com/ (retrieved 4/11/2018)

Recycled Cotton

Mechanical technologies for recycling cotton shorten the fiber length, which means that the resulting yarns and fabrics are weaker than virgin cotton. Mills try to address this drawback by blending these shorter recycled fibers with longer virgin cotton and/or polyester filament to improve strength and durability. For example, Recover[61] manufactures recycled cotton and polyester blends t-shirts. Natural Fiber Welding[62] uses a chemical process to increase the strength of recycled yarns.

An alternative to mechanical recycling is the chemical recycling of cotton. Several companies including Evrnu, Re:newcell, The Infinited Fiber Co, and Lenzing have piloted cotton recycling programs that take cotton waste and use proprietary solvents to make regenerated cellulose yarns.[63] Many of these technologies work only on cotton and cannot process fabrics that also have polyester in them, which limits their applicability given how ubiquitous polyester fibers and blends are. A technology that could separate residual polyester and make a high quality recycled cotton yarn close in performance and feel to virgin cotton would be valuable.

Recycled Polyester

Polyester fibers made from recycled polyester terephthalate (PET) bottles are available from various suppliers including Unifi (REPREVE), Far Eastern (TOPGREEN), RadiciGroup (r-RADYARN) and Teijin (Eco-Circle/Chemical, ECOPET/Mechanical). According to the 2017 Textile Exchange Preferred Fiber Market Report, the use of recycled PET in apparel grew by 58% between 2015 and 2016.[64]

Reclaiming polyester fiber from apparel and turning it back into fiber for the textile industry is rarely done, because chemically recycled polyester is more expensive than virgin fiber. As the market for high quality polyester fiber continues to grow, we expect more companies to explore chemical recycling approaches. For example, French company Carbios[65] is developing a new enzyme-based polyester recycling technology that may "upcycle" textile fibers back into virgin-quality polyester.

Recycled Nylon

Nylon can be chemically recycled into high quality fibers cost effectively. Nylon is recycled through chemical de-polymerization to yield a solution of monomers that are purified

[61] recoverbrands.com/ (retrieved 4/11/2018)
[62] naturalfiberwelding.com/ (retrieved 4/11/2018)
[63] Evrnu: evrnu.com/; Re:newcell: renewcell.com/; Infinited Fiber: infinitedfiber.com/; Lenzing: lenzing.com/en/products/tencel-tm/ (retrieved 4/11/2018)
[64] Textile Exchange, (2017) "Preferred Fiber and Materials Market Report 2017" Published online at: textileexchange.org/2017-market-reports/ (retrieved 4/11/2018)
[65] carbios.fr/en/ (retrieved 4/11/2018)

and re-polymerized to produce a virgin-like material. Recycled nylon can be produced for less than what it costs to make virgin polymer. A significant percentage of nylon from fishing lines, fishing nets and carpets is currently recycled. Unfortunately, there are no easy ways to separate nylon from other materials in blended materials, which means that much of the nylon that is used in apparel is not recycled.

Recycling Fiber Blends

Recycling of textiles made from a blend of different materials is challenging and can be expensive. There are two main methods for recycling fibers: mechanical and chemical.

Currently the only widely available option for recycling blended fabrics uses mechanical methods to shred the fabric. The resulting "shoddy" or "flock" is used in low-value applications including building insulation and nonwoven fabrics.

Ongoing research into chemical methods for recycling blended fabrics focuses on finding ways to eliminate residual polyester from cotton and polyester blends, for textiles in which most of the fiber is cotton. Ionic liquids or other solvents are used to dissolve the fabric, and then phase transfer agents and other separation methods are used to separate the polyester from the dissolved cellulose. The cellulose can then be extruded and spun into a new synthetic cellulose-based material. If the polyester is pure enough, the same method can be applied to polyester taken from the blended textile. However, the polyester portion of the fiber often has dyes and other contaminants, making it difficult to recycle. Table 12 shows examples of innovative companies active in the Fiber Recycling Innovation Area.

NAME	INPUT	PRODUCT	SUMMARY	WEBSITE
Evrnu	Cotton	Cellulosic fiber	Recycling post-consumer and post-industrial cotton garments into new fibers	evrnu.com
Re:newcell	Cotton	Celluloic fiber	Recycling post-consumer and post-industrial cotton garments into new fibers	renewcell.com
The Infinited Fiber Co.	Cotton	Cellulosic fiber	Cotton fiber recycling	infinitedfiber.com
Recover	Cut-sew waste	Cotton/poly blend t-shirts	Recycling cut-sew waste into sustainable t-shirts	recoverbrands.com
Martex Fiber	Mixed cotton/poly	Shoddy and insulation	Complete downstream recycling of post-industrial and post-consumer textile waste	martexfiber.com
Phoenix Fibers	Mixed cotton/poly	Shoddy and insulation	Closed-loop textile recycling for insulating materials	phxfibers.com
Leigh Fibers	Mixed industrial	Mixed fiber and products	Fiber recycling	leighfibers.com

TABLE CONTINUED ON NEXT PAGE...

Ambercycle	Post-consumer fabric	Polyester fiber	Process for recycling and extruding a polyester-like fiber from garment waste	ambercycleinc.com
BioCellection	Mixed waste	Polyester fiber	Municipal waste recycled to fiber	biocellection.com
Aquafil	Nylon fishing nets	Nylon fiber	Recycling abandoned fishing nets into nylon fibers (Econyl)	aquafil.com
Bureo	Nylon fishing nets	Nylon equipment	Fishnet recycling into skateboards, sunglasses and other accessories and equipment	bureo.co
Seaqual	Ocean plastic	Polyester	Recycling plastic collected from marine environments	seaqual.com
Repreve	Plastic waste	Polyester fiber	Post-industrial waste, used plastic bottles recycling, fiber production	repreve.com
FENC	Polyester	Polyester fiber	Recycled post-consumer polyester	fenc.com/?lang=en
Stein Fibers, Ltd.	Polyester	Polyester fiber	Recycled polyester	steinfibers.com
Thread	Polyester	Polyester fiber	Recycled PET fiber and garment productions	threadinternational.com
Worn Again	Post-consumer fabric	Polyester fiber and cellulose	Chemical recycling of mixed cotton poly blends	wornagain.info
Cordura	Recycled polyester	Polyester fiber	Recycled polyester yarns	cordura.com
Polylana	Recycled polyester	Polyester fibers	Low impact alternative to 100% acrylic and wool	polylana-yarn.com
Agraloop Bio-Refinery	Crop waste	Natural fibers	Crop waste management and processing for fiber production	circular-systems.com
The Renewal Workshop	Apparel	Refurbished apparel	Partner with Brands to refurbish and resale returned clothing	renewalworkshop.com/en/home
Tyton BioSciences	Cotton and polyester blends	Dissolved pulp	Recycling post-consumer and post-industrial cotton and polyester into dissolved pulp that can be used to make new fibers	tytonbio.com

TABLE 12

Examples of Innovative Companies Working on Fiber Recycling

Source: Safer Made 2018.

Innovation Area #5: Information Systems that Support Supply Chain and Chemicals Management

The final Innovation Area concerns information and traceability. Understanding and managing how chemicals and materials are used through the textile and apparel supply chain is critical. The textile apparel supply chain—and the chemical inputs used at all stages of the process—is multi-layered and complex. We need increased visibility into the supply chain if we want to advance safer chemistry. Information needs to be reliable, accurate and accessible in order to be actionable.

Many brands are actively working to increase the transparency of their supply chain and improve access to relevant information. They are doing this to improve supply chain management, and to communicate better with consumers, governments and the advocacy community.

Within the Supply Chain Management Information Systems Innovation Area we distinguish two sub-areas: Chemicals Management Systems, and Traceability Systems.

Chemicals Management Information Systems

Chemicals Management Information Systems are software tools and supporting consulting and verification services that allow brands to make their M/RSLs operational, and to monitor compliance within their supply chain. There are several companies working in this space, not necessarily limited to textile and apparel, including Stacks Data (formerly known as PeerAspect), Scivera and ToxNot.[66] An apparel-specific provider is BlueSign, a supply-chain verification service that offers on-the-ground mill verification and oversight.[67]

These tools are supported by the work done by numerous industry associations and nonprofits who monitor and publish M/RSLs, as well as databases of emerging chemicals of concern. Groups like ZDHC and AFIRM maintain reference M/RSLs for both manufacturing and final products respectively, and work closely with other stakeholders to keep these current. Other nonprofit organizations such as ChemSec (SIN-list) and Healthy Building Network (Pharos, Portico and Chemical Hazard Commons) maintain databases of chemicals of concern across industries that also support the development of apparel M/RSLs.[68]

Traceability Systems

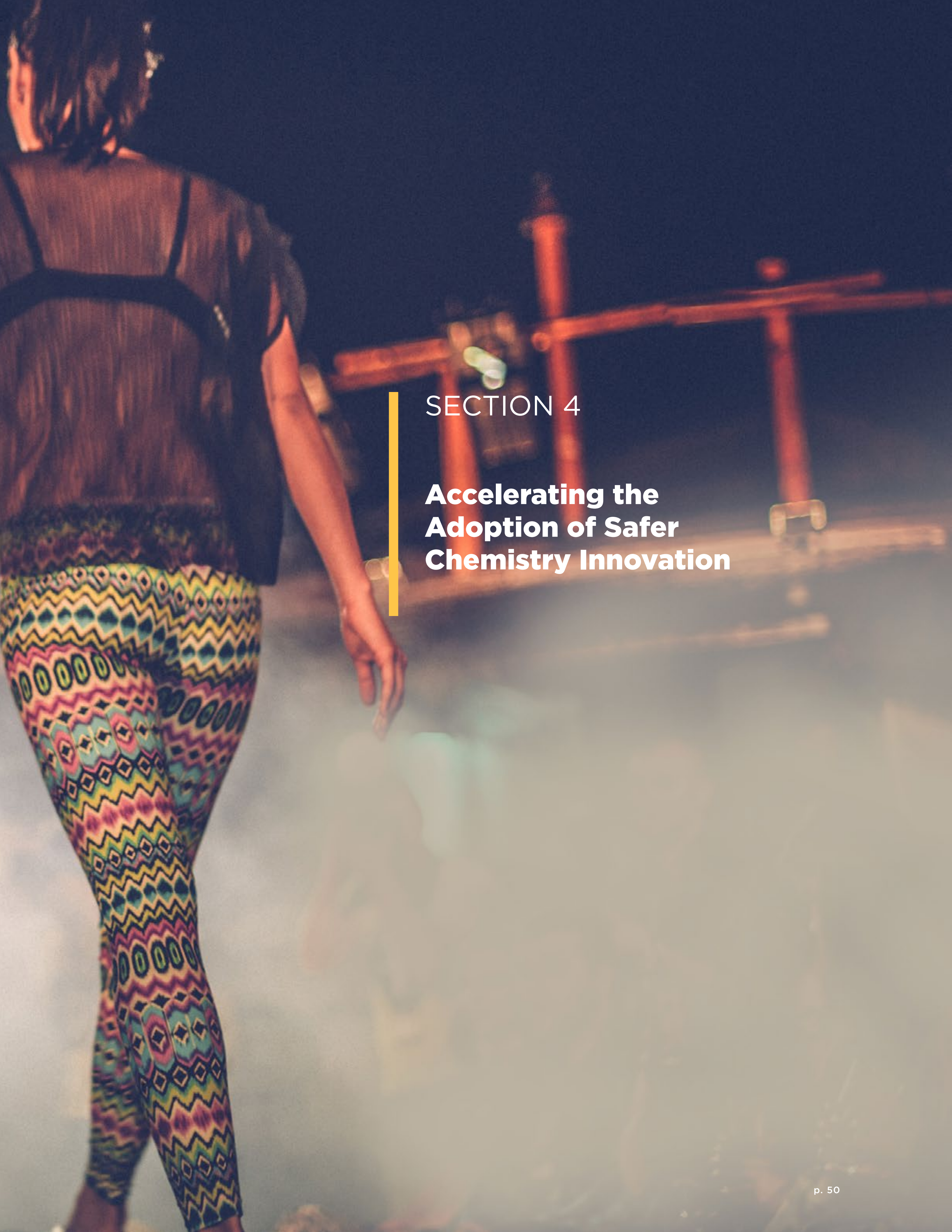
Increasing the traceability of apparel, textiles, materials and chemicals and gaining insight into production processes used are goals for many brands and retailers. Standards and certifications for tracking materials already exist. For example, there are standards for traceable wool and down, as well as broader supply chain standards put forth by the Better Cotton Initiative,[69] Bluesign,[70] Cradle to Cradle,[71] Naturtextil[72] and Oeko-Tex.[73] However, implementation is usually expensive and organizations often fail to capture additional information about the processing.

[66] Stacks Data: welcome.stacksdata.com; Scivera: scivera.com/; and ToxNot: toxnot.com/ (retrieved 4/11/2018)
[67] bluesign.com/ (retrieved 4/11/2018)
[68] SinList: sinlist.chemsec.org/ and Healthy Building Network: healthybuilding.net/ (retrieved 2018)
[69] bettercotton.org/ (retrieved 4/11/2018)
[70] www.bluesign.com/ (retrieved 4/11/2018)
[71] www.c2ccertified.org/ (retrieved 4/11/2018)
[72] naturtextil.de/en/home/ (retrieved 4/11/2018)
[71] www.oeko-tex.com (retrieved 4/11/2018)

Technologies such as DNA or RFID tagging may address some of the traceability challenges in ways that would also provide transparency. Several companies are currently trying to apply the open-ledger blockchain concept to trace items and provide information to consumers. These initiatives are in early stages within the textile industry, but given the cross-sector applications and the textile and apparel sector interest, it is likely that this will be an active innovation area. Table 13 includes examples of companies and organizations that work on developing supply chain management information systems.

COMPANY	TECHNOLOGY	WEBSITE
A Transparent Company	Blockchain for tracking garment production and consumer transparency	atransparentcompany.com
Applied DNA Sciences	DNA tag system for cotton traceability	adnas.com
ChemSec Market Place	Nonprofit platform for safer chemicals spanning multiple industries	marketplace.chemsec.org
Eon ID	RFID-powered textile recycling	eonid.co
I:Co	Data collection infrastructure for apparel	ico-spirit.com
Stacks Data (f.k.a. PeerAspect)	Supply chain information technology system	welcome.stacksdata.com
EcoVadis	Supplier sustainability rating and information management tool	ecovadis.com/us
Scivera	Chemical management and selection software	scivera.com
ToxNot	Chemical hazard database	toxnot.com
ZDHC Gateway	Marketplace for identifying safer chemicals	roadmaptozero.com/gateway

TABLE 13
Examples of Organizations Working on Supply Chain Management Information Systems
Source: Safer Made 2018.



SECTION 4

Accelerating the Adoption of Safer Chemistry Innovation

Accelerating Safer Chemistry Innovation

One of our goals with this report is to share information about the safer chemistry opportunity in textile and apparel, so both sector "insiders"—brands, retailers, chemicals and equipment suppliers, mills—and those outside the sector, such as innovators, investors, governments and the advocacy and philanthropic community, can have impactful conversations, leading to partnerships and resource decisions.

Demand for safer and more sustainable products continues to grow, driving the opportunity to bring better chemistry to market. Brands and retailers are on the expansion frontier of this demand, being key mediators between consumer demand and supply. Brands both react to and influence consumer preferences for products that are safer and more sustainable. In turn, brands and retailers demand safer products and manufacturing processes from their own suppliers.

Established chemical suppliers have optimized their processes and product offerings to provide large quantities of chemicals quickly and at relatively low costs. They have specialized knowledge and capabilities on particular chemistries and processes, and know how to scale up new technologies. They see the trend toward safer and more sustainable products and are looking to address the needs of brands and retailers.

> ***"Innovation is an opportunity for the sector to demonstrate safety and sustainability."***

Existing suppliers can also collaborate with and sometimes invest in young innovative companies. Once young companies validate their technology and the demand for it, existing suppliers can use their scale, resources and experience to bring them to the market.

Innovative young companies are often more likely than established ones to develop technologies and materials that depart from the current manufacturing processes and materials. For example, as mentioned in Section 3, chemistry is applied to fabrics using mostly water-based processes. Established suppliers of both formulations and equipment prefer to work on improving the performance of their current technology, and are unlikely to pursue a fundamental redesign because their expertise and market position lies with the existing process. This leaves innovative young companies with more flexibility to develop waterless dyeing and finishing processes.

Developing systemic innovation is an opportunity for the sector to demonstrate safety and sustainability, as well as push for performance; quite often the new materials, chemistries and processes also translate into new performance characteristics.

In this section, we review the available tools and strategies for accelerating the adoption of safer technology in the textile apparel sector including: (1) adopting M/RSL's and managing the supply chain; (2) implementing safer chemistry tools at the design phase; and (3) participating in the innovation ecosystem by partnering with innovative companies, engaging with accelerators and incubators, and investing.

M/RSLs and Supply Chain Management

We described M/RSLs and their key role as the main tool for chemicals management across the supply chain in Section 2. They can also be viewed as key accelerators for innovation.

Many brands and retailers have spent considerable resources to understand what chemicals and materials are present in their products, or have been used to manufacture them. Brands and retailers that adopt chemicals policies often also have internal teams dedicated to working with their suppliers on implementing transparency and chemicals policies.

Transparency initiatives, adopting M/RSLs and working with the supply chain partners to implement them are established chemicals management strategies that contribute to shifting the industry to safer chemistry. Organizations like the ZDHC group have been accelerating this work by partnering brands and suppliers to scale safer alternatives to the chemicals found on their M/RSLs. ZDHC has worked with brands to identify and test alternatives to chemicals like DMF and denim finishing chemicals that are now being adopted by leading brands. These efforts have been successful and helped the industry use safer ingredients in many areas where solutions are available, and are gaining momentum as more brands and supply chain partners get involved.

Table 14 shows key industry groups and standards programs that help brands and retailers develop and implement chemical management systems.

COMPANY	STANDARDS PROGRAMS
Afirm Group	Is an industry association focused on the global management and communication of restricted substances in apparel and footwear.
Cradle to Cradle Products Innovation Institute (C2C)	Their Fashion Positive Program works with textile and apparel companies to identify C2C-approved suppliers, and is currently working to develop a "library" of C2C approved materials for designers.
Oeko-Tex	Is an independent testing and certification system for textile products from all stages of the textile supply chain. OekoTex has three standards: OekoTex 100 is a product standard; StePis a manufacturing standard; and Eco-Passport is a chemical standard.
Outdoor Industry Association Sustainability Working Group	Is convener of outdoor brands who manage and inform the adoption of standards, including a close collaboration with SAC and the Higg Index.
Sustainable Apparel Coalition (SAC)	Manages the Higg Index, a suite of self-assessment tools for measuring environmental and social sustainability throughout the supply chain. The Higg Index is now used by more than 150 companies, representing a conservative 40% of the apparel and footwear market.
Sustainable Clothing Action Plan (SCAP) | WRAP UK	Manages a voluntary industry program in the UK to reduce the water, carbon and waste impacts of the textile and apparel sectors.

TABLE CONTINUED ON NEXT PAGE...

Sweden Textile Water initiative	Produces reports and documents best practices to help leather and textile companies and factories reduce water, energy and chemical use in their supply chains.
Textile Exchange	Is a global nonprofit that works with members to drive industry transformation in preferred fibers, integrity and standards, and responsible supply chain practices. They manage organic cotton standards; lead standard development for other fibers like down and wool; and play a hub role with its annual international Textile Sustainability Conference.
The bluesign® system	Is a mill-focused certification system for sustainably-produced textiles, which works with mills and chemical suppliers to certify that all raw materials and substances applied meet sustainability criteria. Bluesign also offers a consumer-facing label.
The Global Organic Textile Standard (GOTS)	Is a textile processing standard and associated certification for organic fibers, including ecological and social criteria.
The GreenScreen	Is a chemical hazard assessment tool used by brands and retailers across a number of industry sectors.
The Zero Discharge of Hazardous Chemicals (ZDHC)	Takes a holistic approach to tackling the issue of hazardous chemicals in the global textile, leather and footwear value chain. The ZDHC M/RSL is among the most widely used list of restricted chemicals.

TABLE 14

Industry Groups and Standards Programs

Source: Safer Made 2018.

Implementing Safer Chemistry Tools at the Design Phase

Proactive design and preferred chemistry screening approaches intend to promote best-in-class chemistry, instead of focusing on the problem chemistry found in M/RSLs. Brands can drive chemical selection and design based on preferred chemistries that complement M/RSLs. In turn, this evolution in chemicals management drives the adoption of preferred materials by designers who are focused on creating clothes people want to wear, rather than monitoring M/RSLs.

Two examples of preferred materials programs are the Materials Wise program from Cradle to Cradle, and the Screened Chemistry program at Levi Strauss.

The Cradle to Cradle Product Innovation Institute[74] is a nonprofit organization that promotes the use of circular design and safer materials through their C2C product certification and label, as well as industry-specific initiatives. Within the apparel sector, C2C's Fashion Positive program helps brands identify and certify preferred input materials. The goal of the Fashion Positive program is to aggregate resources and demand, and make certified materials easier to identify in order to accelerate the adoption of safer materials. The C2C Innovation Institute helps designers avoid chemicals of concern by using an automated screening tool for M/RSL compliance called MaterialWise—a program intended to make it easier for designers and product managers to screen for chemicals of concern early in the design process. The Fashion Positive Materials Collection consists of a collection

[74] c2ccertified.org/ (retrieved 4/11/2018)

of C2C-certified input materials or garments. Once expanded, this collection of certified materials could help brands bring certified apparel to market by using certified inputs.

Levi Strauss' Screened Chemistry Program[75] is part of Levi Strauss' larger set of chemicals management strategies that aim to achieve the company's goal of zero hazardous chemicals discharges. The four components of the Chemical Management System at Levi Strauss are: (1) Restricted Substance List; (2) Manufacturing Restricted Substance List; (3) Global Effluent[76] Requirements; and (4) the Screened Chemistry Program. The first three parts are similar to other apparel brands. Levi Strauss developed the fourth part, Screened Chemistry, in an effort to eliminate the need for various regulatory compliance and restricted substance lists. This idea is summarized by Bart Sights, who manages Levi Strauss' innovation lab: "We're looking at the chemicals that we might use before we ever use them to make sure that they're safe and best-in-class, removing harmful chemicals, or finding better alternatives. The long-term vision is that Screened Chemistry can preempt the other parts of the Chemical Management System such as the M/RSL."[77]

Levi Strauss' Screen Chemistry program has been successful by offering partnership incentives to chemical suppliers that participate. The company paid for numerous chemical screens upfront to encourage participation. By working with suppliers to share costs and build sustainable models, by 2015, 12 suppliers participated in the program. Early adopters were Garmon, Switzerland-based Beyond Surface Technologies (BST), German company CHT, and Singapore-based Dystar. At least some of the supply chain partners have also seen benefits to their own businesses. For example, Garmon launched a line of GreenScreen® certified chemicals in 2015.

The Screened Chemistry approach has also benefited Levi Strauss' innovation development. The company identified denim finishing and the use of potassium permanganate bleaching agents as areas to find safer chemistry. Levi Strauss started

Working with suppliers and innovation partners to create the first 100% organic cotton tee-shirt that can be safely composted at home.

C&A, a European clothing retailer, decided to make the first mass-market tee-shirt from 100% cotton that would be cradle to cradle gold certified. This would mean they would need to use the safest chemistry and create a product that would breakdown in a compost bin without leaving behind harmful dyes or persistent plastics.

Creating better apparel demands high attention to detail. C&A had to develop a new thread and care tags which are often made from polyester or nylon. Most cotton thread is also made by wrapping cotton fibers around a synthetic polymer core which provides strength and durability.

C&A worked closely with the team at Cradle to Cradle to identify materials and suppliers that could meet the C2C gold standard. C&A ended up working with Pratibha Syntex, a Fair Trade–certified factory, and Cotton Blossom, a green-powered facility, both in India.

By working closely with both certifiers and suppliers, C&A was able to produce a mass-market 100% cotton tee-shirt using safer chemistry, made in responsible factories, at a competitive cost.

[75] levistrauss.com/unzipped-blog/tag/screened-chemistry/ (retrieved 4/11/2018)
[76] Liquid waste or sewage discharged into a municipal treatment system or body of water
[77] Quote and information about Levi's Screened Chemistry Program taken from: Robert Strand and Martin Mulvihill (2016) "Levi Strauss & Co.:Driving Adoption of Green Chemistry" Berkeley Haas Case Series, July 15, 2016. levistrauss.com/wp-content/uploads/2016/11/UC-Berkeley_Haas-Case-Study_Driving-Adoption-of-Green-Chemistry.pdf (retrieved 4/11/2018)

experimenting with laser systems made by Spanish firm Jeanologia[78] as an alternative to traditional chemical bleaches. Working together, they optimized the laser system to work with washed garments resulting in a new, more responsive, more sustainable workflow currently being scaled in partner factories. This new approach to denim finishing has cut down the chemicals needed for finishing from thousands to tens.

Participating in the Innovation Ecosystem

Brands and retailers can participate in the innovation ecosystem by partnering with innovative companies to jointly develop and scale safer chemistry and materials; engaging with accelerators and incubators; and investing in innovative companies or early stage venture funds.

Good Practices in Setting Up Partnerships Between Brands and Innovative Young Companies.

- Start small and build. Starting with a smaller demonstration project helps validate the technology and demand, to help gain traction within other parts of the organization.
- Create a roadmap for what the relationship will look like after milestones are met.
- Establish a single point of contact the within the brand.
- Choose projects that excite designers and customers.
- Engage outside funders and share details with outside investors.

Active partnerships—between brands and retailers on one side and young innovative companies on the other—have the potential to bring new products or technologies to market that have both new performance and the potential for radical changes to the textile apparel sector.

To manage relationships with young companies, brands and retailers often create internal teams that combine different business and technical expertise, allowing them to evaluate new materials and technologies. These teams also sometimes act as concierges for the young innovative companies, connecting them to other relevant internal teams.

Engaging with innovative companies allows brands to stay up-to-date with innovation developments and provides valuable feedback to the innovators and entrepreneurs. Once innovations reach certain levels of technical and business validation, brands and innovators may enter joint development relationships. This allows brands to develop a deeper, hands-on understanding of a technology and can lead to purchase orders and/or more advanced collaboration.

Active partnering with innovative companies can also signal demand for innovation to other parties such as investors or existing suppliers, and can also provide startups with key technical and business insights that may help them further develop their new technologies. When working with young companies, it is critical to create relationships that are mutually beneficial and to recognize the limitations created by differences in scale and resources.

[78] jeanologia.com/aboutjeanologia/ (retrieved 4/11/2018)

The collaboration between Marmot Mountain Works (Marmot) and Green Theme International (GTI) is a good example of an early-stage partnership between an established brand and a young innovative company. GTI is commercializing a waterless durable water repellency finishing technology that does not use fluorinated chemistry and is more durable than the existing fluorinated chemistry, while providing comparable or better performance. Marmot saw the potential for GTI's chemistry to improve the sustainability and performance of their rain jackets. The initial pilot project between Marmot and GTI used GTI's waterless finishing process for a few of Marmot's rain jackets (Phoenix, Eclipse and Celeste). These jackets were launched in January 2018 in outdoor retailer REI and on Marmot's website. If the pilot project is successful, Marmot may expand the number of garments that use GTI's technology.

Patagonia is a recognized sustainability leader in the outdoor apparel and equipment sector, and has been adopting safer chemistry and more sustainable materials. Patagonia does this by using all the strategies described: transparency, M/RSLs, supply chain management, design phase screening, partnering, and engaging with the innovation ecosystem.

Patagonia has the unique ability to partner with emerging technology companies throughout their growth and development by leveraging investment capital through Tin Shed Ventures, Patagonia's venture arm. Patagonia's materials innovation team also works directly with innovative companies to develop safer chemistry solutions and form supply chain partnerships.

One example of a young innovative company partnered with Patagonia is Bureo, that turns recovered fishing nets into equipment like skateboards and sunglasses. Patagonia's Tin Shed Ventures made an equity investment in Bureo, and Patagonia also helped them validate supply chain impacts. Bureo products are now in Patagonia stores.

Another example is Beyond Surface Technologies, a textile finishing supplier that uses bio-based chemicals in all their formulations for durable water repellants, wicking agents, quick-dry coatings and softeners. Patagonia's Tin Shed Ventures invested in Beyond Surface technologies, and the new chemistries are currently being piloted in Patagonia's apparel.

Accelerators, incubators and early-stage investment funds like Safer Made[79] provide platforms and structures for young companies to share information about their new technologies and products, as well as opportunities for brands to keep up-to-date with new technologies and to share their innovation priorities. This two-way collaboration can guide the development of new technologies to make them more compatible with industry needs, and accelerate their deployment. Table 15 ***(next page)*** shows examples of accelerators, incubators and investment funds relevant to the textile and apparel sector.

[79] www.safermade.net/

COMPANY	ACCELERATORS, INCUBATORS AND INVESTMENT FUNDS
Alante Capital	Venture capital fund focused on sustainable apparel.
Eureka Innovation Lab	Levi Strauss' testing and development facility that pilots sustainable technologies and supports entrepreneurs through their Collaboratory program.
Fashion for Good	Fashion for Good convenes brands, producers, retailers, suppliers, non-profit organizations, innovators and funders in a global platform for innovation.
Future Tech Labs	Fashion innovation platform with staff in Russia, Europe and the U.S.
Green Chemistry and Commerce Council	Nonprofit organization that drives the commercial adoption of green chemistry across different industries.
Hydra Ventures	The corporate venturing arm of Adidas supporting technology that can improve product performance, customer experience and sustainability for Adidas products.
New York Fashion Tech Labs	Nonprofit program co-founded by Springboard Enterprises and fashion retailers to support women-led companies that have developed innovations at the intersection of fashion, retail and technology.
Safer Made	Venture capital fund that invests in teams that bring safer products and technologies to market (and the authors of this report).
The H&M Global Challenge Award	Accelerator program to promote circular innovation in the textile and apparel sector.
Tin Shed Ventures	Patagonia's investment arm supporting companies and projects that improve the environmental performance in the outdoor apparel and equipment space.

TABLE 15
Accelerators, Incubators, and Investment Funds Active in the Textile and Apparel Sector
Source: Safer Made 2018.

Fashion for Good (fashionforgood.com) stands out within the textile and apparel innovation ecosystem as an evolved innovation platform that includes an Accelerator program run in collaboration with Plug and Play, a Scaling Programme that supports young companies past the proof-of-concept phase, and an investment fund called the Good Fashion Fund.

Innovative companies that participate in the Fashion for Good programs receive support in the form of mentorship, training, exposure to brands and retailers, and potentially funding. Brands, retailers and suppliers that participate in Fashion for Good come together around an innovation agenda for the sector and get exposure to the latest technologies and innovation.

Fashion for Good operates from its hub in the heart of Amsterdam, hub that also houses a co-working space bringing organizations like Sustainable Apparel Coalition,[80] ZDHC[81] and IDH[82] under one roof, and also an exhibition open to public. Fashion for Good hosts regular events that convene leading brands, retailers, suppliers, non-profit organizations, innovators and funders working together to change the way we make, use, and dispose of our clothes, for good.

[80] apparelcoalition.org (retrieved 5/16/2018)
[81] roadmaptozero.com (retrieved 5/16/2018)
[82] idhsustainabletrade.com (retrieved 5/16/2018)

SECTION 5

Conclusions

Conclusions

Our goal with this report is to help demystify the challenges and find the right language to facilitate conversations about textile and apparel safer chemistry innovation. We try to bridge the gap between sustainability in a broad sense and the detailed technical challenges related to chemistry in the textile and apparel industry.

Increasing consumer awareness, pressure from advocacy groups and the development of M/RSLs provide brands and their suppliers with motivation and tools to remove harmful chemicals from products and production processes.

M/RSLs are now established tools that chemicals policy brands and retailers use in their work with suppliers, to remove or reduce the use of chemicals of concern. Apart from being supply chain management tools, M/RSLs are also innovation tools by providing the starting point for safer chemistry innovation.

> ***We believe that the best way to eliminate hazardous chemicals is to focus on developing new chemistry and materials that provide superior performance without relying on hazardous chemistry.***

When searching for innovation to address safer chemistry challenges, we believe in focusing on the function delivered by chemicals of concern and seeking safer ways to deliver that function, rather than trying to find specific substitutes for chemicals of concern.

We believe that the best way to eliminate hazardous chemicals is to focus on developing new chemistry and materials that provide superior performance without relying on hazardous chemistry.

By connecting functional aspects to the universe of potential solutions we defined five Innovation Areas: New Materials, New Safer Chemistries, Waterless Processing, Fiber Recycling and Supply Chain Information Management Tools, each with several Innovation Sub-areas.

Within each Innovation Area we highlighted work by both startups and established suppliers to bring safer chemistry and materials to market. The innovation activity will continue to grow and change with the needs of the textile and apparel sector.

We encourage brands and supply chain partners to get involved with one or more of the initiatives highlighted in this report including Fashion for Good and ZDHC group that seek to help scale safer chemistry in the textile, apparel and footwear sectors through collaboration.

Bringing new safer technologies to market within the textile and apparel industry takes both collaboration and capital. We are grateful to all the brands, entrepreneurs and supply chain partners who spoke to us about their work and who continue to share insights and connections to interesting new companies. We look forward to continuing the conversations, and invite anyone interested in supporting companies developing the next generation of safer chemistry and materials to contact us: safermade.net/contact-us. ■