Cradle to MATE: MATE the Label Product Chemistry Hotspot Analysis to Reduce Human Health and Ecological Impacts

FINAL REPORT

March 24, 2023

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This Bren School of Environmental Science & Management Masters group project was completed by the project team under the direction of faculty advisor, Dr. Patricia Holden. It was reviewed by University of California faculty and then submitted to the Bren School for approval. This report serves as partial fulfillment of duties required for all team members to earn the degree of Master in Environmental Science and Management (MESM).

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1. Executive Summary

Cradle to MATE was designed to help MATE the Label understand the human and environmental toxicological impacts of the fibers they use in their products and comparatively rank them with other fibers commonly used in apparel. The fibers included in this study are conventional cotton, organic cotton, lyocell, linen, spandex, and polyester. This project looks at chemicals used in upstream supply chain processes for each fiber from raw material cultivation through manufacturing.

This report contains eight sections. **Section 1** comprises this introduction. **Section 2** summarizes the project's key objectives. **Section 3** discusses the project's significance and why it was of value to pursue. **Section 4** contains background information essential in the development of our project, including a summary of key data sources and a literature review. **Section 5** describes the methodology developed using R and ToxPi to analyze and rank fiber chemistry data. **Section 6** discusses the results and **Section 7** provides a discussion of the project's recommendations and opportunities to improve this analysis in the future. Finally, **Section 8** provides the project conclusion. References and appendices are provided at the end of this report.

Key findings include the following fiber ranking of chemical hazard, from most concerning to least concerning: 1) conventional cotton, 2) linen, 3) polyester, 4) organic cotton, 5) spandex, and 6) lyocell. The most concerning supply chain processes by fiber are: the farming (fertilizers, pesticides and insecticides) process for both organic and conventional cotton and linen; the pre-polymer solution production process for spandex; the yarn spinning process for polyester; and the fabric knitting process for lyocell. The top five most concerning chemicals in our analysis, across all fibers, are the following pesticides and insecticides: 1) phorate, 2) chlorpyrifos, 3) lambda-cyhalothrin, 4) alpha-endosulfan, and 5) monocrotophos. Because linen is the most concerning fiber that MATE uses in their products, exploring organic linen is recommended. Additionally, given that MATE's most concerning chemicals fall within the Raw Materials Cultivation and Extraction phase of its fiber production, the project team recommends that MATE work with its farmers and supply chain partners to gain better visibility into which chemicals and practices are actually being used in the furthest step of its supply chain. Finally, the project team hopes that this research can help move the apparel towards more transparency in its production processes by identifying existing data and information gaps.

The project team is made up of five UCSB Bren School Master of Environmental Science & Management students in the class of 2023: Sarah Hamilton, Margaret Hammond, Carleigh Osen, Alexandra Setmajer, and Caroline Shepherd. This project would not be possible without the help of our advisors, who we thank for their continuous support, resources, and feedback. This includes our faculty advisor, Professor Patricia Holden PhD (Bren), and our four external advisors: Professor Arturo Keller PhD (Bren), Professor David Volz PhD (University of California Riverside), Professor Ronald Tjeerdema PhD (University of California Davis), and Todd Copeland (Industry Expert). The team would also like to thank the project client, MATE the Label, for their willingness to participate in this Group Project. In particular, the project team would like to thank Tyler Cobian (MESM '20), Sustainability Manager at MATE the Label, for the resources and guidance he provided. Finally, the project team would like to thank the following resources for their help in providing additional information integral to this project: Sean Kerr, Satie Airame, Aleah Van Woert, Mike Schaadt, Renee Hackenmiller-Paradis; ToxNot, Bluesign, & MADESAFE representatives; MATE's suppliers: Laguna Fabrics, Harry's Dye & Wash Inc., and MOLA Inc.; and Daniel Rosen, CFO of MATE the Label, who assisted the project's summer internship.

2. Objectives

The main objectives of this project are to:

1. Create an inventory of chemicals used in MATE's upstream supply chain (where 'upstream' is defined as raw material extraction including fiber cultivation, through product manufacturing). This includes chemical inputs such as common pesticides used in farming cotton to chemicals used when fabrics are prepared for color dying.

2. Identify chemicals categorized as known carcinogens, endocrine disruptors, or listed on chemicals of concern and other hazard lists.

3. Recruit, adopt or otherwise develop a method for evaluating MATE's fabrics for the impacts of their supply chain chemicals, then evaluate the chemicals inventoried for hotspots to human health and ecological impacts.

4. Rank the impact of MATE's four fabrics (organic cotton, TENCEL™ Lyocell (lyocell), linen and spandex) along with conventional cotton and polyester, resulting in an evaluation of which fabrics from MATE's supply chain have the highest burden on natural ecosystems and human health.

5. Identify, assess and provide recommendations to MATE for opportunities to collaborate with suppliers to reduce chemical impact of the most severe ecological and human health impacts of their clothing production process.

3. Significance

3.1 The Problem

The fashion industry generates US$620 billion in revenue annually.[1] As MATE states in their 2020 Impact Report, “fashion is not simply an industry but an ecosystem–an inheritance from generations before and one for generations to come”.[2] Fashion has coevolved with human society, but its industrialization has also made it one of humanity’s greatest problems. Statistics from the United Nations Environment Program found that the fashion industry accounts for 10% of annual global carbon emissions and uses 93 billion cubic meters of water annually. Fashion is also a major source of chemical pollution and trash, accounting for approximately 20% of worldwide wastewater, 30% of ocean microplastic pollution, and billions of garments in landfills and littering the landscapes of developing countries.[3] However, the full extent of the environmental, health and social impacts of the fashion industry is vastly misunderstood due to a lack of research. The reputable research that does exist on microfiber pollution, countries refusing second-hand apparel, and worker pollution exposure make it clear that fashion’s impact is felt at every step of its supply chain.[4] As demand for fashion continues to increase, reducing the impacts of production is a necessary change to achieve global climate and health goals.

Textile fibers create pollution at every step of production—from the farms that grow cotton to the cutting and sewing factories that shape and construct the final product—and the people working in these areas are most exposed to harmful chemicals and pollutants used in the industry. As consumers grow more and more aware of the environmental impacts of their products, companies must increase transparency and create products in a more socially and environmentally responsible way.

Before the real impact of the fashion industry can be understood and acted on, more data must exist. This project aims to analyze MATE’s upstream supply chain from raw material extraction through manufacturing to understand and compare the toxicological burdens of supply chains for key fabric types. This research and comparison will provide recommendations for where MATE should focus its effort to find less burdensome means of production to realize the highest impact improvements. It also will be available as a resource for other apparel brands and non-governmental organizations (NGOs) to better understand the impacts and alternatives available to apparel supply chains. By creating more accurate and accessible data on the chemistry involved in the production of MATE the Label’s clothing, MATE and the apparel industry can take steps to improve their environmental burden.

3.2 About MATE the Label

MATE the Label (MATE) is an organic essentials apparel company based out of Los Angeles, California. MATE’s mantra is “Dress Clean”, and their mission is to “provide people everywhere

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[1] “Biggest Companies in the Global Apparel Manufacturing Industry.”

[2] “MATE the Label | Dress Clean®.”

[3] “How Much Do Our Wardrobes Cost to the Environment?”

[4] Henry, Laitala, and Klepp, “Microfibres from Apparel and Home Textiles”; Banigan, “East Africa Doesn’t Want Your Hand-Me-Downs”; Singh and Chadha, “Textile Industry and Occupational Cancer.”

with essentials that are clean from seed to skin".[5] To achieve this, MATE's products are created following the "MATE Eight" approach: Clean chemistry free of known carcinogens, endocrine disruptors, and other toxic chemicals; Essential clothing items made to last; Organic yarns and dyes to minimize impacts throughout the product life cycle; Ethical practices throughout the supply chain; Women-Centered products for all stages of life; Plastic-Free products; Circular products that are collected for recycling and are actually recycled; and Locally made in LA. MATE is far along on the sustainability spectrum, as evidenced by their 2020 Impact Report, and has fully traced their supply chain to Tier 2 suppliers (cut and sew, dye house, fabric mills), with some products traced to Tier 3 (yarn mills). MATE's previous efforts and company commitment to health and sustainability make them well positioned to support and act on the recommendations resulting from this group project.

MATE's choices appeal to their workers, customers, environmental stakeholders, and the apparel industry at large. This project will help MATE take the next step in their sustainability journey by highlighting opportunities to improve their supply chain practices and help them answer customer and stakeholder questions regarding potential health and ecological impact concerns related to the chemicals that are used in the making of MATE's products.

3.3 Project Audience

This project's broader audience includes other apparel brands and industry groups working to improve practices in the apparel industry. The outcomes of this project, including the method used to inventory and assess chemicals, will be available as a resource for other apparel brands and NGOs to better understand the impacts and alternatives available to apparel supply chains. By creating accessible data on the chemistry involved in the production of MATE the Label's clothing, MATE and the apparel industry can take steps to reduce their environmental burden.

[5] https://matethelabel.com/pages/about

4. Background

This project required the project team to gather data from multiple sources and utilize tools to analyze and examine the chemicals used in the production of organic cotton, conventional cotton, linen, polyester, spandex, and lyocell fabrics. The research team used Google Drive, RStudio and GitHub, ToxNot, and ToxPi as tools throughout the project. The Chemical Inventory was populated using the reputable chemical databases of PubChem and CompTox. After completing the Chemical Inventory (Appendix A), each fabric and tier could be analyzed.

In this section, data collection and tools used will be explained, followed by an extensive literature review. The compiled literature review provides additional information on each fabric, eco-certifications relevant to the client, textile supply chain tiers, Restricted Substances Lists (RSLs), Regulatory Hazard Lists (RHLs), textile allergens, and ToxPi chemical prioritization.

4.1 Literature Review

The project team conducted an in-depth literature review on topics pertinent to the apparel industry. These include the six fibers assessed in this project, apparel industry eco-labels, chemical hazard vetting practices, Restricted Substances Lists, Regulatory Hazard Lists, and chemistry innovations for reduced toxicity in app in the apparel industry.

The client shared scientific articles published in peer-reviewed journals focusing on the mechanics of chemical runoff from textile washing and dyeing, the danger of microplastics and microfibers, and select lifecycle analysis studies on conventional cotton. The project team collected information from sustainable fashion-centric books focusing on the definition of “sustainable fashion”, the different eco-certifications within fashion, case studies regarding certain companies’ experience with sustainability, and the pros and cons of each type of commonly used fabric.

Next, the team studied the manufacturing processes behind each fabric type and identified the potential chemical inputs used at each stage of production. In addition to the resources provided by the client, the project team conducted additional scientific and gray literature reviews of each fabric type to understand the potential chemical inputs at each production stage. The following sections provide a comprehensive summary of the research conducted for this project.

4.1.1 Textile Supply Chain Essentials

The project team mapped MATE’s upstream supply chain across four tiers, in alignment with industry standards. See Appendix B for the full mapping. The following sections provide a brief overview of each tier in the typical textile supply chain, specifically accounting for the five fibers included in this project.

Tier 1

Tier 1 of the textile supply chain takes place at the end of the textile production process. This final stage is where a product is cut and sewn, washed or spot cleaned, and then prepared for shipment. While a spot treatment step may happen here, no chemicals are used in this step in

MATE's supply chain and each textile is treated similarly. There *are* energy and labor inputs associated with Tier 1, but these aspects are not analyzed in this report.[6]

Tier 2

Chemicals applied in Tier 2 typically involve bleaching and scouring, followed by dyeing. All fibers analyzed in this report except spandex require some type of bleaching or scouring before being dyed. Tier 2 may also include chemical finishing treatments in the form of waterproofing, stain resistant treatments, and odor reducing treatments. As MATE the Label does not use any finishing treatments, these chemicals have been left out of this analysis and are not included in the Chemical Inventory.[7]

Tier 3

Fibers are spun into thread or yarn in Tier 3. For polyester and spandex, this requires melting and spinning a man-made fiber, or a synthetic pellet into fibers and yarn before knitting and weaving. Cotton (organic and conventional) and linen fibers are spun into yarn before being knit or woven into fabric. Lyocell produces wood pulp which is then spun into fiber that can be knitted or woven into fabric. Chemicals used in Tier 3 processes typically include solvents for wet spinning that allow fibers to be spun into soft, pliable thread. Some threads and fibers are bleached at this stage.[8]

Tier 4

Cotton, linen, and lyocell plants are grown and harvested in Tier 4. Polyester and spandex must be created from crude oil extracts before they can be turned into plastic pellets, which can be spun into fiber. Tier 4 is the farthest tier from the consumer and finished products. Most chemical inputs for natural fibers come from pesticides and herbicides associated with farming in Tier 4.[9]

4.1.3 Textile Fibers & Manufacturing Processes

Each fiber and fabric has varying production and manufacturing processes. The project team studied each fiber individually to understand which chemicals are commonly used in the production of the fibers. The following sections provide a literature review for each fiber analyzed in this project.

Organic & Conventional Cotton

Cotton is a natural fiber produced worldwide with wide-ranging application not only in textile manufacturing but also within other industries. As a textile, cotton is versatile with beneficial

[6] "VF Corporation Launches Enhanced Product Traceability Mapping Data Providing Unprecedented Industry Supply Chain Transparency."
[7] "VF Corporation Launches Enhanced Product Traceability Mapping Data Providing Unprecedented Industry Supply Chain Transparency."
[8] "VF Corporation Launches Enhanced Product Traceability Mapping Data Providing Unprecedented Industry Supply Chain Transparency."
[9] "VF Corporation Launches Enhanced Product Traceability Mapping Data Providing Unprecedented Industry Supply Chain Transparency."

properties like moisture and heat conduction.[10] Within the scope of our project, cotton fabric production can be bifurcated into an agricultural phase and a textile production phase. The agricultural phase includes cotton cultivation, harvesting, ginning, and baling.[11] The textile production phase begins at spinning of the fiber from bales into yarn and includes the production of cotton fabric, the cut-and-sew step of garment production, and ends before the garment reaches the customer.[12]

Primarily grown in countries characterized by a warm, humid climate, cotton fibers are sourced from the plant genus *Gossypium*.[13] Given its globalized cultivation, wide breadth of use-cases, and the technical nature of its cultivation, cotton production has been historically characterized by heavy chemical pesticide, insecticide, and fertilizer use.[14] Within the agricultural phase, major chemical inputs include pesticide, insecticide, and fertilizer application during cultivation. Exposure to these chemical inputs are borne primarily by the cotton farmers and field workers at this stage.[15] However, the extent to which synthetic chemical use in the cultivation stage impacts workers at lower tiers in the production process or the end consumer is unclear.[16]

MATE incorporates organic cotton into almost every product line, barring the linen collection. MATE sources its cotton from Maharashtra, India; therefore, while cotton is a global crop, the project team aimed to find agricultural data from Maharashtra or Central India where possible. Among other environmental goals, organic cotton production seeks to reduce the chemical impacts of conventional cotton cultivation by limiting the use of synthetic chemicals.[17] Thus, alternative pest management and fertilization practices are common in organic cotton production. Examples of application-based strategies for fertilization include livestock and other animal manure. Additionally, naturally-derived insecticides may also be applied in organic cotton farming.[18]

Once mature, the cotton plant is mechanically harvested and the fibers move to the gin, which mechanically separates the cotton fiber from the seed and forms the fibers into bales for shipping.[19]

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[10] Kozlowski, *Handbook of Natural Fibres, Volume 1 - Types, Properties and Factors Affecting Breeding and Cultivation*.

[11] Jewell, "LCA UPDATE OF COTTON FIBER AND FABRIC LIFE CYCLE INVENTORY."

[12] Jewell.

[13] Kozlowski, *Handbook of Natural Fibres, Volume 1 - Types, Properties and Factors Affecting Breeding and Cultivation*.

[14] Blackburn, *Sustainable Textiles - Life Cycle and Environmental Impact*; Delate, Heller, and Shade, "Organic Cotton Production May Alleviate the Environmental Impacts of Intensive Conventional Cotton Production"; Mancini et al., "Acute Pesticide Poisoning among Female and Male Cotton Growers in India."

[15] Blackburn, *Sustainable Textiles - Life Cycle and Environmental Impact*; Mancini et al., "Acute Pesticide Poisoning among Female and Male Cotton Growers in India."

[16] Blackburn, *Sustainable Textiles - Life Cycle and Environmental Impact*; Casadesus-Masanell et al., "Households' Willingness to Pay for 'Green' Goods."

[17] Blackburn, *Sustainable Textiles - Life Cycle and Environmental Impact*; Delate, Heller, and Shade, "Organic Cotton Production May Alleviate the Environmental Impacts of Intensive Conventional Cotton Production."

[18] Blackburn, *Sustainable Textiles - Life Cycle and Environmental Impact*.

[19] "Cotton: From Field to Fabric- Ginning"; Seagull and Alspaugh, *Cotton Fiber Development and Processing an Illustrated Overview*.

In the cotton textile production phase, chemical use varies by production tier. In yarn production facilities, the bales are deconstructed, and the cotton fibers are mechanically cleaned again and carded, or aligned and condensed into "sliver", to prepare for yarn spinning.[20] Lubricants may be applied at the yarn spinning step for some methods of spinning.[21]

After spinning, the cotton yarn may be either dyed (yarn dyed) or formed into fabric and then dyed (piece dyed).[22] Fabric can be produced by weaving or knitting the cotton yarn.[23] The research team chose to focus on the knitting process for this project, as MATE's organic cotton is a knitted fabric.

Prior to dying, the cotton yarn or fabric goes through a prepare-for-dye step, where scouring and mercerization agents and bleaching solutions are applied to purify the fiber and make it more absorbent.[24] After the purification process, the cotton yarn or fabric is dyed and finished. The finishing step can often involve the application of finishing agents, such as those that make the fabric crease-resistant, water-repellent, or antimicrobial.[25] However, MATE does not use finishing agents in their products.

The final step in the cotton textile production phase is cut-and-sew of the fabric to produce a completed garment. This step does not appear to involve chemical inputs. There may be a garment washing and spot cleaning step before the completed garment is shipped, but the chemicals used in this step are not readily available in the literature.

Linen

Linen is an ancient textile that has been used for thousands of years. A few main benefits of linen, sourced from the flax plant, is its limited use of pesticides and herbicides—compared to conventional cotton—and low water use compared to similar textiles.[26]

Given linen's long history of use, there is a considerable amount of literature detailing how flax is turned into linen fiber, and then spun into yarn, in a step-by-step process. First, retting is required to break down the pectin material, degrading the outermost layers of the flax plant to get to the fiber inside. After retting, spinning the flax fiber into linen requires the addition of hot water to draw out the fibers into yarn. Wet spinning produces softer, finer yarns than dry spinning without the hot water. A range of temperatures can be used during this process, but different

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[20] Seagull and Alspaugh, *Cotton Fiber Development and Processing an Illustrated Overview*.

[21] IARC Working Group on the Evaluation of Carcinogenic Risks to Humans, *Some Flame Retardants and Textile Chemicals, and Exposures in the Textile Manufacturing Industry.*

[22] "Cotton: From Field to Fabric-Dyeing, Printing & Finishing"; Cotton Incorporated, "Life Cycle Assessment of Cotton Fiber & Fabric."

[23] Cotton Incorporated, "Life Cycle Assessment of Cotton Fiber & Fabric."; Jewell, "LCA UPDATE OF COTTON FIBER AND FABRIC LIFE CYCLE INVENTORY"; Seagull and Alspaugh, *Cotton Fiber Development and Processing an Illustrated Overview*.

[24] Cotton Incorporated, "Life Cycle Assessment of Cotton Fiber & Fabric."; IARC Working Group on the Evaluation of Carcinogenic Risks to Humans, *Some Flame Retardants and Textile Chemicals, and Exposures in the Textile Manufacturing Industry.*; "Raw Cotton Processing | How Is Cotton Processed | Barnhardt Cotton."

[25] IARC Working Group on the Evaluation of Carcinogenic Risks to Humans, *Some Flame Retardants and Textile Chemicals, and Exposures in the Textile Manufacturing Industry.*

[26] Muthu et al., "Quantification of Environmental Impact and Ecological Sustainability for Textile Fibres."

temperatures can affect fiber length and strength.[27] Chemicals can be applied at this step, but is not necessary.

Pandey et al. claim that demand for natural textiles has increased, along with an increase in demand for sustainable processing of natural fibers. To account for this, “Novel Methods of Degumming and Bleaching of Indian Flax Variety Tiara” discusses several methods of flax fiber degumming to produce high quality linen, while avoiding some less environmentally friendly approaches, such as using fire to burn flax stalks, which leads to air pollution.[28]

Traditional processing of flax requires the use of alkaline media, which cleans the fiber, but also degrades it. Alternatively, enzymes can be used for degumming, which break down the gummy starches while leaving the fiber mostly intact. Common linen-processing techniques used by the Sunhemp Research Institute and other linen producers are detailed in one study, which lists all chemicals used in their linen processing.[29] This paper informed the Chemical Inventory by Fiber & Tier section for linen and can be found in Appendix A.

Although many methods of retting—a process that separates linen fiber from the flax stalk—are used around the world, water retting is recommended and has been commercially successful. MATE the Label currently uses linen processed by water retting, which has less chemical inputs than linen that goes through a chemical or enzymatic retting process. This is reflected in the Chemical Inventory (Appendix A).

Following retting, a degumming, bleaching, and scouring process occurs to clean the fibers. The clean fibers are then able to be knit or woven into high quality linen garments. Linen that does not go through a bleaching or scouring process is more suitable for rugged applications, as it produces thick, canvas-like materials. Different processes of degumming and scouring can affect the quality and feel of the final product, and the resulting fiber length and strength. It can be preferable to yield longer fibers, as it makes weaving more efficient, but methods used to produce softer linen typically reduce fiber length in the process.[30]

Lyocell

Lyocell is a type of regenerated cellulose fiber made from wood pulp, and is classified as a subcategory of rayon. Lyocell fibers are used as either staple fibers or filament fibers, and are used in a variety of product types including apparel, home textiles, medical uses, and footwear.[31]

Lyocell was first developed and manufactured as Tencel™ fiber by Courtaulds Fibers, UK, in the 1980s, but now a majority of the market share is owned by Lenzing. Lenzing is the world’s largest lyocell fiber manufacturer, supplying approximately 130,000 metric tons of lyocell fiber for the global rayon market each year (as of 2002) and 98% of the market (as of 2017).[32]

A majority of the wood used to make lyocell is sourced from sustainably managed forests that have attained FSC or PEFC certification.[33] The Federal Trade Commission defines lyocell as a

[27] Gibson, “The Function of Water in the Wet Spinning of Flax.”
[28] Pandey et al., “Novel Methods of Degumming and Bleaching of Indian Flax Variety Tiara.”
[29] Akin, “Linen Most Useful.”
[30] Pandey et al., “Novel Methods of Degumming and Bleaching of Indian Flax Variety Tiara.”
[31] “Sustainable Fiber - True Transparency | Consumer | TENCEL™.”
[32] Ozipek and Karakas, “9 - Wet Spinning of Synthetic Polymer Fibers.”
[33] “Focus Paper: Responsible Production.”

cellulose fiber that is precipitated from an organic solution in which no substitution of the hydroxyl groups takes place and no chemical intermediates are formed. The manufacturing process for lyocell fibers from wood pulp is as follows[34]:

1. Raw cellulose (wood pulp) is mixed with N-Methylmorpholine-N-oxide (NMNO) solvent, a cyclic amine oxide, and dissolved in NMNO by heating. The formed cellulose solution is called "dope."
2. A solvent spinning technique (also called dry-jet and wet-spun) is used to press the dope through a spinneret into a spin bath where regenerated cellulose fiber precipitates as the NMNO solvent is dissolved in the spin bath.
3. The formed cellulose fiber is further processed by water washing, lubricant finishing, drying, and static removal. At this stage, lyocell filament fiber is produced.

According to Lenzing, use of the NMNO solvent provides multiple benefits. First, use of this solvent results in a reduced number of processing stages required to create lyocell fibers, and Lenzing is proud they have reached almost 99% solvent recovery with this process which they are able to reuse. This results in reduced energy and water use, and only very small amounts of NMNO remain in wastewater, which is treated biologically. Second, Lenzing claims that the NMNO solvent is "non-toxic"[35]; however, the project team was unable to find any toxicological data on this solvent. Additionally, use of the NMNO process results in fiber properties unattainable by the classic production processes, including stronger dry-tensile strength than cotton and better physical, mechanical, and chemical properties than those of viscose, another type of cellulose fiber.[36]

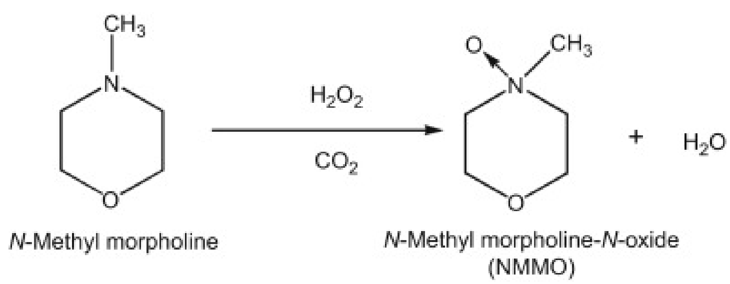

Figure A. N-Methylmorpholine-N-oxide (NMNO) solvent, a cyclic amine oxide[37]

Lyocell is valued for its properties including greater thermal stability than synthetics, soft feel and gentleness to skin, tensile strength, less shrinkage than cotton, efficient moisture absorption, and high heat resistance.[38] Lyocell won't soften or melt at high temperatures, but will decompose at very high temperatures, for which it has attained third-party certification of its biodegradability. Additionally, lyocell can be blended with other fibers to enhance the aesthetics and functionality of the final product.[39]

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[34] "Regenerated Cellulose by the Lyocell Process, a Brief Review of the Process and Properties :: BioResources."
[35] "Focus Paper: Responsible Production."
[36] Chen, "Chapter 4 - Synthetic Textile Fibers."
[37] Shabbir and Mohammad, "7 - Sustainable Production of Regenerated Cellulosic Fibres."
[38] "Lyocell, the Eco-Friendly Fiber - Advantages and Disadvantages."
[39] "Regenerated Cellulose by the Lyocell Process, a Brief Review of the Process and Properties :: BioResources."

There are several drawbacks of lyocell. First, it can be more expensive than other materials to produce, and therefore to purchase. This is because lyocell requires advanced technology to produce and the NMNO solvent is expensive. Additionally, producing lyocell can be an energy-intensive process, so the cleanliness of the energy grid where lyocell is made is important to consider. Lyocell is often blended with synthetic materials, which are not biodegradable and therefore prevent the blended fabric from being able to biodegrade. Finally, fabric made with lyocell is often somewhat delicate, and can pill with time.[40]

Spandex

Spandex, also known as Lycra and Elastane, is a long-chain synthetic polymeric fiber that allows a fiber to stretch up to 600% and recover to its original shape. MATE currently uses Spandex in its activewear line and in loungewear waistbands. Spandex was invented in 1959 by DuPont chemical company as a substitute for rubber, and trademarked as Lycra. Spandex is blended with other natural and man-made fibers such as cotton, wool, silk, and linen.[41] It can be produced from dry spun, reaction spun and melt spun techniques, all from a polyurethane spinning solution.[42] Nearly 95% of the world's spandex is made through dry spinning.[43] Spandex was originally used for women's shapewear, but has expanded into athletic wear, swimwear, and has continued to grow in use; worldwide spandex consumption and growth is 30-40% per year and is expected to keep growing.[44]

China is currently the highest exporting and producing country of spandex, likely due to the intensive process of spandex creation and the low cost of labor. Spandex creation is a seven-step process consisting of reactions, dilutions, heating, twisting, and finishing.[45] The creation of spandex is a very energy intensive process. The result is a long-chain polyglycol combined with a short di-isocyante, which contains at least 85% polyurethane.[46] Spandex contains many beneficial properties: the fabric has high breathability, high moisture-wicking abilities, and exceptionally high stretch capacity. On the other hand, spandex has low heat retention and is prone to pilling.[47]

Spandex contains multiple toxins and poses environmental harm. The most harmful chemicals found in spandex are: barium sulfate, formaldehyde, toluene-2.4-diisocyanate, methylene bisphenyl isocyanate, and hexamethylene diisocyanate. These toxins can cause hyper skin pigmentation, skin allergies, dermatitis, and respiratory sensitivity. Because spandex is a synthetic fiber that does not decompose, it presents lasting environmental harm. This includes microfiber shedding from machine washing, non-biodegradable properties, and the use of petroleum products.[48] Because spandex is woven into other fibers, there is an established recycle program for the fabric, the Global Recycle Standard, but this standard is hard to accomplish.[49]

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[40] "What Is Lyocell Fabric & Is Its Sustainability Up To Snuff?"
[41] Reisch, "What's That Stuff?"
[42] Senthilkumar, "Elastane Fabrics – A Tool for Stretch Applications in Sports."
[43] "What Is Spandex Fabric."
[44] Senthilkumar, "Elastane Fabrics – A Tool for Stretch Applications in Sports."
[45] "What Is Spandex Fabric."
[46] SMM, "Reviewing the Production Process, Physical and Chemical Properties of Spandex Fibers."
[47] "What Is Spandex Fabric."
[48] Bhalla, "Toxicity of Synthetic Fibres & Health."
[49] "Hazards of Isocyanates (TDI, MDI, HDI) In Resins, Coatings and Paints."

For our data analysis, the project team used a U.S. patent titled High Productivity Spandex Fiber Process and Product to determine the chemical composition of spandex in Tiers 3 and 4. All spandex chemicals listed in Tiers 3 and 4 are from the patent.[50] This 2003 patent from Invista North America details the creation of a commercially acceptable spandex. For the purpose of this research, the project team assumes that chemicals listed in this patent are chemicals used in the MATE supply chain. Additionally, the patent lists a variety of common chemical options the manufacturer can choose from. This allowed the project team to ensure that the analysis includes chemicals likely used in MATE's spandex.

Ultimately, spandex is necessary for MATE's clothing line to produce stretchy material needed for activewear. This is the only synthetic fiber MATE uses, but poses a large potential for environmental harm.

Polyester

Another fabric investigated in this report is polyester, also known as polyethylene terephthalate or PET, because it is widely used in the clothing industry. Polyester touts many benefits over other conventional materials, such as high breathability, high moisture wicking capability, high resistance to environmental conditions, stain resistance, and cost-effectiveness.[51] With a low cost of about $1 per pound, polyester fabric costs about $10 per yard.[52] Polyester is a polymer made primarily from ethylene, which is found in petroleum. However, polyester can also be produced from other sources that can make it biodegradable, such as cane sugar, though this is rare.[53] Polyester is commonly used as an alternative for other natural materials, for outdoor clothing, and for other products like towels, blankets, and rugs.[54] China is the largest producer of polyester and countries such as Taiwan, Korea, India, Japan, and Indonesia also manufacture large quantities of the material. Production of polyester is growing faster than any other fiber.[55] Because polyester is one of the most widely produced fabrics in the world, it is essential to understand its impact on humans and the environment.

To obtain the basic materials needed to produce polyester, manufacturers must extract crude oil and refine it into petroleum, which introduces toxins into the environment. After the production of petroleum, more refining takes place to produce ethylene, which results in more toxins being created.[56] Transforming ethylene into PET fibers results in even more harmful byproducts, as do the final steps of dying and treating the polyester fabric.

There are also social costs associated with polyester production. Most polyester producers utilize slave labor, and those who work in the polyester industry are exposed to many toxic chemicals that can cause long term health issues.[57] The use-phase of polyester is also harmful because

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[50] Seeling, Gordon, High Productivity Spandex Fiber Process and Product.
[51] "What Is Polyester Fabric."
[52] Jaffe, Easts, and Feng, "8 - Polyester Fibers."
[53] "What Is Polyester Fabric."
[54] "What Is Polyester Fabric."
[55] Jaffe, Easts, and Feng, "8 - Polyester Fibers."
[56] Ghanta, Fahey, and Subramaniam, "Environmental Impacts of Ethylene Production from Diverse Feedstocks and Energy Sources."
[57] Ghanta, Fahey, and Subramaniam.

washing and drying the fabric releases microfibers into water supplies.[58] Finally, after polyester is discarded, it can take hundreds of years to fully break down in the environment, whereas other fabrics like cotton, linen, and wool can degrade rather quickly.[59]

To determine specific chemicals used in the polyester making process, the research team first referenced the European Outdoor Group's Chemical Guide which outlined textile manufacturing processes in detail.[60] This report provided information on the general processes for polyester manufacturing and provided specific chemicals for some processes. When the report did not provide specific chemicals, the project team researched other industry sources and found the chemicals most commonly used for that specific process step. The Chemical Inventory covers all required processes with examples of commonly used chemicals at each step rather than a complete list of chemicals that could possibly be used. This analysis assumes there were no extraneous finishing processes done on the polyester because MATE does not use finishing agents on their products.

There are a few existing certifications available for polyester including Oeko-Tex Standard 100, which provides criteria for what chemicals can be used in the production of polyester, and Global Recycle Standard and Intertek which certify the recycled status of polyester. No organic certification for polyester exists because even the plant-based forms have gone through so much chemical processing that the origins of the plant material are no longer relevant.[61]

Polyester is derived from fossil fuels and results in harmful byproducts released into the environment at every step of its life cycle. Though MATE does not use polyester in its products, polyester is a useful fabric to compare others against because it is so widely used.

4.1.4 Textile-Related Allergens

Allergies to textiles present themselves in two different ways: as contact dermatitis or eczema. Contact dermatitis is the chronic or acute inflammation process of the skin caused by mechanical stimuli, such as the rubbing of a collar or scratching of a tag. Allergies to textiles have presented themselves throughout history, an example of which is the common stocking coloring allergy in the 1970s. Eczema is a medical condition that can be irritated by allergies to textiles, but less influenced by textiles. For this reason, contact dermatitis is the main concern for hypoallergenic textiles.

Common allergy-inducing textile components can be divided into 5 categories: coloring agents, finish resins, fire retardants, biocides, and metals. Disperse dye coloring agents are hydrophobic, substances with a small molecular weight that are capable of permeating through the skin. Azo dyes are the main component of coloring materials for synthetic fiber pigmentation, and are mainly composed of paraphenylenadiamine (PPD). This chemical compound is known to cause contact dermatitis or eye disorders if exposed to the eye.[62]

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[58] Hartline et al., "Microfiber Masses Recovered from Conventional Machine Washing of New or Aged Garments."
[59] Ghanta, Fahey, and Subramaniam, "Environmental Impacts of Ethylene Production from Diverse Feedstocks and Energy Sources."
[60] "EOG Chemical Guide."
[61] "What Is Polyester Fabric."
[62] Sanchez Armengol, Blanka Kerezsi, and Laffleur, "Allergies Caused by Textiles."

Finish resins are used in fiber manufacturing for anti-wrinkling properties. Formaldehyde-containing chemicals have been used since the 1920s to produce this finish, a smaller amount of chemical is used now than originally introduced. Finish resins have a two-step reaction process. The initial resin reaction conditions have a large effect on features and structure of the resin, thus impacting the possible allergy-inducing properties. Low concentration irritation is caused by friction between garment and skin and released vapor particles when a textile is worn. The most common form of irritation is the mixture of sweat leaching formaldehyde molecules from the finish resin.[63]

Flame or fire retardant finishing is often applied to clothing as a precautionary measure. The most common fire retardants are brominated flame retardants such as polybrominated diphenyl ether (PBDE) or hexabromocyclododecane (HBCD). Skin hydration and sweat production allow the absorption of these brominated flame retardants. Absorption of these chemicals can lead to migration of the compounds to lower tissue layers, causing deeper irritation.[64]

Biocides, or antimicrobial compounds, can be added to textile fibers in order to prevent asthma, eczema, or allergies. However, some biocides can trigger contact dermatitis in sensitive subjects. These biocides include triclosan, zinc pyrithione, silver particles, dimethyl fumarate, and isothiazolinones.[65]

Metals, such as nickel, chromium, or cobalt frequently cause contact dermatitis. Nickel is the most common metal allergy. Consumers can experience a "jeans-button allergy", an allergic reaction to the metal nickel found in zippers, buttons, and rivets. Nickel, chromium, or cobalt can be found in specific textile dyes. If the process is done correctly, the bonding between the dye and metal is strong enough that it does not cause allergic reactions. The allergy-inducing properties highly depend on the dying process.[66]

Hypoallergenic textiles are defined as textiles containing few allergy-producing substances. There are no federal regulations or standards for this title, and any producer may claim that their textiles are hypoallergenic. Natural colorants, extracted from plants, animals, and minerals have a lower allergenic potential than synthetic dyes, are recommended to consumers with a history of contact dermatitis and sensitivity. Most irritant dyes, such as Azo dyes, are applied to synthetic fibers.[67] Breathable, loose fiber clothing allows for higher ventilation and prevents dust mite growth. This is especially important for bed sheets, as those fabrics have a higher potential for hosting dust mites. Overall, cotton silk, and linen are more hypoallergenic than synthetic fabrics.[68]

4.1.5 Textile Eco-Certifications

There are countless eco-certifications available for every product type from food and apparel products to household cleaning products. MATE and other sustainable apparel businesses are interested in obtaining eco-certifications, as they indicate the health and sustainability of a product to the consumer. Many of these certifications are expensive and time-consuming to obtain. The project team compiled a list of common eco-certifications that are relevant to the

[63] Sanchez Armengol, Blanka Kerezsi, and Laffleur.
[64] Sanchez Armengol, Blanka Kerezsi, and Laffleur.
[65] Sanchez Armengol, Blanka Kerezsi, and Laffleur.
[66] Sanchez Armengol, Blanka Kerezsi, and Laffleur.
[67] Sanchez Armengol, Blanka Kerezsi, and Laffleur.
[68] A. Doyle and E. Feinman, "Sensitization to Dyes in Textiles and Other Consumer Products."

client and researched their meanings and, when possible, their banned or restricted chemical lists. The banned chemicals that were found in MATE's textiles are discussed in Section 7.5, while general information on eco-certifications are included below.

Cradle to Cradle

One certification that can be pursued for clothing is Cradle to Cradle. Cradle to Cradle Certified looks at the "safety, circularity, and responsibility of materials and products across five categories of sustainability performance".[69] The five categories are material health, product circularity, clean air and climate protection, water and soil stewardship, and social fairness.

For material health, the company must do a detailed analysis of all ingredients in their products, identify which components are biodegradable and which are not, verify that the ingredients are not on Cradle to Cradle's banned substances list, and assess the materials' toxicity. For product circularity, the company must assess what portion of their product is recyclable or compostable and develop a material recovery strategy for the portion that is not. For clean air and climate protection, the company must quantify the energy use (and sources) of their product and can earn more points for procuring more renewable energy or offsetting some portion of the emissions. For water and soil stewardship, the company must create guidelines for how they handle water, obey local water regulations, analyze water scarcity and sensitive ecosystems near their facilities, and determine how much water they use. They can earn more points in this category by assessing process chemicals and proving their effluent is safe. Finally, for social fairness, the company must perform a self-audit of their operations and make a strategy for improving in regard to protecting human rights. They can earn more points for performing material-specific or issue-related audits, getting a third party certification, or investigating fairness in their supply chain.

At the time of writing this report, there are 50 Cradle to Cradle certified apparel products, most of which are denim or cotton.[70] All of MATE's final products would be eligible for certification, as well as any materials that are used to produce the final product.

MADE SAFE

MADE SAFE certifies products that are healthy for humans and ecosystems. Products submitted to MADE SAFE are first screened for over 6,500 banned chemicals before undergoing a rigorous process to become certified. The banned list of chemicals was previously published on the MADE SAFE website, but has since been removed. Prior to its removal, the project team reviewed the banned list and compared it to the chemicals found and reported in the Chemical Inventory (Appendix A), and chemicals found on the Made Safe banned list are located in Section 6.3, Table 14.

This certification screens for all known or probable carcinogens, endocrine disruptors, toxins, hazardous flame retardants, high-risk pesticides, toxic solvents, and volatile organic compounds (VOCs). The certification refers to its method of restricting chemicals as an "ecosystem approach" designed to protect the environment from known and suspected harms. MADE SAFE takes a

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[69] "Home - Cradle to Cradle Products Innovation Institute."
[70] "Product Registry - Cradle to Cradle Products Innovation Institute."

proactive approach to limit substances that have the potential to cause harm—even banning chemicals before government agencies—making it a very stringent certification.[71]

Global Organic Textile Standard

The Global Organic Textile Standard (GOTS) is an organic textile certification that encompasses both environmental and social standards throughout the textile and apparel manufacturing supply chain.[72] GOTS certification is centered around four key features: organic fibers, ecological and social criteria, third-party certification, and all processing stages. To use a GOTS label, a product must contain at least 70% certified organic fiber, per the International Federation of Organic Agriculture Movements (IFOAM) Family of Standards.[73] This type of GOTS label specifies the percentage of the product that is made with organic fibers. GOTS certified products containing 95% or more organic fiber are labeled "organic". Additionally, depending on the specific standards where production occurs, a product may be labeled "organic in conversion" to support farmers with converting to organic practices over a 3 year period.[74] Third-party GOTS-accredited Certification Bodies audit and monitor GOTS certified production processes throughout a product's supply chain.[75]

Bluesign

Bluesign aims to "unite the entire textile value chain to reduce impact on people and the planet" through a focus on sustainable textile chemistry. They offer several eco-labels, including Bluesign Product, which applies to textile products such as apparel and home goods, and Bluesign Approved, which applies to textile components or chemicals that fully meet Bluesign's criteria. Bluesign also offers services to help brands, retailers, chemical suppliers and manufacturers improve the sustainability of their products and practices to achieve compliance with their eco-labels.[76] Chemicals used in Bluesign products must undergo an assessment that looks into existing regulations banning or restricting the use of the chemical, Globally Harmonized System (GHS) classifications, air emissions data, 'additional' environmental parameters, occupational health & safety limits, and consumer health & safety limits to determine if the chemical should be approved ('blue rated'), approved with some restrictions ('gray rated'), or restricted from use in Bluesign products ('black rated').

For a product to use the bluesign eco-label or trademark, the trademark user must have passed the Bluesign company assessment, become an official bluesign system partner, be authorized to use the label and trademark in writing by Bluesign, and maintain a strong quality management system to manage their supply chain and verify supplier compliance with the program. The trademark user must ensure and document that 90% or more of the textiles it uses and 30% or more accessories it uses in labeled products are Bluesign Approved. Compliance is monitored and enforced by a re-assessment with Bluesign every 3 years, regular reporting, spot tests of labeled products, and unannounced company assessments.[77]

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[71] "MADE SAFE a Program of Nontoxic Certified (NTC)."
[72] "Philosophy - GOTS."
[73] "IFOAM Family of Standards | IFOAM."
[74] "Organic Fibres - GOTS."
[75] "Third-Party Certification - GOTS."
[76] "Bluesign® - Solutions and Services for a Sustainable Textile Industry."
[77] "Bluesign Criteria for Bluesign Products."

Oeko-Tex

Oeko-Tex is a standard for any textile or leather good. Oeko-Tex tests for harmful chemical substances in the production process, low environmental impact, and sustainable operations throughout the supply chain.[78] There are 5 Oeko-Tex certifications: MADE IN GREEN, STANDARD 100, LEATHER STANDARD, STeP, ECO PASSPORT, and RESPONSIBLE BUSINESS. STANDARD 100 certification covers raw, semi-finished and finished products at all processing levels. This certification is focused on the development of methods for testing pH, dangerous substances such as heavy metals, toxic dyes, crop protection substances and carcinogenic substances. The certification is valid for 1 year and companies must reapply every year. The certification is granted on a product level.

MADE IN GREEN holds the same process as STANDARD 100, but includes certifications focused on facility and employee safety. Oeko-Tex facility and employee certification falls under Oeko-Tex STeP (sustainable textile production). To receive a STeP certification, the company must prove to have transparent and continuous improvement of sustainable production and working conditions. This certification is granted for facilities, not products.

4.1.6 Restricted Substance Lists

ToxNot, introduced in Section 4.1.1., provided the project team with a list of chemicals appearing on RSLs. These lists are a common first-step in working toward an eco certification. Products or companies that use any chemicals on a restricted substance list will not be eligible for certification. In addition to the RSLs provided by ToxNot, the research team researched several more RSLs related to eco certifications relevant to MATE and the apparel industry. When adding another eco certification RSL, the project team compared the completed chemical inventory to the banned substance list provided by the eco certification. If any banned or restricted chemicals were found in MATE's chemical inventory, it indicates that MATE would not be able to obtain that certification at present. A complete list of all RSLs analyzed against key chemicals can be found in Table 14, and details regarding each RSL is located in Appendix C.

4.1.7 Regulatory Hazard Lists

While RSLs are mostly comprised of eco certifications, RHLs are often created and published by government agencies. These lists, also identified by ToxNot, ban chemicals for a variety of reasons including chemicals that are workplace hazards, carcinogens, suspected carcinogens, endocrine disruptors, suspected endocrine disruptors, or are harmful to the environment. Each chemical in the chemical inventory was compared against these RHLs. This data can be found in Table 15, while general information on the lists is located in Appendix D.

4.1.8 Chemical Prioritization using ToxPi

ToxPi has been used in a variety of research applications, including ranking the toxicity of landfill pollutants, prioritizing contaminated groundwater sites for remediation, ranking and predicting

[78] "OEKO-TEX® - Tailor-Made Solutions for the Textile and Leather Industry."

acute pesticide toxicity, and profiling potential endocrine disruptors.[79] The application of ToxPi in this project's methodology is closely informed by the work of Rogers et al., in which the researchers conducted a literature review to compile a list of landfill pollutants, collected chemical information from toxicology and chemical databases for each chemical by CAS RN, used ToxPi to rank those pollutants, and cross-referenced the highest ranking pollutants to relevant regulatory hazard lists. Our methodology differs in the data types used in the ToxPi analysis. Additionally, the application of ToxPi in the apparel industry is not widespread or well-known. The analysis herein aims to demonstrate the potential utilization of ToxPi as a toxicological assessment tool in the broader apparel industry.

4.1.2 Water Impacts in the Apparel Industry

Water Impacts of Textile Manufacturing

The dyeing and finishing phases of the clothing production process result in large amounts of harmful effluent, with one estimate stating that 12-15% of dyes are released into the environment as effluent.[80] This effluent can result in increased biological and chemical oxygen demand, increased total dissolved solids, impaired photosynthesis, bioaccumulation, and increased toxicity.[81]

Quantifying the impacts of this effluent is a difficult process requiring a thorough understanding of chemical inputs, interactions, and impacts on receiving water bodies. One paper outlined the following general process for determining the environmental impact of clothing dyes:[82]

1. Classify the dyes being used to better understand their composition and properties.

2. Determine the application method for the dyes to determine the quantity and pathway of effluent.

3. Determine the potential hazards of the effluent (how it may affect turbidity, odor, noise, temperature, pH, etc.). This may require testing effluent wastewater for parameters such as color, biological oxygen demand (BOD), chemical oxygen demand (COD), dissolved oxygen (DO), total dissolved substances (TDS), total suspended solids (TSS), electrical conductivity (EC), and pH.

4. Determine the impact of effluents on the environment by testing parameters of the receiving water bodies and tracing back upstream to see which water sources are feeding the receiving water bodies.

Textile production has an impact on waterways throughout each process, but especially in dyeing and adding finishing treatments. Understanding the influence of this aspect of the supply chain can help MATE and other textile producers reduce their impact by choosing less harmful dyes

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[79] Arcega et al., "Toxicity Prediction"; Silva and Kwok, "Open Access ToxCast/Tox21, Toxicological Priority Index (ToxPi) and Integrated Chemical Environment (ICE) Models Rank and Predict Acute Pesticide Toxicity: A Case Study"; Rogers, Zalesny, and Lin, "A Systematic Approach for Prioritizing Landfill Pollutants Based on Toxicity."
[80] "Textile Dyeing Effluents and Its Impact on Environment."
[81] "Textile Dyeing Effluents and Its Impact on Environment."
[82] Islam and Mostafa, "Textile Dyeing Effluents and Environment Concerns - A Review."

and reducing finishing treatments. MATE has already taken the step to exclude all finishing treatments from their production.

Total Water Footprints of Lyocell & Cotton

A Total Water Footprint Includes water use in the full supply chain. According to the Water Footprint Network, green water is defined as "water from precipitation that is stored in the root zone of the soil and evaporated, transpired or incorporated by plants". Blue water is defined as "water that has been sourced from surface or groundwater resources and is either evaporated, incorporated into a product or taken from one body of water and returned to another, or returned at a different time". Finally, gray water is "the amount of fresh water required to assimilate pollutants to meet specific water quality standards".[83]

The Total Water Footprint for one pair of cotton pants is 2,800–4,900 liters. This is made up of, on average, 8% green, 86% blue, and 6% gray water sources. Of this, cotton growing/irrigation contributed to the largest share of water use.[84] On the other hand, the Total Water Footprint for one pair of lyocell pants is 1,200–1,900 liters, which is less than 50% compared with cotton. Lyocell is made up of, on average, 95% green, 2% blue, and 2% gray water sources. Tree growing contributed the largest share.[85]

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[83] "What Is a Water Footprint?"

[84] Hoekstra and Chapagain, *Globalization of Water: Sharing the Planet's Freshwater Resources*.

[85] Ren et al., "Water Footprint Assessment of Textile Enterprise Based on ISO14046."

5. Methods

The final methodology for this project encompasses an iterative development process. Stemming from the project team's initial literature review of each fiber type and supply chain data provided by the client (Step 1), the Chemical Inventory serves as the foundation for the analysis in this project. Steps 2 and 3 begin the process of data analysis through accounting for large data gaps in the Chemical Inventory. Steps 4 and 5 involve analyzing the attribute data for each chemical using ToxPi, bolstered by statistical analysis in R. Sensitivity analysis in ToxPi supplements the major initial findings by developing an understanding as to how data gaps may affect the chemical ranking. Finally, in Step 6, the project team develops recommendations to MATE on how the company can improve its fiber supply chain processes based on the results of this analysis, while also understanding and accounting for project limitations.

5.1 Data

This project utilizes a combination of qualitative and quantitative data sources, starting with background resources about MATE's manufacturing processes and Safety Data Sheet (SDS) chemical information from MATE's suppliers. Additionally, the project team used several key tools and chemical data sources to complete the project analysis, summarized in the sections below.

5.1.1 Tools

The project team used the following tools in its data compilation and analysis processes:

ToxNot

The project team completed initial investigations into fabrics and chemicals used by MATE using ToxNot, a tool designed to help companies identify harmful chemicals in their supply chains. ToxNot compiles data gathered from SDSs, applies their large database of RSLs and RHLs, and creates an estimated GreenScreen score. This score rates chemicals from low to very high concern level for 18 different parameters of human and ecological health.

Although the project team decided not to use GreenScreen scores from ToxNot, the RSLs and RHLs remained a valuable resource for the project.

Toxicological Priority Index (ToxPi) and ToxPi Graphical User Interface (GUI)

The Toxicological Priority Index (ToxPi™) is an open-access data prioritization and visualization tool accepted by the United States Environmental Protection Agency (U.S. EPA) into its Science Inventory research product database.[86] Reif et al. developed ToxPi as a prioritization method to screen potential endocrine disrupting chemicals in the U.S. EPA's ToxCast database and identify chemicals that warranted further testing.[87] Reif et al. officially defines ToxPi as "a tool for objective chemical prioritization based upon formal integration across multiple domains of information". The tool allows researchers to combine different types of data from multiple sources, assign weights to data sets depending on the intent of the project, and assess relative

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[86] Reif et al., "ToxPi GUI."

[87] Reif et al., "Endocrine Profiling and Prioritization of Environmental Chemicals Using ToxCast Data."

toxicity between a given set of chemicals. The project team used the ToxPi GUI, a Java-based platform, for the chemical ranking analysis in this report.[88]

R/RStudio with Github

The computer software program, R, along with the integrated development environment, RStudio, is an open source computer programming tool. Paired with GitHub, R Studio can be backed up remotely and used collaboratively between multiple users.[89]

The project team used the following R packages in its analysis:

- googlesheets4[90]
- tidyverse[91]
- janitor[92]
- patchwork[93]
- cowplot[94]
- data.table[95]
- kableExtra[96]
- ggbeeswarm[97]
- here[98]

Google Suite (Sheets, Docs, Slides)

The project team housed the Chemical Inventory data in Google Sheets, an online spreadsheet application. This allowed the project team to collaborate on data collection, track edits and comments, and maintain consistent formatting and data collection methodology.

The project team used Google Docs and Google Slides for final deliverables, allowing the team to collaborate on written materials and maintain organization by tracking team edits and comments.

5.1.2 Chemical Data Sources

Throughout its extensive research, the project team used a variety of chemical data resources to compile a comprehensive Chemical Inventory of MATE's entire supply chain. The project team also mapped out a comprehensive Supply Chain Tier diagram to inform their decisions when gathering data (Appendix B). To begin the Chemical Inventory, chemical names and CAS RNs were provided by MATE's SDS. This is our first choice of data, as it is confirmed to be accurate by MATE, but only accounts for chemicals in the yarn spinning and dying stages of the supply chain.

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[88] Reif et al., "ToxPi GUI."
[89] "Posit."
[90] Bryan, "Googlesheets4."
[91] Wickham, "Tidyverse."
[92] Firke et al., "Janitor."
[93] Pedersen, "Patchwork."
[94] Wilke, "Cowplot."
[95] Dowle et al., "Data.Table."
[96] Zhu et al., "KableExtra."
[97] Clarke, Sherrill-Mix, and Dawson, "Ggbeeswarm."
[98] Müller and Bryan, "Here."

Next, the project team dove into each fiber—linen, polyester, conventional cotton, organic cotton, spandex and TENCEL™ Lyocell—to retrieve information on chemicals used higher up in the supply chain in the raw material and cultivation step. A literature review was completed to gather general chemical information for each step in each fiber's supply chain. Using the data sources listed below, the project team was able to collect information on most chemicals to analyze them and rank them based on potential hazard.

Safety Data Sheets (SDS) and Additional Research

MATE provided Safety Data Sheets for as many chemicals as possible in Tiers 2 and 3. Some manufacturers and dye houses were not open to sharing these SDSs, so general data was used in those cases. The SDSs allowed the project team to begin their chemical compilation to create the Chemical Inventory. Most SDSs contain information regarding the chemical name, CAS RN, and safety standards for handling each chemical. A comprehensive literature review of each fiber was then completed to fill gaps left. The literature reviews for each fiber focused on peer-reviewed articles and industry reports, which are compiled in Section 4.2.

CompTox

The computational toxicology website, CompTox, is the U.S. EPA's chemical dashboard with comprehensive data on thousands of commonly used chemicals. The project team utilized this dashboard to extract hazard data on each chemical in the Chemical Inventory (Appendix A). CompTox compiles data on physicochemical properties, environmental fate and transport, exposure hazard, and *in vitro* bioassay. These properties are freely available, and more information is added as independent research is completed. CompTox is a constantly growing database providing open source data to the public, and was vital in completing research for this project.[99]

PubChem

The National Library of Medicine's PubChem database is an open-source database housing chemical records from various sources, including government agencies, chemical vendors, and journals.[100] The records in PubChem are updated frequently, allowing the database to match the most up-to-date science.[101] The project team used PubChem to supplement data from CompTox and attempt to fill in data gaps where possible.

5.2 Scope Definition

At the outset of the project, the project team and client decided upon the six fabrics for this analysis: conventional cotton, organic cotton, lyocell, linen, polyester, and spandex. MATE uses organic cotton, lyocell, linen, and spandex in its products. The client and the project team identified conventional cotton and polyester as important fabrics for this analysis given their prominence and widespread use in the apparel industry.

The scope of this project includes chemical inputs of the six fabric supply chains. Outputs, such as effluents, from the supply chain processes are not included in the analysis due to data

[99] United States Environmental Protection Agency, "CompTox Chemicals Dashboard."
[100] PubChem, "About."
[101] Kim et al., "PubChem 2023 Update."

limitations and location uncertainty. Additionally, this analysis begins at Tier 4 of the fabric supply chain, or “Raw Material Cultivation and Extraction”, due to data limitations and high levels of uncertainty further up the supply chain. Thus, chemical inputs prior to that stage are excluded from this analysis. This is primarily relevant for the polymer-based fibers (polyester and spandex), where extraction of crude oil is excluded from the scope of this project.

The project team integrated certain assumptions into its research methodology. These assumptions attempted to minimize data gaps given resource limitations and to maintain consistency throughout the research process. Namely, the project team kept chemical inputs in tiers past the agricultural stage (Tier 4) of conventional cotton production consistent with organic cotton production (e.g., dyes and lubricants used). The project team made this assumption based on the fact that the major chemical input difference between conventional cotton and organic cotton is in the use of pesticides. Maintaining consistency between the two fibers past Tier 4 allowed for comparable analysis between the two in the context of MATE’s cotton supply chain processes. Assumptions and limitations are discussed further in Section 7, Discussion & Recommendations.

5.3 Methodology

The project team developed a methodology called *Comparative Prioritization of Key Chemical Hazards in Upstream Apparel Supply Chains*, which uses reputable chemical data sources and a comparative ranking tool called ToxPi, as outlined in Table 1 below. The following subsections provide further details on each step of the methodology.

Table 1. Comparative Prioritization of Key Chemical Hazards in Upstream Apparel Supply Chains, *by Fiber & Tier*

Step 1	**Research & Collect Key Information** • Supply Chain Processes • Chemical Inventory • Chemical Data	**Step 4**	**Input data to ToxPi & Analyze in R** • See graphic: *‘Using ToxPI for Cradle2MATE’* • Average ToxPi scores by fiber and by tier • Analyze ToxPi scores using boxplots • Assess statistical significance of results
Step 2	**Filter to Chemicals with Sufficient Data** • CAS RN • 2+ chemical data points	**Step 5**	**Sensitivity Analysis in ToxPi** • Most concerning tier processes • Most concerning chemicals
Step 3	**Clean & Explore Data** • Read data into R & review imported data • Combine data sets by CAS RN • Negative log NOAEL & NOEC • Store chemical inventory • Filter to remove duplicate chemicals	**Step 6**	**Develop Recommendations** • How fibers compare • Most concerning chemicals • Key processes to improve

5.4 Step 1 - Research & Collect Key Information

5.4.1 Tier Processes

Mapping the tier processes allowed the project team to understand where key chemical hotspots might take place, and where the majority of harmful chemicals are used in the supply chain. See Table 2 for an overview of the mapped supply chain Tiers for each fiber. An extended version of this table is available in Appendix B.

Table 2. Summary of Supply Chain Tier Processes for Each Fiber in MATE's Supply Chain.

	Tier 4	Tier 3	Tier 2	Tier 1
Cotton	4a. Growing the cotton *4b. Picking the cotton (no chemistry)* *4c. Ginning the cotton (no chemistry)*	3a. Spinning cotton fibers into cotton yarn 3b. Knitting/Weaving into white cotton fabric	2a. Scouring & bleaching cotton fibers 2b. Dyeing white cotton fabric *2c.Chemical finishing treatments (excluded, MATE does not do)*	*1a. Cut & sew (no chemistry)* 1b. Garment washing & spot clean *1c. Prepare for ship (no chemistry)*
Linen	4a. Growing the flax *4b. Retting the flax (no chemistry; MATE uses non-chemical retting)*	3a. Spinning flax fibers into linen yarn 3b. Knitting/Weaving thread into unbleached "raw" linen fabric	2a. Scouring & bleaching raw linen fabric 2b. Dyeing white linen fabric *2c. Chemical finishing treatments (excluded, MATE does not do)*	*1a. Cut & sew (no chemistry)* 1b. Garment washing & spot clean *1c. Prepare for ship (no chemistry)*
Lyocell	4a. Responsible forestry (FSC/PEFC certified) 4b. Wood pulp creation	3a. Turning wood pulp into lyocell fibers (including bleaching) 3b. Spinning lyocell fibers into lyocell yarn 3c. Knitting/Weaving lyocell thread into lyocell fabric	2a. Scouring & bleaching lyocell fabric 2b. Dyeing white lyocell fabric *2b.Chemical finishing treatments (excluded, MATE does not do)*	*1a. Cut & sew (no chemistry)* 1b. Garment washing & spot clean *1c. Prepare for ship (no chemistry)*
Spandex	4a. Production of pre-polymer 4b. Chain extension reaction to create pre-polymer solution 4c. Diluting to create pre-polymer 'spandex' solution	3a. Solvent spinning/wet spinning of spandex fibers, adding finishing 3b. Wrapping of spandex fiber into spandex yarn 3c. Knitting/Weaving spandex fiber into spandex (blended) fabric	2a. Dyeing (blended) white spandex fabric *2b. Chemical finishing treatments (excluded, MATE does not do)*	*1a. Cut & sew (no chemistry)* *1b. Prepare for ship (no chemistry)*
Polyester	4a. Extraction of p-xylene and ethylene glycol from petroleum 4b. Polymerization of terephthalic acid and ethylene glycol 4c. Extrusion of polymer pellets	3a. Melt spinning (melting polymer pellets, extruding into fibers) 3b. Drawing and texturizing 3c. Knitting/Weaving polyester yarn into polyester fabric	2a. Scouring fabric prior to dyeing 2b. Dyeing white polyester fabric 2c. Mechanical finishing treatments 2d. Chemical finishing treatments (excluded, MATE does not do)	*1a. Cut & sew (no chemistry)* 1b. Garment washing & spot cleaning *1c. Prepare for ship (no chemistry)*

5.4.2 Chemical Inventory

The client provided the project team with SDSs for some chemicals used in MATE's organic cotton, lyocell, and linen supply chains. Additionally, the client provided a flowchart of the supply chain processes of MATE's organic cotton, lyocell, and linen products, which the project team deconstructed into the aforementioned industry Supply Chain Tiers. The project team compiled the Supply Chain Tier data for spandex and polyester via literature review. Combining the information from the SDSs and literature review sources, the project team compiled a list of chemicals, broken up by Supply Chain Tier process, for each fabric. The project team housed this data in a Chemical Inventory using Google Sheets.

5.4.3 Chemical Data

For each chemical included in the Chemical Inventory, the project team compiled the following information using the chemical's CAS Number as a search query. First, the project team used ToxNot to identify whether a chemical is present in various RSLs and RHLs of interest. Subsequently, the project team compiled No Observed Adverse Effect Level (NOAEL), No Observed Effect Concentration (NOEC), n-octanol-water partition coefficient ($logK_{OW}$), and half-life biodegradation and/or half-life biotransformation values for each chemical from the U.S. EPA's CompTox database. The project team cross-referenced these values with $logK_{OW}$ and half-life values extracted from PubChem, where available. Chemicals ranged in the number of property data points acquired.

5.5 Step 2 - Filter Chemicals

Initial filtering of chemicals from the full chemical inventory removed any chemicals that did not have CAS RNs and lacked data points. Some chemicals provided from the SDSs were listed as "propriety", so these were not included in data analysis as no information could be collected. The team decided to leave chemicals with only one chemical data point out of the initial data analysis.

5.6 Step 3 - Clean & Explore Data

Data managers read in the data to RStudio to store and review the data collected through Google Sheets. Any duplicate chemicals were removed before analysis began, resulting in a Unique Chemical List (Appendix E). RStudio was utilized to get the data into a suitable format to be used in ToxPi. The team downloaded all values for NOAEL and NOEC available on CompTox. To distill these values into one value per chemical, they classified each risk assessment type as chronic or acute based on the nature of the assessment, then grouped all NOAEL and NOEC values by CAS RN, endpoint type, and level (chronic or acute). Then, the project team calculated the average NOAEL or NOEC of each group. Subsequently, the project team filtered the data to only keep values in units of mg/kg-day for NOAEL and mg/L for NOEC, as these were the most common in each data set. This resulted in a maximum of one NOAEL acute, one NOAEL chronic, one NOEC acute, and one NOEC chronic for each chemical, depending on data availability. There was already a maximum of one value for each chemical for the other chemical properties, as the project team took the average of the range of values in CompTox and PubChem for these (biodegradation half-life, biotransformation half-life, $logK_{OW}$). Please see Appendix F, Key Toxicology Data Points for a table describing each data point.

5.7 Step 4 - Input Data to ToxPi & Analyze in R

After cleaning the data, the data managers conducted three ToxPi tests with the remaining chemicals for each fiber and each tier. **Table 3** shows the data types used in the three ToxPi analyses: using only environmental data points, using only human health data points, and an overall test with combined environmental and human health data. $LogK_{OW}$ was excluded from the combined test because it is non-directional, meaning that a given value is not decidedly better or worse than another. The data managers used negative log(NOAEL) and negative log(NOEC) values, given that a higher NOEC or NOAEL value denotes a less persistent chemical. This served to standardize the data points and ensure that a higher score in ToxPi represented a more potentially harmful chemical.[102]

Table 3. Data types and corresponding ToxPi test types.

	Environmental Test	Human Test	Combined Test
Data Points Used	Negative log(NOEC) Biodegradation half-life Biotransformation half-life Negative $LogK_{ow}$	Negative log(NOAEL) Biotransformation half-life $LogK_{ow}$	Negative log(NOEC) Negative log(NOAEL) Biotransformation half-life Biodegradation half-life

After the ToxPi analysis, the data managers exported the results from ToxPi, imported them into R and created boxplots of the distributions of ToxPi scores in each fiber to show the mean, range, and quartiles of ToxPi scores. They then ran a One-Way ANOVA by fiber for each of the three tests to determine if the mean ToxPi scores were statistically significantly different from each other. Subsequently, the data managers ran a Tukey HSD Post-Test of the ANOVA results to determine which fibers' mean ToxPi scores were statistically significantly different.

5.8 Step 5 - Sensitivity Analysis in ToxPi

To analyze the validity of the ToxPi results, the research team conducted a sensitivity analysis on the variables used in the chemical ranking analysis. The team conducted further ToxPi analyses on a combination of the independent toxicology variables to assess how that would change the distribution of ToxPi scores in each fiber. The combinations included:

- NOAEL and NOEC
- $LogK_{OW}$, Biodegradation and biotransformation half-life
- NOAEL, Biodegradation and biotransformation half-life
- NOEC, Biodegradation and biotransformation half-life

These new data combinations aimed to reveal whether the most concerning fibers change under new circumstances and therefore how sensitive the results of this project may be to different types or numbers of data points. These chemicals were then analyzed further by looking at each data point (NOAEL, NOEC, half-life, etc.) singularly and seeing which chemicals were most concerning for each property. Adding this analysis ensures that no concerning chemicals were inadvertently missed in this analysis if they only had one or two data points.

5.9 Step 6 - Develop Recommendations

The client expressed interest in improving its supply chain chemical processes to align with select industry certification standards. These certifications include Cradle-to-Cradle, MADESAFE,

[102] Rogers, Zalesny, and Lin, "A Systematic Approach for Prioritizing Landfill Pollutants Based on Toxicity."

GOTS, Bluesign, and Oeko-Tex. Additionally, the client's products are sold internationally, creating an interest in aligning with international chemical hazard standards.

The project team used the ToxPi results and cross-referenced select RSLs and RHLs (see **Tables 14 and 15**) to develop recommendations to MATE on how best to improve its fiber production processes in alignment with the certification standards of interest.

6. Results

Results of this project include the complete Chemical Inventory and ToxPi analysis on the Unique Chemical List. The project team has identified overall chemical impacts of the six fibers and for human and environmental endpoints specifically. Additionally, the project team identified the most concerning Tier processes across the six fibers and the most concerning Tier within each fiber. On the chemical level, the project team also identified the overall most concerning chemicals across all six fibers, in addition to the most concerning chemicals by each chemical property. Finally, the project team identified the most concerning chemicals potentially used in the production of MATE's four fabrics.

6.1 Chemical Inventory

A Chemical Inventory was compiled with all chemicals used in the six fibers throughout their Tier processes. For all Tier 3 and 4 chemical information, research relied on published academic literature to find which chemicals are typically used in the fiber production process. For all Tier 1 and 2 chemical information, MATE supplied chemical information from their suppliers. After collecting information on which chemicals were in the production process for each fiber and Tier, the project team placed the data into a spreadsheet with columns pertaining to chemical name, CAS number, fiber, and Tier level (Appendix A). The project team then compiled chemical property data, including NOAEL, NOEC, $\log K_{OW}$, and half-life biodegradation and/or half-life biotransformation values.

6.2 ToxPi Results

The results of the ToxPi score analysis are outlined below in a series of figures and tables. 83 chemicals had enough chemical property data (at least 2 data points) to warrant calculation of a ToxPi score, so the results below were performed on this subset of 83 chemicals (identified in Appendix E: Unique Chemical Inventory List).

Overall Toxpi Scores

Combined ToxPi Scores

Figure 1 visualizes the distribution of all combined ToxPi scores in every fiber (more detail is available in Appendix G: Combined ToxPi Scores). The ToxPi scores are plotted along the x-axis, with each box plot representing the distribution of scores in one fiber. Conventional cotton has the highest mean ToxPi score, followed by linen and polyester. Conventional cotton and polyester also had the widest distributions of ToxPi scores.

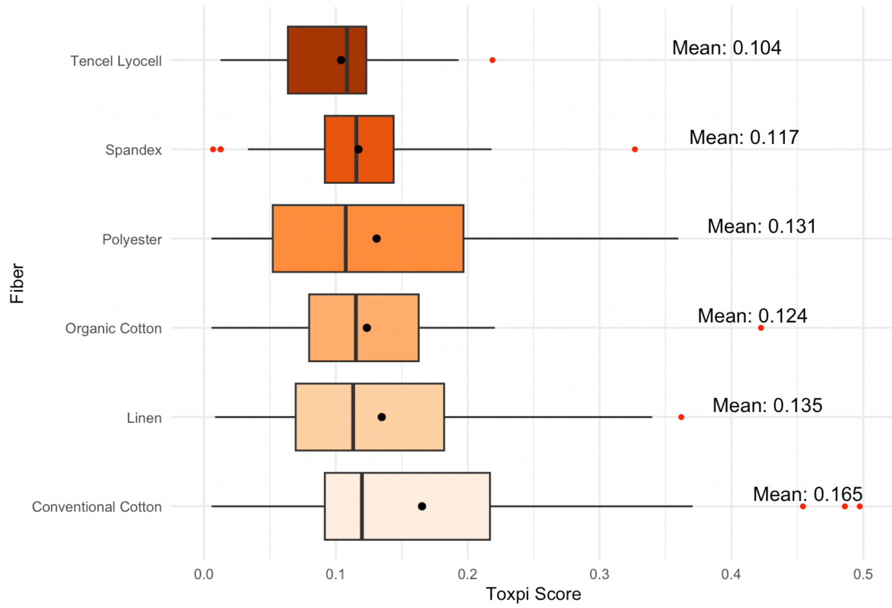

Figure 1: Combined ToxPi Score Distribution including human and environmental endpoints for all six fibers analyzed.

Environmental ToxPi Scores

Figure 2 visualizes the distribution of environmental ToxPi scores in every fiber. Conventional cotton has the highest mean environmental ToxPi score, followed by linen and polyester. Conventional cotton and polyester also had the widest distributions of environmental ToxPi scores.

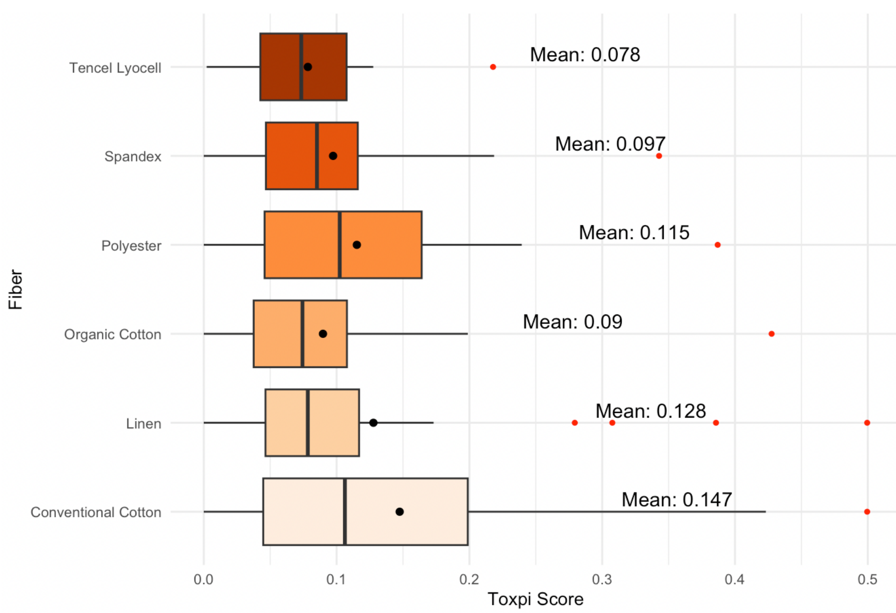

Figure 2: Environmental ToxPi Score Distribution including only environmental endpoints for all six fibers analyzed.

Human ToxPi Scores

Figure 3 visualizes the distribution of human ToxPi scores in every fiber. Conventional cotton has the highest mean human ToxPi score, followed by polyester and linen. Conventional cotton and polyester also had the widest distributions of human ToxPi scores.

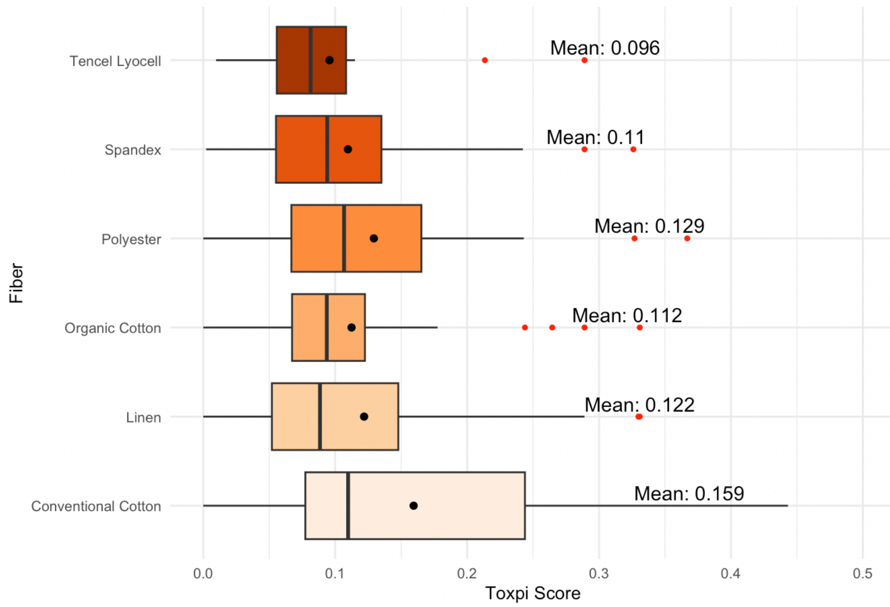

Figure 3: Human ToxPi Score Distribution including only human endpoints for all six fibers analyzed.

Most Concerning Chemicals Across All Fibers

Table 4 identifies the most concerning tier process out of all tier processes across all fibers by averaging the ToxPi scores of all chemicals that appear in each fiber for each process and ordering the processes by highest to lowest ToxPi score.

Most Concerning Tier Processes

Table 4. Combined ToxPi Results - Most Concerning Tier Processes

	Fiber	Tier	Average ToxPi Score	Processes Within Tier
1	Conventional Cotton	4a	0.39	Farming (Fertilizer, Pesticides, Insecticides)
2	Linen	4a	0.34	Farming (Fertilizer, Pesticides, Insecticides)
3	Organic Cotton	4a	0.29	Farming (Fertilizer, Pesticides, Insecticides)
4	Spandex	4b	0.22	Pre-polymer solution production
5	Spandex	3a	0.22	Fiber production

The results show that the conventional cotton farming stage is the most concerning (highest ToxPi score), with a ToxPi score of 0.39. This process involves the application of fertilizers, pesticides, and insecticides. The second most concerning process is the linen farming stage, followed by the organic cotton farming stage. These also involve the application of fertilizers, pesticides, and insecticides. The fourth and fifth most concerning processes are spandex pre-polymer solution production and fiber production.

Most Concerning Tier Processes by Fiber

Table 5 identifies the most concerning process for each of the six fibers analyzed. These were identified using the same method as described above, but instead of sorting the tiers overall, the tiers within each fiber were sorted from highest to lowest ToxPi score.

Table 5. Combined ToxPi Results - Most Concerning Tier Processes by Fiber

	Fiber	Tier	Average ToxPi Score	Processes Within Tier
1	Conventional Cotton	4a	0.39	Farming (Fertilizer, Pesticides, Insecticides)
2	Linen	4a	0.34	Farming (Fertilizer, Pesticides, Insecticides)
3	Organic Cotton	4a	0.29	Farming (Fertilizer, Pesticides, Insecticides)
4	Spandex	4b	0.22	Pre-polymer solution production
5	Polyester	3a	0.20	Yarn Spinning
6	Lyocell	3c	0.13	Fabric Knitting

The results show that for conventional cotton, linen, and organic cotton, the most concerning process is the farming stage. For spandex, the most concerning process is the pre-polymer solution production. For polyester, the most concerning process is yarn spinning. For lyocell, the most concerning process is fabric knitting.

Most Concerning Chemicals Across all Fibers Analyzed

Table 6 identifies the chemicals with the highest ToxPi scores to determine specific chemicals that should be avoided if possible. ToxPi assigns a score to every chemicals, so the list of scores for all 83 chemicals was sorted. The five highest scoring chemicals are listed in the table below.

Table 6. Combined ToxPi Results - Most Concerning Chemicals

	Chemical	Chemical Application	ToxPi Score	Fibers Using This Chemical	Estimated Quantity
1	Phorate	Pesticide	0.75	Conventional Cotton, 4a	Extensive
2	Chlorpyrifos	Insecticide	0.56	Conventional Cotton, 4a	Extensive
3	Lambda-Cyhalothrin	Insecticide	0.56	Conventional Cotton, 4a Linen, 4a	Extensive
4	Alpha-Endosulfan	Insecticide	0.53	Conventional Cotton, 4a	Extensive
5	Monocrotophos	Insecticide	0.51	Conventional Cotton, 4a	Extensive

The results show that the five highest scoring chemicals are all pesticides or insecticides, and all are applied during the farming stage for conventional cotton. One (lambda-cyhalothrin) is also applied at the farming stage for linen.

Most Concerning Chemicals by Chemical Properties

Table 7 to Table 12 show the five highest scoring chemicals for each of six chemical properties analyzed above (NOAEL acute, NOAEL chronic, NOEC acute, NOEC chronic, biodegradation half-life, and biotransformation half-life) to identify the chemicals that are most concerning regarding a specific chemical property. This analysis is to ensure that chemicals with concerning properties were not lost due to data gaps that may have resulted in lower overall ToxPi scores. Most concerning $LogK_{OW}$ chemicals were not recorded, as $LogK_{OW}$ was excluded from the combined test because it is non-directional (a given value is not decidedly better or worse)

Table 7. ToxPi Results - Most Concerning Chemicals by NOAEL Acute

	Chemical	Chemical Application	NOAEL Acute ToxPi Score	Overall ToxPi Score	Fibers Using This Chemical
1	Triazophos	Insecticide	1.0	0.31	Conventional Cotton, 4a
2	Monocrotophos	Insecticide	0.95	0.51	Conventional Cotton, 4a
3	Chlorpyrifos	Insecticide	0.76	0.56	Conventional Cotton, 4a
4	Phorate	Pesticide	0.75	0.75	Conventional Cotton, 4a
5	Acrylamide	Antistatic Ingredient	0.75	0.36	Polyester, 3a

Table 8. ToxPi Results - Most Concerning Chemicals by NOAEL Chronic

	Chemical	Chemical Application	NOAEL Chronic ToxPi Score	Overall ToxPi Score	Fibers Using This Chemical
1	Phorate	Pesticide	1.0	0.75	Conventional Cotton, 4a
2	Alpha-endosulfan	Insecticide	0.89	0.53	Conventional Cotton, 4a
3	Lambda-cyhalothrin	Insecticide	0.85	0.56	Conventional Cotton, 4a Linen, 4a
4	Monocrotophos	Insecticide	0.80	0.51	Conventional Cotton, 4a
5	Chlorpyrifos	Insecticide	0.80	0.56	Conventional Cotton, 4a

Table 9. ToxPi Results - Most Concerning Chemicals by NOEC Acute

	Chemical	Chemical Application	NOEC Acute ToxPi Score	Overall ToxPi Score	Fibers Using This Chemical
1	Alpha-endosulfan	Insecticide	1.0	0.53	Conventional Cotton, 4a
2	Lambda-cyhalothrin	Insecticide	0.88	0.56	Conventional Cotton, 4a Linen, 4a
3	Phorate	Pesticide	0.69	0.75	Conventional Cotton, 4a
4	Spiromesifin	Pesticide	0.67	0.36	Linen, 4a
5	Sodium hypochlorite	Degumming Ingredient	0.66	0.29	Linen, 3a

Table 10. ToxPi Results - Most Concerning Chemicals by NOEC Chronic

	Chemical	Chemical Application	NOEC Chronic ToxPi Score	Overall ToxPi Score	Fibers Using This Chemical
1	Phorate	Pesticide	1.0	0.75	Conventional Cotton, 4a
2	Fenvalerate	Insecticide	0.95	0.45	Conventional Cotton, 4a
3	Cypermethrin	Insecticide	0.87	0.50	Conventional Cotton, 4a
4	Spiromesifin	Pesticide	0.76	0.36	Linen, 4a
5	Phosalone	Pesticide	0.72	0.37	Conventional Cotton, 4a

Table 11. ToxPi Results - Most Concerning Chemicals by Biodegradation Half-Life

	Chemical	Chemical Application	Biodeg. Half-Life ToxPi Score	Overall ToxPi Score	Fibers Using This Chemical
1	Phorate	Pesticide	1.0	0.75	Conventional Cotton, 4a
2	Azadirachtin	Pesticide	0.95	0.42	Organic Cotton, 4a
3	Disperse Blue 1	Disperse Dye	0.66	0.11	Polyester, 2b
4	Phosalone	Pesticide	0.66	0.37	Conventional Cotton, 4a
5	Cyanox CY 1790	Fiber Production Finishing Agent	0.62	0.22	Spandex, 3a

Table 12. ToxPi Results - Most Concerning Chemicals by Biotransformation Half-Life

	Chemical	Chemical Application	Biotrans. Half-Life ToxPi Score	Overall ToxPi Score	Fibers Using This Chemical
1	Lambda-cyhalothrin	Insecticide	1.0	0.56	Conventional Cotton, 4a Linen, 4a
2	Methylene diphenyl diisocyanate	Polyurethane Urea Production for Fiber Production	0.68	0.12	Spandex, 4b
3	Chlorpyrifos	Insecticide	0.61	0.56	Conventional Cotton, 4a
4	Dimethyl diallyl ammonium chloride	Antistatic Ingredient	0.57	0.22	Polyester, 3a
5	Alpha-endosulfan	Insecticide	0.56	0.53	Conventional Cotton, 4a

These results show that pesticides and insecticides still dominate the lists of most concerning chemicals for the toxicity related chemical properties (NOAEL acute, NOAEL chronic, NOEC acute, NOEC chronic). However, for the persistence indicators (biodegradation and biotransformation half-life), more spandex and polyester chemicals appear on the most concerning lists. Therefore, while pesticides and insecticides are the most toxic of all chemicals in the inventory, some chemicals used in production of spandex and polyester may be just as concerning due to high persistence in the environment.

Most Concerning Chemicals in MATE's Supply Chain

After understanding where the chemical hotspots lie across all 6 fabrics, the project team wanted to understand where the chemical hotspots fell in MATE's supply chains specifically. When looking at the Top 5 ToxPi scores used only in the supply chains of MATE's 4 fabrics (Table 13), insecticides continue to dominate the ranking as the most concerning chemicals. Additionally, the most concerning chemicals possibly used in MATE's supply chain are those used in Tier 4.

Table 13. ToxPi Results - Most Concerning Chemicals in MATE's Supply Chain

	Chemical	Chemical Application	ToxPi Score	Fibers Using This Chemical
1	Lambda-cyhalothrin	**Insecticide**	0.56	Linen, 4a
2	Azadirachtin	**Insecticide**	0.42	Organic Cotton, 4a
3	Spiromesifen	**Insecticide**	0.36	Linen, 4a
4	ortho-Dichlorobenzene	**Insecticide**	0.34	Linen, 4a
5	Ethylenediamine (EDA)	**Solvent**	0.33	Spandex, 4b

6.3 Restricted Substance Lists

The project team used ToxNot to gather data on chemical presence on regulatory hazard lists and RSLs. See Appendix C for details describing each RSL a chemical in the project inventory was identified on. The top four RSLs inventoried chemicals appeared on are: MADESAFE's Banned List, Cradle to Cradle's Banned List, Oeko-Tex Eco Passport's RSL, and Bluesign's RSL. All of these eco-labels have a textile focus. Chemicals in the project inventory which appear on these lists are provided in Table 14 below, along with the combined ToxPi score resulting from the methodology developed in this report.

The RSLs included in Table 14 were chosen by the project team because they represent the eco-certifications most relevant to the client.

Table 14. Inventoried Chemicals Cross-Referenced with Eco-Label Restricted Substances Lists.

Chemical	CAS RN	MADESAFE Banned List	Cradle to Cradle Banned List	Oeko-Tex Eco Passport RSL/MRSL	Bluesign v13.0 RSL/MRSL	# of Lists	Combined ToxPi Score
Lambda-cyhalothrin (ISO)	**91465-08-06**	x	x	x	x	4	**0.56**
Alpha-endosulfan	**959-98-8**	x	x	x	x	4	**0.53**
Cypermethrin	**52315-07-8**	x	x	x	x	4	**0.5**
Profenofos	**41198-08-7**	x	x	x	x	4	0.35
Ortho-Dichlorobenzene	**95-50-1**	x	x	x	x	4	0.34
Naphthalene	**91-20-3**	x	x	x	x	4	**0.32**
Chlorobenzenes	**108-90-7**	x	x	x	x	4	**0.25**
Imidacloprid	**138261-41-3**	x	x	x	x	4	0.22
Di Methyl Formamide (DMF)	**68-12-2**	x	x	x	x	4	**0.14**
Disperse Blue 1	**2475-45-8**	x	x	x	x	4	**0.11**
Dimethyl acetamide	**127-19-5**	x	x	x	x	4	**0.06**
Chlorpyrifos	2921-88-2	x	x		x	3	0.56
Monocrotophos	6923-22-4	x		x	x	3	0.51
Dimethoate	60-51-5	x		x	x	3	0.49
Fenvalerate	51630-58-1	x		x	x	3	0.45
Acrylamide	79-06-1	x	x		x	3	0.36
4-Chlorotoluene	106-43-4		x	x	x	3	0.27
Ammonia	7664-41-7	x	x		x	3	0.22
3(2H)-Isothiazolone, 2-methyl-	2682-20-4	x	x		x	3	0.16
Quinalphos	13593-03	x		x	x	3	0.14

Chemical	CAS RN	MADESAFE Banned List	Cradle to Cradle Banned List	Oeko-Tex Eco Passport RSL/MRSL	Bluesign v13.0 RSL/MRSL	# of Lists	Combined ToxPi Score
	-8						
Disperse Yellow 3	2832-40-8	x		x	x	3	0.006
Zinc Oxide	1314-13-2	x	x			2	0.20
Dimethyl sulfaoxide	67-68-5	x	x			2	0.13
Methylene diphenyl diisocyanate (MDI)	101-68-8	x			x	2	0.12
Titanium Dioxide	13463-67-7	x	x			2	0.09
Strong-inorganic-acid mists containing sulfuric acid	7664-93-9	x				2	0.05
Polyoxyethylene	9002-92-0	x	x			2	0.03
Disperse Red 1	2872-52-8			x	x	2	0.01
Polyethylene glycol 4-(tert-octylphenyl) ether	9002-93-1	x		x		2	Not scored
Polyethylene glycol mono(octyl)phenyl ether	9036-19-5	x		x		2	Not scored
Poly (oxy-1,2-ethanediyl), alpha-(octylphenyl)-omega-hydroxy-, branched	68987-90-6	x		x		2	Not scored
Sodium Hydroxide	1310-73-2		x			2	Not scored
Phosalone	2310-17-0		x			1	0.37
Ethylenediamine (EDA)	107-15-3	x				1	0.33
Acephate	30560-19-1	x				1	0.32
Bleach plus Ammonia (Mixture)	7681-52-9	x				1	0.29
Nitrate	14797-55-8					1	0.22
Sodium Sulfide	1313-82-2			x		1	0.22
P-xylene	106-42-3			x		1	0.20
Barium sulfate	7727-43-7		x			1	0.17
Glycine, tetrasodium salt	64-02-8			x		1	0.16
Hydrotalcite	11097-59-9		x			1	0.14
Hydrogen Peroxide	7722-84-1		x			1	0.11
Polyethylene ether glycol	25322-68-3	x				1	0.10
Ethylene glycol	107-21-1	x				1	0.05
Diethylene Glycol	111-46-6		x			1	0.05

Chemical	CAS RN	MADESAFE Banned List	Cradle to Cradle Banned List	Oeko-Tex Eco Passport RSL/MRSL	Bluesign v13.0 RSL/MRSL	# of Lists	Combined ToxPi Score
Mineral Oil	8042-47-5	x				1	0.04
Acetamiprid	160430-64-8			x		1	0.01
Poly-dimethylsiloxane	9006-65-9	x				1	Not scored
Polyurethane	9009-54-5	x				1	Not scored

6.4 Endocrine Disruptors and Carcinogens per Regulatory Hazard Lists

The project team also used ToxNot to gather data on chemical presence on RHLs. See Appendix D for details describing each RHL relevant to the chemicals included on the Unique Chemical List. The RHLs were filtered to the lists concerning known or suspected endocrine disruptors and carcinogens of concern. Chemicals on the Unique Chemical List which appear on these RHLs is provided in Table 15 below, in alignment with Objective #2 of this project.

Table 15. Inventoried Chemicals Cross-Referenced with Chemical Hazard Lists Concerning Endocrine Disruptors and Carcinogens.

Chemical	CAS RN	CA Prop 65 (ED & C)	EU - Annex VI Category 1 (CMR)	EU - Priority Endocrine Disruptor (ED)	EU - SVHC Candidate List (CMR)	OSPAR - Priority PBTs & EDs (ED)	US CDC - Occupational Carcinogens	US EPA - IRIS Carcinogens	US OSHA Carcinogens	US NIH - Report on Carcinogens	# of Lists
Acrylamide	**79-06-1**	x	x		x		x	x	x	x	7
Di Methyl Formamide (DMF),	**68-12-2**	x	x	x	x				x		5
Naphthalene	**91-20-3**	x				x		x	x	x	5
Chlorpyrifos	**2921-88-2**	x		x		x					3
Dimethyl acetamide	**127-19-5**	x	x		x						3
Disperse Blue 1	**2475-45-8**	x	x							x	3
Ethylenediamine (EDA)	**107-15-3**				x			x			2
Polyethylene glycol 4-(tert-octylphenyl) ether	**9002-93-1**			x	x						2
Polyethylene glycol mono(octyl)p	**9036-19-5**			x	x						2

Chemical	CAS RN	CA Prop 65 (ED & C)	EU - Annex VI Category 1 (CMR)	EU - Priority Endocrine Disruptor (ED)	EU - SVHC Candidate List (CMR)	OSPAR - Priority PBTs & EDs (ED)	US CDC - Occupational Carcinogens	US EPA - IRIS Carcinogens	US OSHA Carcinogens	US NIH - Report on Carcinogens	# of Lists
henyl ether											
Titanium dioxide	**13463-67-7**	x					x				2
Acephate	30560-19-1			x							1
Alpha-endosulfan	959-98-8			x							1
Azadirachtin	11141-17-6			x							1
Barium sulfate	7727-43-7							x			1
Chlorobenzenes	108-90-7							x			1
Cypermethrin	52315-07-08			x							1
Dimethoate	60-51-5			x							1
Disperse Yellow 3	2832-40-8	x									1
Ethylene glycol	107-21-1	x									1
Fenvalerate	51630-58-1			x							1
Lambda-cyhalothrin (ISO)	91465-08-6			x							1
Methylene diphenyl diisocyanate (MDI)	101-68-8							x			1
Monocrotophos	6923-22-4		x								1
Ortho-Dichlorobenzene	95-50-1							x			1
Poly (oxy-1,2-ethanediyl), alpha-(octylphenyl)-omega-hydroxy-, branched	68987-90-6			x							1
Quinalphos	13593-03-8			x							1
Sulfur Dioxide	7446-09-5	x									1
Triazophos	24017-47-8								x		1

Chemical	CAS RN	CA Prop 65 (ED & C)	EU - Annex VI Category 1 (CMR)	EU - Priority Endocrine Disruptor (ED)	EU - SVHC Candidate List (CMR)	OSPAR - Priority PBTs & EDs (ED)	US CDC - Occupational Carcinogens	US EPA - IRIS Carcinogens	US OSHA Carcinogens	US NIH - Report on Carcinogens	# of Lists
Zinc oxide	1314-13-2							x			1

6.4 Sensitivity Analysis

To analyze the sensitivity of the ToxPi results to the various model inputs, a sensitivity analysis was conducted on the independent variables in the chemical hazard ranking assessment. The analysis was conducted on a random combination of the independent toxicology variables to assess the change of distribution of ToxPi scores in each fiber. The results were analyzed by reviewing how much the distribution of ToxPi scores changed per fiber and which fibers had the largest average ToxPi score. The boxplots figures are located below, detailing the distribution of values within each fiber in each sensitivity analysis simulation.

Sensitivity Analysis 1

Figure 4 visualizes the distribution of the combination of chronic and acute NOEC and NOAEL scores in every fiber. Conventional cotton has the highest mean ToxPi score, followed by linen. Conventional cotton and polyester have the widest distribution of ToxPi scores.

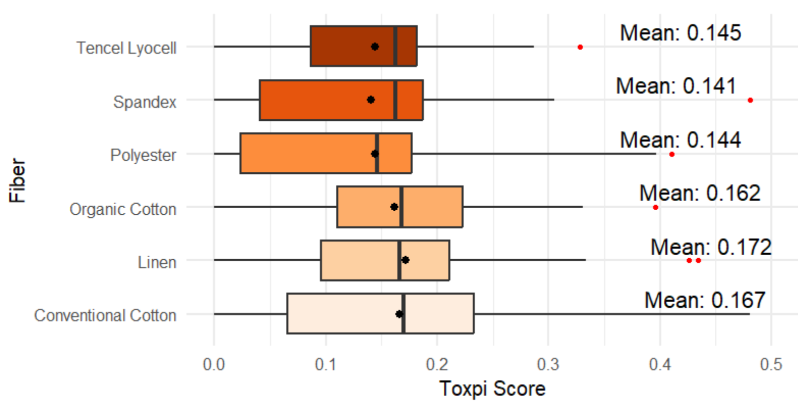

Figure 4: Sensitivity Analysis - NOEC, NOAEL ToxPi Score Distribution.

Sensitivity Analysis 2

Figure 5 visualizes the distribution of the combination of biotransformation and biodegradation half-life scores in every fiver. Conventional cotton has the highest mean ToxPi score, followed by polyester and linen. Polyester and conventional cotton have the widest distributions of ToxPi scores. Many chemicals did not have data for biotransformation and biodegradation half-life, as represented by box plot distributions.

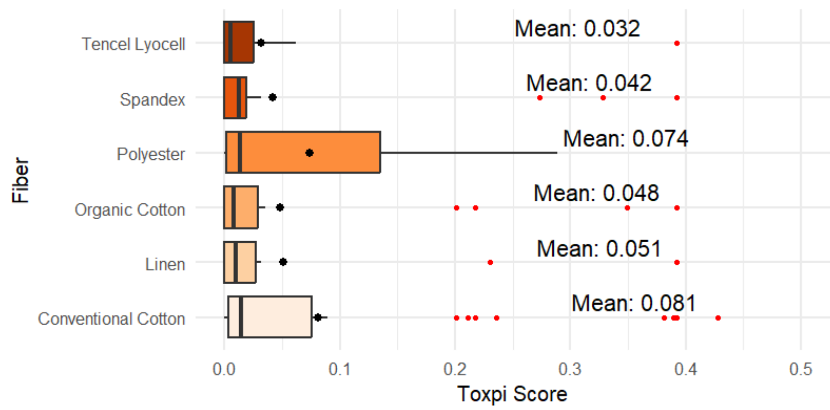

Figure 5: Sensitivity Analysis - Biotransformation, Biodegradation Half-life and $LogK_{OW}$ ToxPi Score Distribution.

Sensitivity Analysis 3

Figure 6 visualizes the distribution of the combination of chronic and acute NOEC, and biotransformation and biodegradation half-life. Conventional cotton has the highest mean ToxPi score, followed by polyester and spandex. Conventional cotton and polyester have the widest distributions of ToxPi scores, not including outliers.

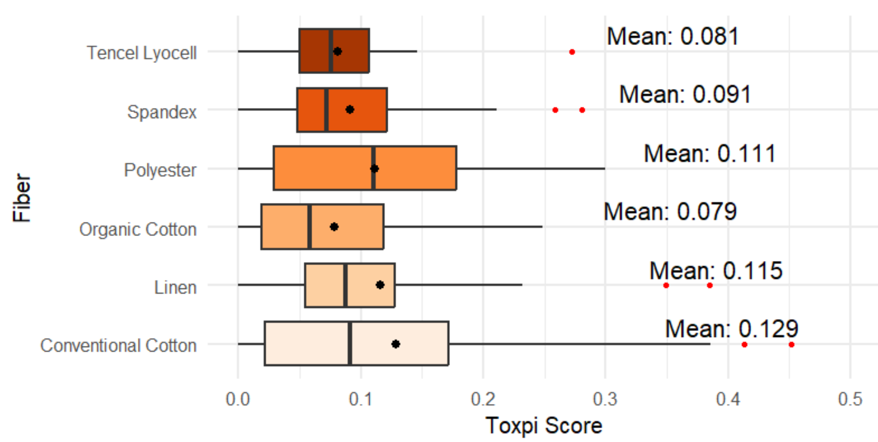

Figure 6: Sensitivity Analysis - NOEC, Biotransformation and Biodegradation Half-life ToxPi Score Distribution.

Sensitivity Analysis 4

Figure 7 visualizes the distribution of the combination of chronic and acute NOAEL, and biotransformation and biodegradation half-life. Linen and conventional cotton have the highest mean ToxPi score, followed by polyester and spandex. Conventional cotton and linen have the widest distributions of ToxPi scores.

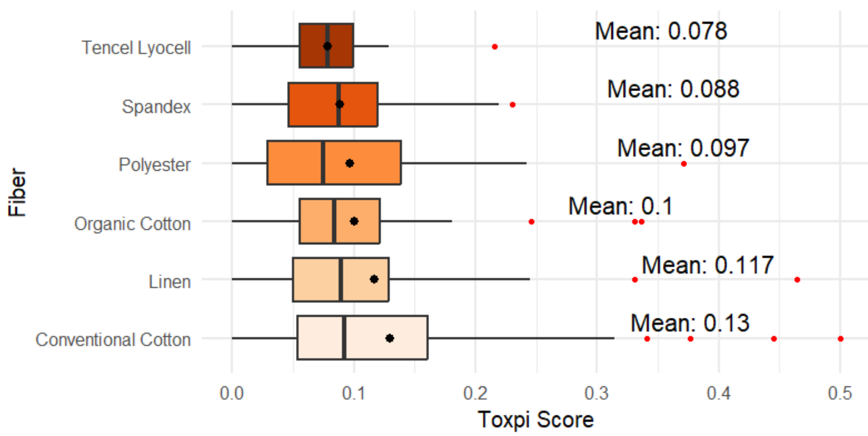

Figure 7: Sensitivity Analysis - NOAEL, Biotransformation and Biodegradation Half-life ToxPi Score Distribution.

The results of the sensitivity analysis show that the distributions of ToxPi scores are highly sensitive to which data points are included, indicating that the data gaps present in the chemical inventory likely influenced the results. These results highlight the importance of performing the additional analyses described above—such as identifying the most concerning chemicals for each chemical property—and assessing each chemical individually when making recommendations to ensure the recommendations are based on complete information. They also show that future work should focus on finding more sources of chemical property data to reduce data gaps and improve the quality of results. However, the overall fiber trends from the sensitivity analysis are consistent with the findings in the initial analysis. Overall, conventional cotton and linen have the highest average ToxPi score in three of the four sensitivity analyses and in the original analysis, so this main finding seems to be robust.

7. Discussion & Recommendations

7.1 Interpretation of Results

An important takeaway from the results is the similarity in the distributions of ToxPi scores across the six fibers. Though there are differences in the mean ToxPi scores, most of these differences are not statistically significant. Further, all the fibers have very similar ranges of scores, except for lyocell which has the lowest maximum score of all fibers. The similarity in means and ranges shows that all fibers use concerning chemicals at some point in their supply chain. Therefore, instead of ranking fibers against each other, it makes more sense to identify the hotspots of chemical impact overall and within each fiber and make recommendations based on these hotspots, not based on which fiber is better as a whole.

7.2 Assumptions

Each of the independent variables in the hazard ranking assessment was chosen due to their toxicological properties. The NOAEL and NOEC values presented the lowest concentration without noticeable impacts to human and aquatic species, respectively. These values were selected as indicators for toxicity to humans and aquatic species. Both acute and chronic values were included in the analysis to represent acute and chronic toxicity. Biodegradation and biotransformation half-life represent the time required to reduce the concentration by 50% from any point in time by chemical degradation and metabolism, respectively. Biodegradation half-life was used as an indicator of potential persistence in the environment, specifically soil. Biotransformation half-life was used as an indicator of potential persistence in human and fish, as biotransformation half-life studies were originally conducted on fish tissue. Lastly, $LogK_{OW}$ represents the ratio of the chemical concentration partitioned between water and octanol. $LogK_{OW}$ was used as an indicator of chemical tendency for bioaccumulation and hydrophobicity.

Between the 5 chemical endpoints, the variables cover chronic and acute toxicity for the environment, aquatic species, and humans. For the human ToxPi analysis, NOAEL (chronic and acute), biotransformation half-life, and $LogK_{OW}$ were chosen to represent human toxicological potential. For the environmental ToxPi analysis, NOEC (chronic and acute), biodegradation and biotransformation half-life, and the negative of $LogK_{OW}$ were selected to represent environmental toxicological potential. Both biodegradation and biotransformation half-life were analyzed in the environmental analysis because they represent persistence in soil and aquatic species. The negative of $LogK_{OW}$ was taken to give a higher score to $LogK_{OW}$ values with more hydrophilic tendencies. The combined ToxPi analysis does not include $LogK_{OW}$ analysis, as the negative and positive values of $LogK_{OW}$ analysis from environmental and human would cancel out.

7.3 Limitations

The project team identified the following research limitations related to the set project assumptions. Limitations in this study largely encompass data availability issues, methods by which the project team attempted to fill data gaps, and how those methods may have impacted the results of this study.

One limitation of this project lies in the process uncertainty around steps in the fibers' supply chain. MATE provided the project team with a flowchart of its supply chains for organic cotton, linen, lyocell, and spandex with locations of each process, in addition to SDSs for some chemicals used in its dye processes. However, there were remaining data gaps in chemicals used in other tiers. This required the project team to attempt to fill those data gaps through literature review of each production step for each fiber. This resulted in a chemical inventory with possible steps of production and chemicals used in those steps for each fiber, based on the literature. As such, the chemicals not provided by MATE included in this analysis are *possible* chemicals used; the exact chemicals used in each step of the supply chain remain unknown. Thus, a chemical showing up in this analysis as highly concerning may not be actually used in MATE's supply chain. Lack of chemical quantity data also results in limitations of this study. Not knowing exactly how much of each chemical is used in each step of the supply chain creates additional uncertainty in the results. For example, a chemical that showed up as one of relatively high concern in this analysis might not be harmful if it is used in small amounts. Conversely, a chemical that had a lower ToxPi score in this analysis might actually be harmful if it is used in large quantities in a certain step in the supply chain.

A related limitation of the research arises from the potential location discrepancy between where production processes occur and the available data included in the Chemical Inventory. The project team attempted to use data only from the places identified in MATE's supply chain graphic. However, where information from the exact location did not exist, the project team used data from the closest available location. This could also lead to discrepancies between what chemicals analyzed in this research and the actual chemicals used in the supply chain processes.

Additional limitations of the research relate to the availability of the chemical property data and resulting data gaps and uncertainty. For example, some chemicals identified by the project team or provided by industry experts did not have CAS Numbers associated with them to allow the project team to collect their chemical property data. As such, the project team eliminated those chemicals without CAS Numbers from analysis in ToxPi. This could have inadvertently filtered out concerning chemicals in the supply chain from this analysis.

Another limitation to this research is uncertainty in the chemical property data used. As outlined in Section 5 (Methods), the NOAEL and NOEC values were calculated by averaging many estimates. This was assumed to produce a useful representation for the NOAEL and NOEC of each chemical, but the aggregation of many values carries uncertainty with it. The half-lives and $LogK_{OW}$ values were also calculated by averaging the ranges found in CompTox and PubChem, so the same uncertainty is present for these values.

Further, there is uncertainty associated with each individual estimate for each property, as chemical testing does not produce consistent and exact results, and these results vary based on the quality of the test and the conditions under which the test is being conducted. The project team compiled half-life values from CompTox and PubChem, which do not appear to have a standardized temperature at which half-life is recorded. This is due to the fact that these values, while reputable and quality checked by the databases, are collected from a variety of other reputable databases and studies.[103] This could impact the results of this project if half-life values were compared from studies that used different pH values or temperatures to calculate the half-life. Future work should focus on refining these estimates for the specific conditions present along the supply chain or perform a sensitivity analysis on the individual chemical properties to see how varying these values from the minimum to maximum estimates changes the results.

[103] United States Environmental Protection Agency, "CompTox Chemicals Dashboard."

7.4 Chemical Hotspots Across all Fibers

The most concerning chemicals analyzed were found to be phorate, chlorpyrifos, lambda-cyhalothrin, endosulfan, and monocrotophos, in order of highest overall ToxPi score. Each of these chemicals is a type of insecticide or pesticide used in agriculture, indicating that these chemicals are most likely found in Tier 4 for natural fibers. Of the top five most concerning chemicals, only lambda-cyhalothrin is used in MATE's supply chain, and will be discussed in the next section. Most of these chemicals are not found in MATE's supply chain because they are not used in organic farming, which comprises the vast majority of MATE's natural fibers.

Organophosphate Pesticide Concerns

Phorate, chlorpyrifos, and monocrotophos—three of the top five most harmful chemicals identified in this report—are organophosphates. This class of chemical is commonly used in agriculture and is known to cause adverse health effects in humans and the environment. Organophosphates can alter the function of the nervous system and can be absorbed through the skin, inhaled, or ingested.[104] Because of these modes of exposure, farmworkers are most impacted by these chemicals. It is not likely that these chemicals would be found in high concentrations in produce or in the textile fibers they are used on; however, they can end up in water and soil and persist in the environment. Some of these chemicals can also be used as solvents and even nerve gas, so agricultural work is not the only avenue for organophosphates to harm humans and the environment, although it is the most prevalent avenue today.[105]

Various bans have been put into place in the US and other countries to control or eliminate the use of organophosphates in agriculture, but restrictions are limited in India and China.[106] Conventional cotton grown outside the US and European Union (EU) may use organophosphates to control pests and weeds, harming farmworkers in the process. To reduce the likelihood of organophosphates being used on a product, companies should source organic fibers or choose to buy fibers from countries with bans on organophosphates. In addition, the textile industry should support movements to ban and restrict organophosphates throughout the world.

Endosulfan Pesticide Concerns

Endosulfans are another toxic chemical used in agriculture that can harm humans and wildlife, causing seizures, tremors, or death. Alpha and beta-endosulfans create a highly effective insecticide in agriculture that can control many species of insects. This chemical is completely banned in the US after being phased out in the 2010s because the US EPA considers the chemical to be highly toxic, and a threat to the environment. Endosulfans are being phased-out globally, but may still be used in countries outside the US and EU.[107] Persistence in the environment is a concern with this chemical, but its half-life can vary widely based on environmental conditions. It should be used with caution, although it is not expected to travel well through soil, which reduces its risk of impacting groundwater supplies. As with many agricultural chemicals, it is applied in mass quantities from large sprayers, allowing for the possibility of surface water contamination.[108]

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[104] US EPA, "Chlorpyrifos."
[105] Adeyinka, Muco, and Pierre, "Organophosphates."
[106] US EPA, "Chlorpyrifos."
[107] "Endosulfan | Public Health Statement | ATSDR."
[108] "Endosulfan - an Overview | ScienceDirect Topics."

The last chemical on the top five most concerning chemicals list is lambda-cyhalothrin, which is possibly used in MATE's supply chain for linen production. More information on this chemical is available in the next section detailing the most concerning chemicals found in MATE's supply chain.

7.5 Chemical Hotspots in MATE's Supply Chain

MATE's Top 5 Most Concerning Chemicals are primarily found in Tier 4, or the Raw Material Cultivation and Extraction phase. Insecticides lambda-cyhalothrin, spiromesifen, and ortho-Dichlorobenzene cause linen cultivation specifically to stand out as a major hotspot in MATE's supply chain. Azadirachtin, a bio-pesticide used in organic farming, and ethylenediamine, a chemical used in the production of Spandex, also topped the list of the most concerning chemicals used in MATE's supply chain.

Lambda-cyhalothrin

Lambda-cyhalothrin not only ranks as MATE's most concerning chemical, but also as a top concerning chemical across all fabrics. A broad-spectrum insecticide that targets the neuromuscular system, also known as a pyrethroid, this chemical causes paralysis in organisms.[109] Lambda-cyhalothrin is classified as "not likely to be carcinogenic to humans" by the U.S. EPA. Additionally, the chemical is present on the EU's Priority Endocrine Disruptor Candidate list, but is categorized in Group 3 for having no evidence of endocrine disrupting activity.[110] While it has low predicted mobility in the environment, lambda-cyhalothrin's high persistence and low degradation characteristics[111] remain concerning for ecological health and are most likely why the chemical has such a high ToxPi score. Lambda-cyhalothrin has been shown to have high toxicity to aquatic organisms, namely fish and shellfish, in addition to high toxicity to bees.[112] Thus, non-target pollinator toxicity is a major concern associated with this broad-spectrum insecticide. While pyrethroid insecticides such as lambda-cyhalothrin may not always result in death to non-target species, sub-lethal impacts that affect food consumption and reproduction behaviors are also concerning for the survival of key pollinator species.[113]

Spiromesifen

Spiromesifen is another insecticide potentially used in linen cultivation. Spiromesifen is used most commonly against spider mites, whiteflies, and psyllids by inhibiting acetyl-CoA carboxylase,[114] and therefore, impacting lipid synthesis.[115] In its most recent interim registration review, the U.S. EPA concluded that spiromesifen posed potential human health risks, namely from dietary exposure via groundwater-sourced drinking water and occupational handler risk for

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[109] William T. Drew et al., "MEMORANDUM: Lambda-Cyhalothrin. Human Health Risk Assessment for the Proposed Food/Feed Uses of the Insecticide on Cucurbit Vegetables (Group 9),Tuberous and Corm Vegetables (Subgroup 1C), Grass Forage, Fodder, and Hay (Group 17), Barley, Buckwheat, Oat, Rye, Wild Rice, and Pistachios. Petition Numbers 5F6994, 3E6593, and 6E7077."
[110] "Chemicals - Environment - European Commission."
[111] William T. Drew et al.56
[112] He et al., "Environmental Chemistry, Ecotoxicity, and Fate of Lambda-Cyhalothrin."
[113] Ceuppens et al., "Effects of Dietary Lambda-Cyhalothrin Exposure on Bumblebee Survival, Reproduction, and Foraging Behavior in Laboratory and Greenhouse."
[114] "Regulations.Gov."
[115] "Mode of Action Classification | Insecticide Resistance Management."

those working with or near the chemical Additionally, the agency concluded that there are potential ecological risks of concern to mammals, pollinators, monocot plants and freshwater aquatic invertebrates.[116] Spiromesifen is not present on Regulatory Hazard Lists included in this study.

ortho-Dichlorobenzene

The third insecticide from the linen cultivation step included among MATE's most concerning chemicals is ortho-Dichlorobenzene. Ortho-Dichlorobenzene has a wide variety of use cases apart from its insecticidal properties and has been flagged as having hepatotoxic effects, impacting liver function.[117] Ortho-Dichlorobenzene is present in the U.S. EPA's Integrated Risk Information System (IRIS) database, classified as "not classifiable as to human carcinogenicity",[118] which is likely due to inadequate cancer studies in the literature.[119] As of December 2019, the U.S. EPA designated ortho-Dichlorobenzene as a high-priority chemical under the Toxic Substances Control Act. Thus, the chemical is undergoing risk evaluation by the U.S. EPA at time of this report.[120]

Given the presence of three potential insecticides used in the linen supply chain on MATE's Top 5 Most Concerning Chemicals, the project team recommends that MATE conduct a deep dive into its linen supply chain. This includes working with its supply chain partners, specifically its linen farmers, to better understand if these chemicals are being used to cultivate the linen used in its products. Confirming whether these chemicals are used in MATE's supply chain is critical if the company plans to pursue MADESAFE, Cradle to Cradle, Oeko-Tex, or Bluesign certification of its linen products, as the use of lambda-cyhalothrin and ortho-Dichlorobenzene is banned under all of these certifications. To this end, MATE might also benefit from looking into GOTS-certified linen production to determine if organic linen could fit into its business model. Using organic linen would ensure that these chemicals are not used in MATE's linen supply chain, as organic cultivation prohibits the use of synthetic insecticides.

Azadirachtin

Azadirachtin is a naturally-occurring chemical extracted from the oil of the neem tree.[121] Azadirachtin works as a pesticide by interfering with insects' normal feeding and reproductive behavior.[122] While a major component of some chemical pest control strategies used in organic farming, the potential negative impacts of azadirachtin, namely the impact to non-target species and pollinators, has been recently called into question.[123] However, researchers have also found that azadirachtin is one of the more selective biopesticides, posing less of a threat to non-target species than other natural chemical pest controls.[124] The presence of azadirachtin on MATE's

[116] "Regulations.Gov."
[117] Admin, "1,2-Dichlorobenzene."
[118] "Dichlorobenzene CASRN 95-50-1 | IRIS | US EPA, ORD."
[119] Admin, "1,2-Dichlorobenzene."
[120] "Risk Evaluation for O-Dichlorobenzene."
[121] "Neem Oil General Fact Sheet."
[122] "Azadirachtin (121701) Clarified Hydrophobic Extract of Neem Oil (025007) Fact Sheet."
[123] Barbosa et al., "Lethal and Sublethal Effects of Azadirachtin on the Bumblebee Bombus Terrestris (Hymenoptera."
[124] Challa, Firake, and Behere, "Bio-Pesticide Applications May Impair the Pollination Services and Survival of Foragers of Honey Bee, Apis Cerana Fabricius in Oilseed Brassica."

most concerning chemicals surprised the project team, given its reputation as a relatively fast degrading biopesticide.[125]

After further evaluation, the project team determined that the reasoning behind azadriachtin's presence on the list of MATE's most concerning chemicals could possibly be attributed to the high amount of uncertainty in azadirachtin's biodegradation parameters, as discussed in Section 7.2. This is reflected in the apparent broader lack of knowledge on azadirachtin. For example, the exact mechanism by which azadirachtin acts as a pesticide is not yet fully understood.[126] Additionally, azadirachtin is present on the EU-Priority Endocrine Disruptor Candidate List, but has been categorized in Group 3 due to lack of data.[127]

Nonetheless, the project team recommends that MATE take a similar approach to its linen supply chain and try to track its organic cotton back to the cultivation step. MATE should work with the farmers to understand if and how azadirachtin is being used in the cultivation of its organic cotton. Additionally, MATE could look to partner with farmers that practice insecticide-free farming and other regenerative agricultural strategies that reduce the need for chemical pesticide management.

Ethylenediamine

Ethylenediamine is a chain extender used in the production of polymers for Spandex.[128] This is a corrosive chemical that is produced in large quantities for a variety of uses. Very little is known about the amount of ethylenediamine released in effluents given the wide breadth of use cases.[129] The chemical is listed on the European Chemicals Agency (ECHA) Candidate List of Substances of Very High Concern as of 2018 for its respiratory sensitizing effects and probable serious health effects in humans.[130] The Candidate List is part of ECHA's Authorisation process, which has the ultimate goal of eventually finding less dangerous replacements for these concerning substances.[131] Ethylenediamine is the preferred single chain extender in Spandex production,[132] which is a chemically-intensive process itself. Thus, Spandex and chemicals like ethylenediamine are intrinsically combined.

MATE uses a very small amount of Spandex in its products. However, if MATE is looking to pursue MADESAFE certification, the company should look into possibly including a bio-based stretch fabric replacement to Spandex in its products.

[125] Kilani-Morakchi, Morakchi-Goudjil, and Sifi, "Azadirachtin-Based Insecticide."
[126] Kilani-Morakchi, Morakchi-Goudjil, and Sifi.
[127] "Chemicals - Environment - European Commission."
[128] Seeling, Gordon, High Productivity Spandex Fiber Process and Product.
[129] PubChem, "Ethylenediamine."
[130] "Candidate List of Substances of Very High Concern for Authorisation - ECHA."
[131] "Authorisation - ECHA."
[132] Seeling, Gordon, High Productivity Spandex Fiber Process and Product.

8. Conclusion

The most concerning chemicals identified in this analysis are primarily used in non-organic farming of natural fibers. This indicates that MATE's current practice of using organic cotton has likely reduced its impact on the environment compared to the potential impacts from conventional cotton. Of the fibers that MATE uses for their clothing, linen and spandex appear to be the most concerning. The concern over linen is driven by the use of insecticides and pesticides in the farming stage, while the concern over spandex is driven by the synthetic chemicals used to produce it.

Although linen and spandex appear to be most concerning on average, all of the fibers use chemicals that have concerning chemical properties. To reduce the impact of its clothing, MATE should make an effort to work with its supply chain partners to source complete chemical data throughout its supply chain, prioritizing data collection for the hotspots identified in this analysis such as linen farming and spandex prepolymer solution production. MATE should cross-reference these chemicals with the chemicals identified in this report and prioritize eliminating those that are ranked as more concerning.

This research also has broader implications for the textile industry. It highlights the importance of increased transparency around the chemicals used along the textile supply chain so that consumers and companies can more accurately assess the chemical impacts of the products they buy or produce. This is critical as many apparel manufacturers are currently unable to form a complete understanding of the impacts of their products due to lack of data and transparency in the industry, especially at steps further up the supply chain.

Future research in this area should incorporate chemicals used in the use-phase and end-of-life phase of the garments into the analysis, such as chemicals used to treat and wash garments after they are sold to the customer. As chemical outputs were out of scope of this analysis, future research could also consider the fate and transport of the chemicals after they are used in the textile manufacturing process by understanding how the chemicals mix together and how they are treated before being released into the environment. Additionally, to form a deeper understanding of water quality impacts from apparel manufacturing, future research could also analyze microfiber shedding, which is a growing concern with synthetic fibers and contributes to microplastic pollution.

The project team hopes that the tools and methodology used in this research will help MATE and other apparel companies organize and analyze chemical data as it becomes more readily available and better understand the chemical impacts of their products. As such, the project team hopes that this project also serves the broader purpose of highlighting current data gaps and helping propel the apparel industry forward in reducing the human health and environmental impacts of its operations.

9. References

A. Doyle, Elizabeth, and Susan E. Feinman. "Sensitization to Dyes in Textiles and Other Consumer Products." *Journal of Toxicology: Cutaneous and Ocular Toxicology* 7, no. 3 (January 1988): 195–222. https://doi.org/10.3109/15569528809052329.

Adeyinka, Adebayo, Erind Muco, and Louisdon Pierre. "Organophosphates." In *StatPearls*. Treasure Island (FL): StatPearls Publishing, 2022. http://www.ncbi.nlm.nih.gov/books/NBK499860/.

Admin, OEHHA. "1,2-Dichlorobenzene." Text. OEHHA, March 22, 2015. https://oehha.ca.gov/chemicals/12-dichlorobenzene.

Akin, Danny E. "Linen Most Useful: Perspectives on Structure, Chemistry, and Enzymes for Retting Flax." *ISRN Biotechnology* 2013 (December 30, 2013): 1–23. https://doi.org/10.5402/2013/186534.

Arcega, Rachelle D., Rong-Jane Chen, Pei-Shan Chih, Yi-Hsuan Huang, Wei-Hsiang Chang, Ting-Khai Kong, Ching-Chang Lee, et al. "Toxicity Prediction: An Application of Alternative Testing and Computational Toxicology in Contaminated Groundwater Sites in Taiwan." *Journal of Environmental Management* 328 (February 15, 2023): 116982. https://doi.org/10.1016/j.jenvman.2022.116982.

"Authorisation - ECHA." Accessed February 27, 2023. https://echa.europa.eu/substances-of-very-high-concern-identification-explained.

"Azadirachtin (121701) Clarified Hydrophobic Extract of Neem Oil (025007) Fact Sheet." United States Environmental Protection Agency, Office of Pesticide Programs, n.d. https://www3.epa.gov/pesticides/chem_search/reg_actions/registration/fs_G-127_01-Oct-01.pdf.

Banigan, Melissa. "East Africa Doesn't Want Your Hand-Me-Downs." Racked, January 25, 2018. https://www.racked.com/2018/1/25/16923226/east-africa-used-clothing-ban.

Barbosa, Wagner Faria, Laurens De Meyer, Raul Narciso C. Guedes, and Guy Smagghe. "Lethal and Sublethal Effects of Azadirachtin on the Bumblebee Bombus Terrestris (Hymenoptera: Apidae)." *Ecotoxicology* 24, no. 1 (January 1, 2015): 130–42. https://doi.org/10.1007/s10646-014-1365-9.

Bhalla, Sunita. "Toxicity of Synthetic Fibres & Health." *Advance Research in Textile Engineering* 2, no. 1 (January 5, 2017). https://doi.org/10.26420/advrestexteng.2017.1012.

IBISWorld. "Biggest Companies in the Global Apparel Manufacturing Industry," August 12, 2021. https://www.ibisworld.com/global/market-research-reports/global-apparel-manufacturing-industry/.

Blackburn, Richard. *Sustainable Textiles - Life Cycle and Environmental Impact*. Cambridge: Elsevier Science & Technology, 2009. https://app-knovel-com.proxy.library.ucsb.edu.

"Bluesign® - Solutions and Services for a Sustainable Textile Industry." Accessed March 2, 2023. https://www.bluesign.com/en.

"Bluesign Criteria for Bluesign Products." bluesign Technologies, March 2020.

Bryan, Jennifer. "Googlesheets4: Access Google Sheets Using the Sheets API V4," August 13, 2022. https://CRAN.R-project.org/package=googlesheets4.

"Candidate List of Substances of Very High Concern for Authorisation - ECHA." Accessed February 27, 2023. https://echa.europa.eu/candidate-list-table?p_p_id=disslists_WAR_disslistsportlet&p_p_lifecycle=1&p_p_state=normal&p_p_mode=view&_disslists_WAR_disslistsportlet_javax.portlet.action=searchDissLists.

Casadesus-Masanell, Ramon, Michael Crooke, Forest Reinhardt, and Vishal Vasishth.

"Households' Willingness to Pay for 'Green' Goods: Evidence from Patagonia's Introduction of Organic Cotton Sportswear." *Journal of Economics & Management Strategy* 18, no. 1 (2009): 203–33. https://doi.org/10.1111/j.1530-9134.2009.00212.x.

Ceuppens, Bob, Maxime Eeraerts, Tim Vleugels, Gerda Cnops, Isabel Roldan-Ruiz, and Guy Smagghe. "Effects of Dietary Lambda-Cyhalothrin Exposure on Bumblebee Survival, Reproduction, and Foraging Behavior in Laboratory and Greenhouse." *Journal of Pest Science* 88, no. 4 (December 1, 2015): 777–83. https://doi.org/10.1007/s10340-015-0676-9.

Challa, G. K., D. M. Firake, and G. T. Behere. "Bio-Pesticide Applications May Impair the Pollination Services and Survival of Foragers of Honey Bee, Apis Cerana Fabricius in Oilseed Brassica." *Environmental Pollution* 249 (June 1, 2019): 598–609. https://doi.org/10.1016/j.envpol.2019.03.048.

"Chemicals - Environment - European Commission." Accessed February 27, 2023. https://ec.europa.eu/environment/chemicals/endocrine/strategy/substances_en.htm#priority_list.

Chen, J. "Chapter 4 - Synthetic Textile Fibers: Regenerated Cellulose Fibers." In *Textiles and Fashion*, edited by Rose Sinclair, 79–95. Woodhead Publishing Series in Textiles. Woodhead Publishing, 2015. https://doi.org/10.1016/B978-1-84569-931-4.00004-0.

Clarke, Erik, Scott Sherrill-Mix, and Charlotte Dawson. "Ggbeeswarm: Categorical Scatter (Violin Point) Plots," December 16, 2022. https://CRAN.R-project.org/package=ggbeeswarm.

"Cotton: From Field to Fabric- Dyeing, Printing & Finishing." Accessed January 17, 2023. https://www.cotton.org/pubs/cottoncounts/fieldtofabric/dyeing.cfm.

Cotton Incorporated. "Life Cycle Assessment of Cotton Fiber & Fabric.," 2012. http://resource.cottoninc.com/LCA/LCA-Full-Report.pdf.

Delate, Kathleen, Ben Heller, and Jessica Shade. "Organic Cotton Production May Alleviate the Environmental Impacts of Intensive Conventional Cotton Production." *Renewable Agriculture and Food Systems* 36, no. 4 (August 2021): 405–12. https://doi.org/10.1017/S1742170520000356.

US EPA National Center for Environmental. "Dichlorobenzene CASRN 95-50-1 | IRIS | US EPA, ORD." Reports & Assessments. Accessed February 27, 2023. https://iris.epa.gov/ChemicalLanding/&substance_nmbr=408.

Dowle, Matt, Arun Srinivasan, Jan Gorecki, Michael Chirico, Pasha Stetsenko, Tom Short, Steve Lianoglou, et al. "Data.Table: Extension of 'Data.Frame,'" November 16, 2022. https://CRAN.R-project.org/package=data.table.

"Endosulfan | Public Health Statement | ATSDR." Accessed March 1, 2023. https://wwwn.cdc.gov/TSP/PHS/PHS.aspx?phsid=607&toxid=113.

"Endosulfan - an Overview | ScienceDirect Topics." Accessed March 3, 2023. https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/endosulfan.

"EOG Chemical Guide." European Outdoor Group, 2018.

Firke, Sam, Bill Denney, Chris Haid, Ryan Knight, Malte Grosser, and Jonathan Zadra. "Janitor: Simple Tools for Examining and Cleaning Dirty Data," February 2, 2023. https://CRAN.R-project.org/package=janitor.

"Focus Paper: Responsible Production." *Lenzing*, April 2022.

Ghanta, Madhav, Darryl Fahey, and Bala Subramaniam. "Environmental Impacts of Ethylene Production from Diverse Feedstocks and Energy Sources." *Applied Petrochemical Research* 4, no. 2 (June 1, 2014): 167–79. https://doi.org/10.1007/s13203-013-0029-7.

Gibson, W. H. "The Function of Water in the Wet Spinning of Flax." *Transactions of the Faraday Society* 20, no. December (January 1, 1924): 314–17. https://doi.org/10.1039/TF9242000314.

Hartline, Niko L., Nicholas J. Bruce, Stephanie N. Karba, Elizabeth O. Ruff, Shreya U. Sonar, and

Patricia A. Holden. “Microfiber Masses Recovered from Conventional Machine Washing of New or Aged Garments.” *Environmental Science & Technology* 50, no. 21 (November 1, 2016): 11532–38. https://doi.org/10.1021/acs.est.6b03045.

Atlantic Environmental Incorporated. “Hazards of Isocyanates (TDI, MDI, HDI) In Resins, Coatings and Paints,” March 20, 2019. https://www.atlenv.com/hazards-of-resins-and-isocyanates.

He, Li-Ming, John Troiano, Albert Wang, and Kean Goh. “Environmental Chemistry, Ecotoxicity, and Fate of Lambda-Cyhalothrin.” In *Reviews of Environmental Contamination and Toxicology*, edited by David M. Whitacre, 195:71–91. Reviews of Environmental Contamination and Toxicology. New York, NY: Springer New York, 2008. https://doi.org/10.1007/978-0-387-77030-7_3.

Henry, Beverley, Kirsi Laitala, and Ingun Grimstad Klepp. “Microfibres from Apparel and Home Textiles: Prospects for Including Microplastics in Environmental Sustainability Assessment.” *Science of The Total Environment* 652 (February 20, 2019): 483–94. https://doi.org/10.1016/j.scitotenv.2018.10.166.

Hoekstra, Arjen Y., and Ashok Chapagain. *Globalization of Water: Sharing the Planet’s Freshwater Resources*. 1st Edition. Wiley-Blackwell, 2008.

“Home - Cradle to Cradle Products Innovation Institute.” Accessed September 26, 2022. https://www.c2ccertified.org/.

World Bank. “How Much Do Our Wardrobes Cost to the Environment?” Accessed March 2, 2023. https://www.worldbank.org/en/news/feature/2019/09/23/costo-moda-medio-ambiente.

IARC Working Group on the Evaluation of Carcinogenic Risks to Humans. *Some Flame Retardants and Textile Chemicals, and Exposures in the Textile Manufacturing Industry. Some Flame Retardants and Textile Chemicals, and Exposures in the Textile Manufacturing Industry*. Lyon, France: International Agency for Research on Cancer, 1990. https://www.ncbi.nlm.nih.gov/books/NBK519215/.

“IFOAM Family of Standards | IFOAM.” Accessed March 2, 2023. https://www.ifoam.bio/our-work/how/standards-certification/organic-guarantee-system/ifoam-family-standards.

Islam, M., and Md Mostafa. “Textile Dyeing Effluents and Environment Concerns - A Review.” *Journal of Environmental Science and Natural Resources* 11 (October 1, 2019): 131–44. https://doi.org/10.3329/jesnr.v11i1-2.43380.

Jaffe, Michel, Anthony J. Easts, and Xianhong Feng. “8 - Polyester Fibers.” In *Thermal Analysis of Textiles and Fibers*, edited by Michael Jaffe and Joseph D. Menczel, 133–49. The Textile Institute Book Series. Woodhead Publishing, 2020. https://doi.org/10.1016/B978-0-08-100572-9.00008-2.

Jewell, John. “LCA UPDATE OF COTTON FIBER AND FABRIC LIFE CYCLE INVENTORY,” 2016.

Kilani-Morakchi, Samira, Houda Morakchi-Goudjil, and Karima Sifi. “Azadirachtin-Based Insecticide: Overview, Risk Assessments, and Future Directions.” *Frontiers in Agronomy* 3 (2021). https://www.frontiersin.org/articles/10.3389/fagro.2021.676208.

Kim, Sunghwan, Jie Chen, Tiejun Cheng, Asta Gindulyte, Jia He, Siqian He, Qingliang Li, et al. “PubChem 2023 Update.” *Nucleic Acids Research* 51, no. D1 (January 6, 2023): D1373–80. https://doi.org/10.1093/nar/gkac956.

Kozlowski, Ryszard M. *Handbook of Natural Fibres, Volume 1 - Types, Properties and Factors Affecting Breeding and Cultivation*. Woodhead Publishing, 2012. https://app.knovel.com/web/view/khtml/show.v/rcid:kpHNFVTPF1/cid:kt00BS0GS2/viewerType:khtml/?view=collapsed&zoom=1&page=2&q=cotton.

“Lyocell, the Eco-Friendly Fiber - Advantages and Disadvantages.” Accessed March 21, 2023. https://lyocell.info/.

MADE SAFE a program of Nontoxic Certified. "MADE SAFE a Program of Nontoxic Certified (NTC)," March 2, 2023. https://madesafe.org/.
Mancini, Francesca, Ariena H. C. Van Bruggen, Janice L.S. Jiggins, Arun C. Ambatipudi, and Helen Murphy. "Acute Pesticide Poisoning among Female and Male Cotton Growers in India." *International Journal of Occupational and Environmental Health* 11, no. 3 (July 2005): 221–32. https://doi.org/10.1179/oeh.2005.11.3.221.
"MATE the Label | Dress Clean®." Accessed March 2, 2023. https://matethelabel.com/.
IRAC. "Mode of Action Classification | Insecticide Resistance Management." Accessed February 27, 2023. https://irac-online.org/mode-of-action/classification-online/.
Müller, Kirill, and Jennifer Bryan. "Here: A Simpler Way to Find Your Files," December 13, 2020. https://CRAN.R-project.org/package=here.
Muthu, Subramanian Senthilkannan, Y. Li, J. Y. Hu, and P. Y. Mok. "Quantification of Environmental Impact and Ecological Sustainability for Textile Fibres." *Ecological Indicators* 13, no. 1 (February 1, 2012): 66–74. https://doi.org/10.1016/j.ecolind.2011.05.008.
"Neem Oil General Fact Sheet." Accessed February 27, 2023. http://npic.orst.edu/factsheets/neemgen.html.
"OEKO-TEX® - Tailor-Made Solutions for the Textile and Leather Industry." Accessed January 4, 2023. https://www.oeko-tex.com/en/.
"Organic Fibres - GOTS." Accessed January 25, 2023. https://global-standard.org/the-standard/gots-key-features/organic-fibres.
Ozipek, B., and H. Karakas. "9 - Wet Spinning of Synthetic Polymer Fibers." In *Advances in Filament Yarn Spinning of Textiles and Polymers*, edited by Dong Zhang, 174–86. Woodhead Publishing, 2014. https://doi.org/10.1533/9780857099174.2.174.
Pandey, Ritu, Seiko Jose, Gautam Basu, and Mukesh Kumar Sinha. "Novel Methods of Degumming and Bleaching of Indian Flax Variety Tiara." *Journal of Natural Fibers* 18, no. 8 (August 3, 2021): 1140–50. https://doi.org/10.1080/15440478.2019.1687067.
Pedersen, Thomas Lin. "Patchwork: The Composer of Plots," August 19, 2022. https://CRAN.R-project.org/package=patchwork.
"Philosophy - GOTS." Accessed January 25, 2023. https://global-standard.org/the-standard/philosophy.
Posit. "Posit." Accessed January 29, 2023. https://www.posit.co/.
"Product Registry - Cradle to Cradle Products Innovation Institute." Accessed November 26, 2022. https://www.c2ccertified.org/products/registry.
PubChem. "About." Accessed February 8, 2023. https://pubchem.ncbi.nlm.nih.gov/docs/about.
"Ethylenediamine." Accessed February 27, 2023. https://pubchem.ncbi.nlm.nih.gov/compound/3301.
Barnhardt Purified Cotton. "Raw Cotton Processing | How Is Cotton Processed | Barnhardt Cotton." Accessed October 14, 2022. https://barnhardtcotton.net/technology/cotton-processing/.
"Regenerated Cellulose by the Lyocell Process, a Brief Review of the Process and Properties :: BioResources." Accessed October 9, 2022. https://bioresources.cnr.ncsu.edu/resources/regenerated-cellulose-by-the-lyocell-process-a-brief-review-of-the-process-and-properties/.
"Regulations.Gov." Accessed February 27, 2023. https://www.regulations.gov/document/EPA-HQ-OPP-2014-0263-0043.
Reif, David M., Matthew T. Martin, Shirlee W. Tan, Keith A. Houck, Richard S. Judson, Ann M. Richard, Thomas B. Knudsen, David J. Dix, and Robert J. Kavlock. "Endocrine Profiling and Prioritization of Environmental Chemicals Using ToxCast Data." *Environmental Health*

Perspectives 118, no. 12 (December 2010): 1714–20. https://doi.org/10.1289/ehp.1002180.
Reif, David M., Myroslav Sypa, Eric F. Lock, Fred A. Wright, Ander Wilson, Tommy Cathey, Richard R. Judson, and Ivan Rusyn. “ToxPi GUI: An Interactive Visualization Tool for Transparent Integration of Data from Diverse Sources of Evidence.” *Bioinformatics* 29, no. 3 (February 1, 2013): 402–3. https://doi.org/10.1093/bioinformatics/bts686.
Reisch, Marc. “What’s That Stuff?” *Chemical & Engineering News*, February 15, 1999.
Ren, Xiaojing, Xue Bai, Mengting Hu, Dan Liu, Yue Wu, and Zhongguo Zhang. “Water Footprint Assessment of Textile Enterprise Based on ISO14046.” *DESALINATION AND WATER TREATMENT* 168 (2019): 216–23. https://doi.org/10.5004/dwt.2019.24203.
“Risk Evaluation for O-Dichlorobenzene.” Overviews and Factsheets, March 31, 2020. https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/risk-evaluation-o-dichlorobenzene.
Rogers, Elizabeth R., Ronald S. Zalesny, and Chung-Ho Lin. “A Systematic Approach for Prioritizing Landfill Pollutants Based on Toxicity: Applications and Opportunities.” *Journal of Environmental Management* 284 (April 2021): 112031. https://doi.org/10.1016/j.jenvman.2021.112031.
Sanchez Armengol, Eva, Aletta Blanka Kerezsi, and Flavia Laffleur. “Allergies Caused by Textiles: Control, Research and Future Perspective in the Medical Field.” *International Immunopharmacology* 110 (September 1, 2022): 109043. https://doi.org/10.1016/j.intimp.2022.109043.
Seagull, Robert, and Pam Alspaugh, eds. *Cotton Fiber Development and Processing an Illustrated Overview*. Lubbock–Texas, USA: Cotton Incorporated, International Textile Center, Texas Tech University, 2001. https://www.cottoninc.com/quality-products/textile-resources/cotton-fiber-development-and-processing/.
Seeling, Gordon, Houser, Nathan. High Productivity Spandex Fiber Process and Product. US 6916896. Wilmington, DE, filed May 5, 2003, and issued July 12, 2005. https://patents.google.com/patent/US6916896B2/en.
Senthilkumar, M. “Elastane Fabrics – A Tool for Stretch Applications in Sports,” 2011, 9.
Shabbir, Mohd, and Faqeer Mohammad. “7 - Sustainable Production of Regenerated Cellulosic Fibres.” In *Sustainable Fibres and Textiles*, edited by Subramanian Senthilkannan Muthu, 171–89. The Textile Institute Book Series. Woodhead Publishing, 2017. https://doi.org/10.1016/B978-0-08-102041-8.00007-X.
Silva, M H, and A Kwok. “Open Access ToxCast/Tox21, Toxicological Priority Index (ToxPi) and Integrated Chemical Environment (ICE) Models Rank and Predict Acute Pesticide Toxicity: A Case Study,” n.d.
Singh, Zorawar, and Pooja Chadha. “Textile Industry and Occupational Cancer.” *Journal of Occupational Medicine and Toxicology* 11, no. 1 (August 15, 2016): 39. https://doi.org/10.1186/s12995-016-0128-3.
SMM, Alam. “Reviewing the Production Process, Physical and Chemical Properties of Spandex Fibers,” June 20, 2020, 6.
Tencel.com. “Sustainable Fiber - True Transparency | Consumer | TENCEL™.” Accessed May 18, 2022. https://www.tencel.com/true-transparency.
“Textile Dyeing Effluents and Its Impact on Environment.” Accessed November 26, 2022. https://www.textiletoday.com.bd/textile-dyeing-effluents-and-its-impact-on-environment/.
“Third-Party Certification - GOTS.” Accessed January 26, 2023. https://global-standard.org/the-standard/gots-key-features/third-party-certification.
United States Environmental Protection Agency. “CompTox Chemicals Dashboard.” Database, n.d.

https://comptox.epa.gov/dashboard/.
US EPA, OCSPP. “Chlorpyrifos.” Overviews and Factsheets, December 29, 2014. https://www.epa.gov/ingredients-used-pesticide-products/chlorpyrifos.
VF Corporation. “VF Corporation Launches Enhanced Product Traceability Mapping Data Providing Unprecedented Industry Supply Chain Transparency,” February 7, 2023. https://www.vfc.com/news/press-release/1746/vf-corporation-launches-enhanced-product-traceability.
“What Is a Water Footprint?” Accessed March 2, 2023. https://waterfootprint.org/en/water-footprint/what-is-water-footprint/.
“What Is Lyocell Fabric & Is Its Sustainability Up To Snuff?,” November 22, 2022. https://www.sustainablejungle.com/sustainable-fashion/what-is-lyocell/.
Sewport. “What Is Polyester Fabric: Properties, How Its Made and Where.” Accessed May 15, 2022. https://sewport.com/fabrics-directory/polyester-fabric.
Wickham, Hadley. “Tidyverse: Easily Install and Load the ‘Tidyverse,’” July 18, 2022. https://CRAN.R-project.org/package=tidyverse.
Wilke, Claus O. “Cowplot: Streamlined Plot Theme and Plot Annotations for ‘Ggplot2,’” December 30, 2020. https://CRAN.R-project.org/package=cowplot.
William T. Drew, Kim Harper, Anant Parmar, Registration Action Branch 2, Mark Dow, Alternate Risk Integration Assessment Team, and Risk Integration Minor Use & Emergency Response Branch. “MEMORANDUM: Lambda-Cyhalothrin. Human Health Risk Assessment for the Proposed Food/Feed Uses of the Insecticide on Cucurbit Vegetables (Group 9),Tuberous and Corm Vegetables (Subgroup 1C), Grass Forage, Fodder, and Hay (Group 17), Barley, Buckwheat, Oat, Rye, Wild Rice, and Pistachios. Petition Numbers 5F6994, 3E6593, and 6E7077.” United States Environmental Protection Agency, July 18, 2007. https://www3.epa.gov/pesticides/chem_search/cleared_reviews/csr_PC-128897_18-Jul-07_a.pdf.
Zhu, Hao, Thomas Travison, Timothy Tsai, Will Beasley, Yihui Xie, GuangChuang Yu, Stéphane Laurent, et al. “KableExtra: Construct Complex Table with ‘kable’ and Pipe Syntax,” February 20, 2021. https://CRAN.R-project.org/package=kableExtra.

10. Appendices

Appendix List:

A. Chemical Inventory List
B. Supply Chain Diagram—Tier & Fiber
C. Restricted Substance List Index
D. Regulatory Hazard List Index
E. Unique Chemical Inventory List
F. Key Toxicology Data Points
G. Combined ToxPi Scores

APPENDIX A: Chemical Inventory List

Tier #	Tier Name	Fiber	Process	Material Name	Chemical	CAS RN
4a	Raw Material Cultivation, Extraction, and Conversion	Conventional Cotton	Cultivation (fertilization)	Ammonia	NH3	7664-41-7
4a	Raw Material Cultivation, Extraction, and Conversion	Conventional Cotton	Cultivation (fertilization)	Nitrogen	N	7727-37-9
4a	Raw Material Cultivation, Extraction, and Conversion	Conventional Cotton	Cultivation (fertilization)	Phosphorus pentoxide	P2O5	1314-56-3
4a	Raw Material Cultivation, Extraction, and Conversion	Conventional Cotton	Cultivation (fertilization)	Potassium oxide	K2O	12136-45-7
4a	Raw Material Cultivation, Extraction, and Conversion	Conventional Cotton	Cultivation (insecticide)	monocrotophos	C7H14NO5P	6923-22-4
4a	Raw Material Cultivation, Extraction, and Conversion	Conventional Cotton	Cultivation (insecticide)	endosulfan	C9H6Cl6O3S	959-98-8
4a	Raw Material Cultivation, Extraction, and Conversion	Conventional Cotton	Cultivation (insecticide)	quinalphos	C12H15N2O3PS	13593-03-8
4a	Raw Material Cultivation, Extraction, and Conversion	Conventional Cotton	Cultivation (insecticide)	fenvalerate	C25H22ClNO3	51630-58-1
4a	Raw Material Cultivation, Extraction, and Conversion	Conventional Cotton	Cultivation (insecticide)	chlorpyrifos	C9H11Cl3NO3PS	2921-88-2
4a	Raw Material Cultivation, Extraction, and Conversion	Conventional Cotton	Cultivation (insecticide)	dimethoate	C5H12NO3PS2	60-51-5
4a	Raw Material Cultivation, Extraction, and Conversion	Conventional Cotton	Cultivation (insecticide)	imidacloprid	C9H10ClN5O2	138261-41-3
4a	Raw Material Cultivation, Extraction, and Conversion	Conventional Cotton	Cultivation (insecticide)	acephate	C4H10NO3PS	30560-19-1
4a	Raw Material Cultivation, Extraction, and Conversion	Conventional Cotton	Cultivation (insecticide)	triazophos	C12H16N3O3PS	24017-47-8
4a	Raw Material Cultivation, Extraction, and Conversion	Conventional Cotton	Cultivation (insecticide)	profenofos	C11H15BrClO3PS	41198-08-7
4a	Raw Material Cultivation, Extraction, and Conversion	Conventional Cotton	Cultivation (insecticide)	lamdacyhalothri n	C23H19ClF3NO3	91465-08-6
4a	Raw Material Cultivation, Extraction, and Conversion	Conventional Cotton	Cultivation (insecticide)	cypermethrin	C22H19Cl2NO3	52315-07-8
4a	Raw Material Cultivation, Extraction, and Conversion	Conventional Cotton	Cultivation (pesticide)	phorate	C7H17O2PS3	298-02-2
4a	Raw Material Cultivation, Extraction, and Conversion	Conventional Cotton	Cultivation (pesticide)	Phosalone	C12H15ClNO4PS2	2310-17-0
4a	Raw Material Cultivation, Extraction, and Conversion	Conventional Cotton	Cultivation (pesticide)	Acetamiprid	C10H11ClN4	160430-64-8
4a	Raw Material Cultivation, Extraction, and Conversion	Organic Cotton	Cultivation (fertilization)	Nitrate	NO3-	14797-55-8
4a	Raw Material Cultivation, Extraction, and Conversion	Organic Cotton	Cultivation (pesticide)	Azadirachtin	C35H44O16	11141-17-6
4a	Raw Material Cultivation, Extraction, and Conversion	Organic Cotton	Cultivation (fertilization)	Ammonia	NH3	7664-41-7
4a	Raw Material Cultivation, Extraction, and Conversion	Tencel Lyocell	Raw Material (Trees - Beech & Spruce)	Trees		
4a	Raw Material Cultivation, Extraction, and Conversion	Tencel Lyocell	Raw Material (Trees - Beech & Spruce)	FSC/PEFC/EU compliant		
4a	Raw Material Cultivation, Extraction, and Conversion	Tencel Lyocell	Raw Material (Trees - Beech & Spruce)	FSC/PEFC/EU compliant		
4a	Raw Material Cultivation, Extraction, and Conversion	Tencel Lyocell	Raw Material (Trees - Beech & Spruce)	FSC/PEFC/EU compliant		
4a	Raw Material Cultivation, Extraction, and Conversion	Tencel Lyocell	Raw Material (Trees - Beech & Spruce)	FSC/PEFC/EU compliant		
4b	Raw Material Cultivation, Extraction, and Conversion	Tencel Lyocell	Wood Pulp Creation (process chemical)	Magnesium bisulfite	Mg(HSO3)2	13774-25-9
4b	Raw Material Cultivation, Extraction, and Conversion	Tencel Lyocell	Wood Pulp Creation (pulp cooking chemical)	Sulfur Dioxide	SO2	7446-09-5

Tier #	Tier Name	Fiber	Process	Material Name	Chemical	CAS RN
4b	Raw Material Cultivation, Extraction, and Conversion	Tencel Lyocell	Wood Pulp Creation (pulp cooking chemical)	Magnesium oxide	MgO	1309-48-4
4b	Raw Material Cultivation, Extraction, and Conversion	Tencel Lyocell	Wood Pulp Creation (pulp cooking chemical)	Sodium Hydroxide	NaOH	1310-73-2
4b	Raw Material Cultivation, Extraction, and Conversion	Tencel Lyocell	Wood Pulp Creation (pulp cooking chemical)	Sodium Sulfide	Na2S	1313-82-2
4a	Raw Material Cultivation, Extraction, and Conversion	Linen		Nitrate	NO3	14797-55-8
4a	Raw Material Cultivation, Extraction, and Conversion	Linen		Nitrate	K2O	12136-45-7
4a	Raw Material Cultivation, Extraction, and Conversion	Linen		Phosphate	P2O5	1314-56-3
4a	Raw Material Cultivation, Extraction, and Conversion	Linen		Dichlorobenzene	1, 2 Dichlorobenzene	95-50-1
4a	Raw Material Cultivation, Extraction, and Conversion	Linen		Mikado	IMIDACLOPRID	138261-41-3
4a	Raw Material Cultivation, Extraction, and Conversion	Linen		Jodo	Spiromesifen	283594-90-1
4a	Raw Material Cultivation, Extraction, and Conversion	Linen		Karate Zéon	lambda-cyhalothrin	91465-08-6
4c	Raw Material Cultivation, Extraction, and Conversion	Spandex	fiber production	Di Methyl Formamide (DMF),	$HCON(CH_3)_2$	68-12-2
4c	Raw Material Cultivation, Extraction, and Conversion	Spandex	fiber production	dimethyl acetamide	$CH_3CON(CH_3)_2$	127-19-5
4c	Raw Material Cultivation, Extraction, and Conversion	Spandex	fiber production	dimethyl sulfaoxide	(CH3)2SO	67-68-5
4a	Raw Material Cultivation, Extraction, and Conversion	Spandex	fiber production	micro polyester	(C10H8O4)n	113669-95-7
4b	Raw Material Cultivation, Extraction, and Conversion	Spandex	fiber production	Polyurethane	C3H8N2O	9009-54-5
4b	Raw Material Cultivation, Extraction, and Conversion	Spandex	fiber production	Ethylenediamine (EDA)	C2H8N2	107-15-3
4a	Raw Material Cultivation, Extraction, and Conversion	Spandex	fiber production	polytetramethylene glycol	(C4H8O)nH2O	25190-06-1
4a	Raw Material Cultivation, Extraction, and Conversion	Spandex	fiber production	polyethylene ether glycol	H-(O-CH2-CH2)n-OH	25322-68-3
4a	Raw Material Cultivation, Extraction, and Conversion	Spandex	fiber production	copoly(ethylene adipate)	(OCH2CH2O2CCH2CH2CH2CH2CO)-n	24938-37-2
4b	Raw Material Cultivation, Extraction, and Conversion	Spandex	fiber production	methylene diphenyl diisocyanate (MDI)	C15H10N2O2	101-68-8
4c	Raw Material Cultivation, Extraction, and Conversion	Spandex	2	2-methyl1-1, 5-pentanediamine (MPMD)	C6H16N2	15520-10-2
4c	Raw Material Cultivation, Extraction, and Conversion	Spandex	fiber production	titanium dioxide	TiO2	13463-67-7
4c	Raw Material Cultivation, Extraction, and Conversion	Spandex	fiber production	hydrotalcite	Mg6Al2(CO3)(OH)16•4H2O	11097-59-9
4c	Raw Material Cultivation, Extraction, and Conversion	Spandex	fiber production	huntite	C4H8CaMg3O12	19569-21-2
4c	Raw Material Cultivation, Extraction, and Conversion	Spandex	fiber production	hydromagnesite	CH2MgO3+2	12072-90-1
4c	Raw Material Cultivation, Extraction, and Conversion	Spandex	fiber production	barium sulfate	BaSO4	7727-43-7
4c	Raw Material Cultivation, Extraction, and Conversion	Spandex	fiber production	zinc oxide	ZnO	1314-13-2

Tier #	Tier Name	Fiber	Process	Material Name	Chemical	CAS RN
4a	Raw Material Cultivation, Extraction, and Conversion	Polyester	polymer pellet production		water	7732-18-5
4a	Raw Material Cultivation, Extraction, and Conversion	Polyester	polymer pellet production		p-xylene	106-42-3
4a	Raw Material Cultivation, Extraction, and Conversion	Polyester	polymer pellet production		acetic acid	64-19-7
4b	Raw Material Cultivation, Extraction, and Conversion	Polyester	polymer pellet production		terephthalic acid	100-21-0
4b	Raw Material Cultivation, Extraction, and Conversion	Polyester	polymer pellet production		ethylene glycol	107-21-1
4b	Raw Material Cultivation, Extraction, and Conversion	Polyester	polymer pellet production		polyethylene terephthalate	25038-59-9
3a	Raw Material Processing	Conventional Cotton	Scouring	Water	H20	7732-18-5
3a	Raw Material Processing	Conventional Cotton	Scouring	Sodium hydroxide	NaOH	1310-73-2
3a	Raw Material Processing	Conventional Cotton	Mercerization	Anhydrous liquid ammonia	NH3	7664-41-7
3a	Raw Material Processing	Conventional Cotton	Fiber prep for spinning			
3a	Raw Material Processing	Conventional Cotton	Yarn Spinning			
3b	Raw Material Processing	Conventional Cotton	Fabric Knitting	Hydrogen Peroxide	Water	7732-18-5
3b	Raw Material Processing	Conventional Cotton	Fabric Knitting	Enzyme H2O2	Soda Ash	497-19-8
3b	Raw Material Processing	Conventional Cotton	Fabric Knitting	SOF-CKY	Quaternary ammonium compounds, di-C14-18-alkyldimethyl, Me sulfates	68002-58-4
3b	Raw Material Processing	Conventional Cotton	Fabric Knitting	SOF-CKY	POE alkylaryl ether	69227-20-9
3b	Raw Material Processing	Conventional Cotton	Fabric Knitting	Dilute Acetic Acid	Acetic Acid	64-19-7
3b	Raw Material Processing	Conventional Cotton	Fabric Knitting	Dilute Acetic Acid	Water	7732-18-5
3b	Raw Material Processing	Conventional Cotton	Fabric Knitting	Hydrogen Peroxide Stabilizer / Stabigen CPM-CONC.	Sodium Chloride	7647-14-5
3b	Raw Material Processing	Conventional Cotton	Fabric Knitting	Hydrogen Peroxide Stabilizer / Stabigen CPM-CONC.	Disodium Phosphate	7558-79-4
3b	Raw Material Processing	Conventional Cotton	Fabric Knitting	Hydrogen Peroxide Stabilizer / Stabigen CPM-CONC.	Ethylénediaminetetraacetic acid	64-02-8
3a	Raw Material Processing	Organic Cotton	Scouring	Water	H20	7732-18-5
3a	Raw Material Processing	Organic Cotton	Scouring	Sodium hydroxide	NaOH	1310-73-2
3a	Raw Material Processing	Organic Cotton	Mercerization	Anhydrous liquid ammonia	NH3	7664-41-7
3a	Raw Material Processing	Organic Cotton	Fiber prep for spinning			
3a	Raw Material Processing	Organic Cotton	Yarn Spinning			
3b	Raw Material Processing	Organic Cotton	Fabric Knitting	Hydrogen Peroxide	Hydrogen Peroxide	7722-84-1

Tier #	Tier Name	Fiber	Process	Material Name	Chemical	CAS RN
3b	Raw Material Processing	Organic Cotton	Fabric Knitting	Hydrogen Peroxide	Water	7732-18-5
3b	Raw Material Processing	Organic Cotton	Fabric Knitting	Enzyme H2O2	Soda Ash	497-19-8
3b	Raw Material Processing	Organic Cotton	Fabric Knitting	SOF-CKY	Quaternary ammonium compounds, di-C14-18-alkyldimethyl, Me sulfates	68002-58-4
3b	Raw Material Processing	Organic Cotton	Fabric Knitting	SOF-CKY	POE alkylaryl ether	69227-20-9
3b	Raw Material Processing	Organic Cotton	Fabric Knitting	Dilute Acetic Acid	Acetic Acid	64-19-7
3b	Raw Material Processing	Organic Cotton	Fabric Knitting	Dilute Acetic Acid	Water	7732-18-5
3b	Raw Material Processing	Organic Cotton	Fabric Knitting	Hydrogen Peroxide Stabilizer / Stabigen CPM-CONC.	Sodium Chloride	7647-14-5
3b	Raw Material Processing	Organic Cotton	Fabric Knitting	Hydrogen Peroxide Stabilizer / Stabigen CPM-CONC.	Disodium Phosphate	7558-79-4
3b	Raw Material Processing	Organic Cotton	Fabric Knitting	Hydrogen Peroxide Stabilizer / Stabigen CPM-CONC.	Ethylénediaminetetraacetic acid	64-02-8
3a	Raw Material Processing	Tencel Lyocell	Lyocell Fiber Production (Dissolve cellulose)	NMNO Solvent	N-Methylmorpholine N-oxide	7529-22-8
3a	Raw Material Processing	Tencel Lyocell	Lyocell Fiber Production (Stabilizer for commercial water distillation process)	Propyl gallate	C10H12O5	121-79-9
3b	Raw Material Processing	Tencel Lyocell	Lyocell Thread Spinning (TCF bleaching agent)	Oxygen	O2	7782-44-7
3b	Raw Material Processing	Tencel Lyocell	Lyocell Thread Spinning (TCF bleaching agent)	Ozone	O3	10028-15-6
3b	Raw Material Processing	Tencel Lyocell	Lyocell Thread Spinning (TCF bleaching agent)	Hydrogen Peroxide	H2O2	7722-84-1
3b	Raw Material Processing	Tencel Lyocell	Lyocell Thread Spinning (TCF bleaching agent)	Sodium Hydroxide	NaOH	1310-73-2
3c	Raw Material Processing	Tencel Lyocell	Fabric Knitting	Sodium Hydroxide 50%	Sodium Hydroxide	1310-73-2
3c	Raw Material Processing	Tencel Lyocell	Fabric Knitting	Dyesoft 1000	POE Fatty Alchohol Phosphoric Ester	68201-36-5
3c	Raw Material Processing	Tencel Lyocell	Fabric Knitting	Dyesoft 1001	Water	7732-18-5
3c	Raw Material Processing	Tencel Lyocell	Fabric Knitting	Hydrogen Peroxide 50	Hydrogen Peroxide	7722-84-1
3c	Raw Material Processing	Tencel Lyocell	Fabric Knitting	Hydrogen Peroxide 50	Water	7732-18-5
3c	Raw Material Processing	Tencel Lyocell	Fabric Knitting	Actiron ASL	Phosphonic acid	22042-96-2
3c	Raw Material Processing	Tencel Lyocell	Fabric Knitting	Actiron ASL	Hydrogen Peroxide Stabilizer	1344-09-08
3c	Raw Material Processing	Tencel Lyocell	Fabric Knitting	Actiron ASL	Water	7732-18-5
3c	Raw Material Processing	Tencel Lyocell	Fabric Knitting	Protepon SCFN3	Poly(oxy-1,2-ethanediyl), α-isotridecyl-ω-hydroxy	9043-30-5
3c	Raw Material Processing	Tencel Lyocell	Fabric Knitting	Acetic Acid >80%	Acetic Acid	64-19-7

Tier #	Tier Name	Fiber	Process	Material Name	Chemical	CAS RN
3a	Raw Material Processing	Linen	Degumming/Preparing to Spin	sodium hydroxide	sodium hydroxide	1310-73-2
3a	Raw Material Processing	Linen	Degumming/Preparing to Spin	cellulose powder	C6H10O5	9004-34-6
3a	Raw Material Processing	Linen	Degumming/Preparing to Spin	alpha-amylase	alpha-amylase	9000-90-2
3a	Raw Material Processing	Linen	Degumming/Preparing to Spin	Hydrogen Peroxide	Hydrogen Peroxide	7722-84-1
3a	Raw Material Processing	Linen	Degumming/Preparing to Spin	sulfuric acid	H_2SO_4	7664-93-9
3a	Raw Material Processing	Linen	Degumming/Preparing to Spin	oxalic acid	C2H2O4	144-62-7
3a	Raw Material Processing	Linen	Degumming/Preparing to Spin	acetic acid	CH_3COOH	64-19-7
3a	Raw Material Processing	Linen	Degumming/Preparing to Spin	sodium hypochlorite	sodium hypochlorite	7681-52-9
3a	Raw Material Cultivation, Extraction, and Conversion	Spandex	fiber production	nitrogen gas	N2	7727-37-9
3a	Raw Material Cultivation, Extraction, and Conversion	Spandex	fiber production	poly-dimethylsiloxane	CH3[Si(CH3)2O]nSi(CH3)3	9006-65-9
3a	Raw Material Cultivation, Extraction, and Conversion	Spandex	fiber production	CYANOX 1790	C42H57N3O6	40601-76-1
3a	Raw Material Cultivation, Extraction, and Conversion	Spandex	fiber production	METHACROL 2462		
3b	Raw Material Cultivation, Extraction, and Conversion	Spandex	fiber production	magnesium stearate	C36H70MgO4	557-04-0
3c	Raw Material Processing	Spandex	Fabric Knitting	Hydrogen Peroxide	Hydrogen Peroxide	7722-84-1
3c	Raw Material Processing	Spandex	Fabric Knitting	Hydrogen Peroxide	Water	7732-18-5
3c	Raw Material Processing	Spandex	Fabric Knitting	Enzyme H2O2	Soda Ash	497-19-8
3c	Raw Material Processing	Spandex	Fabric Knitting	SOF-CKY	Quaternary ammonium compounds, di-C14-18-alkyldimethyl, Me sulfates	68002-58-4
3c	Raw Material Processing	Spandex	Fabric Knitting	SOF-CKY	POE alkylaryl ether	69227-20-9
3c	Raw Material Processing	Spandex	Fabric Knitting	Dilute Acetic Acid	Acetic Acid	64-19-7
3c	Raw Material Processing	Spandex	Fabric Knitting	Dilute Acetic Acid	Water	7732-18-5
3c	Raw Material Processing	Spandex	Fabric Knitting	Hydrogen Peroxide Stabilizer / Stabigen CPM-CONC.	Sodium Chloride	7647-14-5
3c	Raw Material Processing	Spandex	Fabric Knitting	Hydrogen Peroxide Stabilizer / Stabigen CPM-CONC.	Disodium Phosphate	7558-79-4
3c	Raw Material Processing	Spandex	Fabric Knitting	Hydrogen Peroxide Stabilizer / Stabigen CPM-CONC.	Ethylénediaminetetraacetic acid	64-02-8
3a	Raw Material Processing	Polyester	Yarn Spinning		Mineral Oil	8042-47-5
3a	Raw Material Processing	Polyester	Yarn Spinning		Dimethyl diallyl ammonium chloride	7398-69-8
3a	Raw Material Processing	Polyester	Yarn Spinning		Acrylamide	79-06-1
3a	Raw Material Processing	Polyester	Yarn Spinning		Benzotriazole	95-14-7

Tier #	Tier Name	Fiber	Process	Material Name	Chemical	CAS RN
3c	Raw Material Processing	Polyester	Fabric Knitting		Polyvinyl alcohol	9002-89-5
3c	Raw Material Processing	Polyester	Fabric Knitting		Polyoxyethylene	9002-92-0
3c	Raw Material Processing	Polyester	Fabric Knitting		Polyvinylpyrrolidone	9003-39-8
3c	Raw Material Processing	Polyester	Fabric Knitting		Polyvinyl methyl ether	9003-09-2
2a	Material Production	Conventional Cotton	Prepare for dye			
2b	Material Production	Conventional Cotton	Piece Dye			
2b	Material Production	Conventional Cotton	Garment Dye	REWIN GCF	Polyammonium compound	
2b	Material Production	Conventional Cotton	Garment Dye	BNA Smark Enzyme Anti-Peeler	Cellulase	9012-54-8
2b	Material Production	Conventional Cotton	Garment Dye	Scour RM	Isotridecanol, ethoxylated	69011-36-5
2b	Material Production	Conventional Cotton	Garment Dye	Scour RM	2-[2-(2-butoxyethoxy)ethoxy]ethanol	143-22-6
2b	Material Production	Conventional Cotton	Garment Dye	Scour RM	3,6,9,12-Tetraoxahexadecan-1-ol	1559-34-8
2b	Material Production	Conventional Cotton	Garment Dye	TUBINGAL 6069-A	Octadecanamide, N-[2-[(2-hydroxyethyl)amino]ethyl]-	141-21-9
2b	Material Production	Conventional Cotton	Garment Dye	Sera Wet M-A70 (3)	sodium-di-alkyl-sulfosuccinate	577-11-7
2b	Material Production	Conventional Cotton	Garment Dye	Sera Wet M-A70 (3)	diethylene glycol	111-46-6
2b	Material Production	Conventional Cotton	Garment Dye	Sera Wet M-A70 (3)	2-methyl-2,4-pentanediol	107-41-5
2b	Material Production	Conventional Cotton	Garment Dye	Multiprep SS-400		
2b	Material Production	Conventional Cotton	Garment Dye	Sera Sperse C-SS 600	2-methyl-2H-Isothiazolone-2-one	2682-20-4
2b	Material Production	Conventional Cotton	Garment Dye	Sera Sperse C-SS 601	water	7732-18-5
2b	Material Production	Conventional Cotton	Garment Dye	Sera Sperse C-SS 602	sodium polyacrylate	7446-81-3
2b	Material Production	Conventional Cotton	Garment Dye	Procion Yellow H-E4R		
2b	Material Production	Conventional Cotton	Garment Dye	EVERZOL BLACK ED	Remazol Black B	17095-24-8
2b	Material Production	Conventional Cotton	Garment Dye	EVERZOL BLACK ED	2,4-diamino-5-[4-[(2-sulfoxyl ethyl)sulfonyl]phenylazo]benzenesulfonic acid	27624-67-5
2b	Material Production	Conventional Cotton	Garment Dye	EVERZOL BLACK ED	disodium 8-amino-5-{4-[2-(sulfonatoethoxy)sulfonyl]phenylazo}naphthalene-2-sulfonate	250688-43-8
2b	Material Production	Conventional Cotton	Garment Dye	Procion Red H-E7B		

Tier #	Tier Name	Fiber	Process	Material Name	Chemical	CAS RN
2b	Material Production	Conventional Cotton	Garment Dye	SYNO WHITE BYB	Sulfuric acid disodium salt	7757-82-6
2b	Material Production	Conventional Cotton	Garment Dye	SYNO WHITE BYB	Benzenesulfonic acid, 2,2'-(1,2-ethenediyl)bis[5-[[4-[bis(2-hydroxyethyl) amino]-6-(phenylamino)-1 ,3,5-triazin-2-yl]amino]-, disodium salt	4193-55-9
2b	Material Production	Conventional Cotton	Garment Dye	SYNO WHITE BYB	Soda Ash	497-19-8
2b	Material Production	Conventional Cotton	Garment Dye	SYNO WHITE BYB	Fatty acids, (C16-C18) and C18 unsaturated, isobutyl ester	10024-47-2
2b	Material Production	Conventional Cotton	Garment Dye	SYNO WHITE BYB	Trade Secret	
2b	Material Production	Conventional Cotton	Garment Dye	SYNO WHITE BYB	Trade Secret	
2b	Material Production	Conventional Cotton	Garment Dye	Procion Navy H-ER 150%		
2b	Material Production	Conventional Cotton	Garment Dye	ULTRAWET WS	ULTRAWET WS	
2b	Material Production	Conventional Cotton	Garment Dye	Sodium thiosulfate	Thiosulfuric acid (H2S2O3), disodium salt	7772-98-7
2b	Material Production	Conventional Cotton	Garment Dye	OPTISIL - M50 PLUS	Siloxanes and Silicones, di-Me, [[[3-[(2-aminoethyl)amino]-2-methylpropyl]methoxymethylsilyl]oxy]- and (C13-15-alkyloxy)-terminated	188627-10-3
2b	Material Production	Conventional Cotton	Garment Dye	OPTISIL - M50 PLUS	Alcohols, C9-11-iso-, C10-rich, ethoxylated	78330-20-8
2b	Material Production	Conventional Cotton	Garment Dye	OPTIPOL - DAP		
2b	Material Production	Conventional Cotton	Garment Dye	FELOSAN RGN	Poly(oxy-1,2-ethanediyl), α-tridecyl-ω-hydroxy-, branched	69011-36-5
2b	Material Production	Conventional Cotton	Garment Dye	FELOSAN RGN	Ethanol, 2-[2-(2-butoxyethoxy)ethoxy]	143-22-6
2b	Material Production	Conventional Cotton	Garment Dye	FELOSAN RGN	3,6,9,12-Tetraoxahexadecan-1-ol	1559-34-8
2b	Material Production	Conventional Cotton	Garment Dye	Dilute Acetic Acid, 80%	Acetic acid	64-19-7
2b	Material Production	Conventional Cotton	Garment Dye	Dilute Acetic Acid, 80%	Water	7732-18-5
2a	Material Production	Organic Cotton	Prepare for dye			
2b	Material Production	Organic Cotton	Piece Dye			
2b	Material Production	Organic Cotton	Garment Dye	REWIN GCF	Polyammonium compound	
2b	Material Production	Organic Cotton	Garment Dye	BNA Smark Enzyme Anti-Peeler	Cellulase	9012-54-8

Tier #	Tier Name	Fiber	Process	Material Name	Chemical	CAS RN
2b	Material Production	Organic Cotton	Garment Dye	Scour RM	Isotridecanol, ethoxylated	69011-36-5
2b	Material Production	Organic Cotton	Garment Dye	Scour RM	2-[2-(2-butoxyethoxy)ethoxy]ethanol	143-22-6
2b	Material Production	Organic Cotton	Garment Dye	Scour RM	3,6,9,12-Tetraoxahexadecan-1-ol	1559-34-8
2b	Material Production	Organic Cotton	Garment Dye	TUBINGAL 6069-A	Octadecanamide, N-[2-[(2-hydroxyethyl)amino]ethyl]-	141-21-9
2b	Material Production	Organic Cotton	Garment Dye	Sera Wet M-A70 (3)	sodium-di-alkyl-sulfosuccinate	577-11-7
2b	Material Production	Organic Cotton	Garment Dye	Sera Wet M-A70 (3)	diethylene glycol	111-46-6
2b	Material Production	Organic Cotton	Garment Dye	Sera Wet M-A70 (3)	2-methyl-2,4-pentanediol	107-41-5
2b	Material Production	Organic Cotton	Garment Dye	Multiprep SS-400		
2b	Material Production	Organic Cotton	Garment Dye	Sera Sperse C-SS 600	2-methyl-2H-Isothiazolone-2-one	2682-20-4
2b	Material Production	Organic Cotton	Garment Dye	Sera Sperse C-SS 601	water	7732-18-5
2b	Material Production	Organic Cotton	Garment Dye	Sera Sperse C-SS 602	sodium polyacrylate	7446-81-3
2b	Material Production	Organic Cotton	Garment Dye	Procion Yellow H-E4R		
2b	Material Production	Organic Cotton	Garment Dye	EVERZOL BLACK ED	Remazol Black B	17095-24-8
2b	Material Production	Organic Cotton	Garment Dye	EVERZOL BLACK ED	2,4-diamino-5-[4-[(2-sulfoxyl ethyl)sulfonyl]phenylazo]benzenesulfonic acid	27624-67-5
2b	Material Production	Organic Cotton	Garment Dye	EVERZOL BLACK ED	disodium 8-amino-5-{4-[2-(sulfonatoethoxy)sulfonyl]phenylazo}naphthalene-2-sulfonate	250688-43-8
2b	Material Production	Organic Cotton	Garment Dye	Procion Red H-E7B		
2b	Material Production	Organic Cotton	Garment Dye	SYNO WHITE BYB	Sulfuric acid disodium salt	7757-82-6
2b	Material Production	Organic Cotton	Garment Dye	SYNO WHITE BYB	Benzenesulfonic acid, 2,2'-(1,2-ethenediyl)bis[5-[[4-[bis(2-hydroxyethyl)amino]-6-(phenylamino)-1 ,3,5-triazin-2-yl]amino]-, disodium salt	4193-55-9
2b	Material Production	Organic Cotton	Garment Dye	SYNO WHITE BYB	Soda Ash	497-19-8
2b	Material Production	Organic Cotton	Garment Dye	SYNO WHITE BYB	Fatty acids, (C16-C18) and C18 unsaturated, isobutyl ester	10024-47-2
2b	Material Production	Organic Cotton	Garment Dye	SYNO WHITE BYB	Trade Secret	

Tier #	Tier Name	Fiber	Process	Material Name	Chemical	CAS RN
2b	Material Production	Organic Cotton	Garment Dye	SYNO WHITE BYB	Trade Secret	
2b	Material Production	Organic Cotton	Garment Dye	Procion Navy H-ER 150%		
2b	Material Production	Organic Cotton	Garment Dye	ULTRAWET WS	ULTRAWET WS	
2b	Material Production	Organic Cotton	Garment Dye	Sodium thiosulfate	Thiosulfuric acid (H2S2O3), disodium salt	7772-98-7
2b	Material Production	Organic Cotton	Garment Dye	OPTISIL - M50 PLUS	Siloxanes and Silicones, di-Me, [[[3-[(2-aminoethyl)amino]-2-methylpropyl]methoxymethylsilyl]oxy]- and (C13-15-alkyloxy)-terminated	188627-10-3
2b	Material Production	Organic Cotton	Garment Dye	OPTISIL - M50 PLUS	Alcohols, C9-11-iso-, C10-rich, ethoxylated	78330-20-8
2b	Material Production	Organic Cotton	Garment Dye	OPTIPOL - DAP		
2b	Material Production	Organic Cotton	Garment Dye	FELOSAN RGN	Poly(oxy-1,2-ethanediyl), α-tridecyl-ω-hydroxy-, branched	69011-36-5
2b	Material Production	Organic Cotton	Garment Dye	FELOSAN RGN	Ethanol, 2-[2-(2-butoxyethoxy)ethoxy]	143-22-6
2b	Material Production	Organic Cotton	Garment Dye	FELOSAN RGN	3,6,9,12-Tetraoxahexadecan-1-ol	1559-34-8
2b	Material Production	Organic Cotton	Garment Dye	Dilute Acetic Acid, 80%	Acetic acid	64-19-7
2b	Material Production	Organic Cotton	Garment Dye	Dilute Acetic Acid, 80%	Water	7732-18-5
2b	Material Production	Tencel Lyocell	Garment Dye	Procion Yellow H-E4R		
2b	Material Production	Tencel Lyocell	Garment Dye	EVERZOL BLACK ED	Remazol Black B	17095-24-8
2b	Material Production	Tencel Lyocell	Garment Dye	EVERZOL BLACK ED	2,4-diamino-5-[4-[(2-sulfoxyl ethyl)sulfonyl]phenylazo] benzenesulfonic acid	27624-67-5
2b	Material Production	Tencel Lyocell	Garment Dye	EVERZOL BLACK ED	disodium 8-amino-5-{4-[2-(sulfonatoethoxy)sulfonyl]phenylazo}naphthalene-2-sulfonate	250688-43-8
2b	Material Production	Tencel Lyocell	Garment Dye	Procion Red H-E7B		
2b	Material Production	Tencel Lyocell	Garment Dye	SYNO WHITE BYB	Sulfuric acid disodium salt	7757-82-6
2b	Material Production	Tencel Lyocell	Garment Dye	SYNO WHITE BYB	Benzenesulfonic acid, 2,2'-(1,2-ethenediyl)bis[5-[[4-[bis(2-hydroxyethyl)amino]-6-(phenylamino)-1 ,3,5-triazin-2-yl]amino]-, disodium salt	4193-55-9

Tier #	Tier Name	Fiber	Process	Material Name	Chemical	CAS RN
2b	Material Production	Tencel Lyocell	Garment Dye	SYNO WHITE BYB	Soda Ash	497-19-8
2b	Material Production	Tencel Lyocell	Garment Dye	SYNO WHITE BYB	Fatty acids, (C16-C18) and C18 unsaturated, isobutyl ester	10024-47-2
2b	Material Production	Tencel Lyocell	Garment Dye	SYNO WHITE BYB	Trade Secret	
2b	Material Production	Tencel Lyocell	Garment Dye	SYNO WHITE BYB	Trade Secret	
2b	Material Production	Tencel Lyocell	Garment Dye	Procion Navy H-ER 150%		
2b	Material Production	Tencel Lyocell	Garment Dye	ULTRAWET WS	ULTRAWET WS	
2b	Material Production	Tencel Lyocell	Garment Dye	Sodium thiosulfate	Thiosulfuric acid (H2S2O3), disodium salt	7772-98-7
2b	Material Production	Tencel Lyocell	Garment Dye	OPTISIL - M50 PLUS	Siloxanes and Silicones, di-Me, [[[3-[(2-aminoethyl)amino]-2-methylpropyl]methoxymethylsilyl]oxy]- and (C13-15-alkyloxy)-terminated	188627-10-3
2b	Material Production	Tencel Lyocell	Garment Dye	OPTISIL - M50 PLUS	Alcohols, C9-11-iso-, C10-rich, ethoxylated	78330-20-8
2b	Material Production	Tencel Lyocell	Garment Dye	OPTIPOL - DAP		
2b	Material Production	Tencel Lyocell	Garment Dye	FELOSAN RGN	Poly(oxy-1,2-ethanediyl), α-tridecyl-ω-hydroxy-, branched	69011-36-5
2b	Material Production	Tencel Lyocell	Garment Dye	FELOSAN RGN	Ethanol, 2-[2-(2-butoxyethoxy)ethoxy]	143-22-6
2b	Material Production	Tencel Lyocell	Garment Dye	FELOSAN RGN	3,6,9,12-Tetraoxahexadecan-1-ol	1559-34-8
2b	Material Production	Tencel Lyocell	Garment Dye	Dilute Acetic Acid, 80%	Acetic acid	64-19-7
2b	Material Production	Tencel Lyocell	Garment Dye	Dilute Acetic Acid, 80%	Water	7732-18-5
2b	Material Production	Linen	Garment Dye	Procion Yellow H-E4R		
2b	Material Production	Linen	Garment Dye	EVERZOL BLACK ED	Remazol Black B	17095-24-8
2b	Material Production	Linen	Garment Dye	EVERZOL BLACK ED	2,4-diamino-5-[4-[(2-sulfoxyl ethyl)sulfonyl]phenylazo]benzenesulfonic acid	27624-67-5
2b	Material Production	Linen	Garment Dye	EVERZOL BLACK ED	disodium 8-amino-5-{4-[2-(sulfonatoethoxy)sulfonyl]phenylazo}naphthalene-2-sulfonate	250688-43-8
2b	Material Production	Linen	Garment Dye	Procion Red H-E7B		

Tier #	Tier Name	Fiber	Process	Material Name	Chemical	CAS RN
2b	Material Production	Linen	Garment Dye	SYNO WHITE BYB	Sulfuric acid disodium salt	7757-82-6
2b	Material Production	Linen	Garment Dye	SYNO WHITE BYB	Benzenesulfonic acid, 2,2'-(1,2-ethenediyl)bis[5-[[4-[bis(2-hydroxyethyl) amino]-6-(phenylamino)-1 ,3,5-triazin-2-yl]amino]-, disodium salt	4193-55-9
2b	Material Production	Linen	Garment Dye	SYNO WHITE BYB	Soda Ash	497-19-8
2b	Material Production	Linen	Garment Dye	SYNO WHITE BYB	Fatty acids, (C16-C18) and C18 unsaturated, isobutyl ester	10024-47-2
2b	Material Production	Linen	Garment Dye	SYNO WHITE BYB	Trade Secret	
2b	Material Production	Linen	Garment Dye	SYNO WHITE BYB	Trade Secret	
2b	Material Production	Linen	Garment Dye	Procion Navy H-ER 150%		
2b	Material Production	Linen	Garment Dye	ULTRAWET WS	ULTRAWET WS	
2b	Material Production	Linen	Garment Dye	Sodium thiosulfate	Thiosulfuric acid (H2S2O3), disodium salt	7772-98-7
2b	Material Production	Linen	Garment Dye	OPTISIL - M50 PLUS	Siloxanes and Silicones, di-Me, [[[3-[(2-aminoethyl)amino]-2-methylpropyl]methoxymethylsilyl]oxy]- and (C13-15-alkyloxy)-terminated	188627-10-3
2b	Material Production	Linen	Garment Dye	OPTISIL - M50 PLUS	Alcohols, C9-11-iso-, C10-rich, ethoxylated	78330-20-8
2b	Material Production	Linen	Garment Dye	OPTIPOL - DAP		
2b	Material Production	Linen	Garment Dye	FELOSAN RGN	Poly(oxy-1,2-ethanediyl), α-tridecyl-ω-hydroxy-, branched	69011-36-5
2b	Material Production	Linen	Garment Dye	FELOSAN RGN	Ethanol, 2-[2-(2-butoxyethoxy)ethoxy]	143-22-6
2b	Material Production	Linen	Garment Dye	FELOSAN RGN	3,6,9,12-Tetraoxahexadecan-1-ol	1559-34-8
2b	Material Production	Linen	Garment Dye	Dilute Acetic Acid, 80%	Acetic acid	64-19-7
2b	Material Production	Linen	Garment Dye	Dilute Acetic Acid, 80%	Water	7732-18-5
2a	Material Production	Spandex	Garment Dye	Procion Yellow H-E4R		
2a	Material Production	Spandex	Garment Dye	EVERZOL BLACK ED	Remazol Black B	17095-24-8
2a	Material Production	Spandex	Garment Dye	EVERZOL BLACK ED	2,4-diamino-5-[4-[(2-sulfoxyl ethyl)sulfonyl]phenylazo] benzenesulfonic acid	27624-67-5

Tier #	Tier Name	Fiber	Process	Material Name	Chemical	CAS RN
2a	Material Production	Spandex	Garment Dye	EVERZOL BLACK ED	disodium 8-amino-5-{4-[2-(sulfonatoethoxy)sulfonyl]phenylazo}naphthalene-2-sulfonate	250688-43-8
2a	Material Production	Spandex	Garment Dye	Procion Red H-E7B		
2a	Material Production	Spandex	Garment Dye	SYNO WHITE BYB	Sulfuric acid disodium salt	7757-82-6
2a	Material Production	Spandex	Garment Dye	SYNO WHITE BYB	Benzenesulfonic acid, 2,2'-(1,2-ethenediyl)bis[5-[[4-[bis(2-hydroxyethyl)amino]-6-(phenylamino)-1 ,3,5-triazin-2-yl]amino]-, disodium salt	4193-55-9
2a	Material Production	Spandex	Garment Dye	SYNO WHITE BYB	Soda Ash	497-19-8
2a	Material Production	Spandex	Garment Dye	SYNO WHITE BYB	Fatty acids, (C16-C18) and C18 unsaturated, isobutyl ester	10024-47-2
2a	Material Production	Spandex	Garment Dye	SYNO WHITE BYB	Trade Secret	
2a	Material Production	Spandex	Garment Dye	SYNO WHITE BYB	Trade Secret	
2a	Material Production	Spandex	Garment Dye	Procion Navy H-ER 150%		
2a	Material Production	Spandex	Garment Dye	ULTRAWET WS	ULTRAWET WS	
2a	Material Production	Spandex	Garment Dye	Sodium thiosulfate	Thiosulfuric acid ($H_2S_2O_3$), disodium salt	7772-98-7
2a	Material Production	Spandex	Garment Dye	OPTISIL - M50 PLUS	Siloxanes and Silicones, di-Me, [[[3-[(2-aminoethyl)amino]-2-methylpropyl]methoxymethylsilyl]oxy]- and (C13-15-alkyloxy)-terminated	188627-10-3
2a	Material Production	Spandex	Garment Dye	OPTISIL - M50 PLUS	Alcohols, C9-11-iso-, C10-rich, ethoxylated	78330-20-8
2a	Material Production	Spandex	Garment Dye	OPTIPOL - DAP		
2a	Material Production	Spandex	Garment Dye	FELOSAN RGN	Poly(oxy-1,2-ethanediyl), α-tridecyl-ω-hydroxy-, branched	69011-36-5
2a	Material Production	Spandex	Garment Dye	FELOSAN RGN	Ethanol, 2-[2-(2-butoxyethoxy)ethoxy]	143-22-6
2a	Material Production	Spandex	Garment Dye	FELOSAN RGN	3,6,9,12-Tetraoxahexadecan-1-ol	1559-34-8
2a	Material Production	Spandex	Garment Dye	Dilute Acetic Acid, 80%	Acetic acid	64-19-7
2a	Material Production	Spandex	Garment Dye	Dilute Acetic Acid, 80%	Water	7732-18-5
2a	Material Production	Polyester	Desizing/Scouring		Polyethylene glycol	9002-93-1

Tier #	Tier Name	Fiber	Process	Material Name	Chemical	CAS RN
					4-(tert-octylphenyl) ether	
2a	Material Production	Polyester	Desizing/Scouring		Polyethylene glycol mono(octyl)phenyl ether	9036-19-5
2a	Material Production	Polyester	Desizing/Scouring		Poly (oxy-1,2-ethanediyl), alpha-(octylphenyl)-omega-hydroxy-, branched	68987-90-6
2b	Material Production	Polyester	Dye		Lignin sodium sulfonate	8061-51-6
2b	Material Production	Polyester	Dye		PEG-10 hydrogenated tallow amine	61791-26-2
2b	Material Production	Polyester	Dye		Naphthalene	91-20-3
2b	Material Production	Polyester	Dye		Sulfuric acid	7664-93-9
2b	Material Production	Polyester	Dye		Sodium Hydroxide	1310-73-2
2b	Material Production	Polyester	Dye		Calcium Carbonate	1317-65-3
2b	Material Production	Polyester	Dye		Sodium Chloride	7647-14-5
2b	Material Production	Polyester	Dye		Acetic acid	64-19-7
2b	Material Production	Polyester	Dye		Chlorobenzenes	108-90-7
2b	Material Production	Polyester	Dye		4-Chlorotoluene	106-43-4
2b	Material Production	Polyester	Dye		Disperse Yellow 3	2832-40-8
2b	Material Production	Polyester	Dye		Disperse Blue 1	2475-45-8
2b	Material Production	Polyester	Dye		Disperse Red 1	2872-52-8
2b	Material Production	Polyester	Dye		Sodium Hydroxide	1310-73-2
2b	Material Production	Polyester	Dye		Sodium dithionite	7775-14-6
2b	Material Production	Polyester	Dye		Sodium hydroxide	1310-73-2
2b	Material Production	Polyester	Dye		Potassium carbonate	584-08-7
2b	Material Production	Polyester	Dye		Citric acid	77-92-9
1a	Finished Product Assembly	Conventional Cotton				N/A
1a	Material Production	Organic Cotton	Cut and Sew			N/A
1a	Material Production	Organic Cotton	Cut and Sew			N/A
1a	Material Production	Organic Cotton	Cut and Sew			N/A
1c	Finished Product Assembly	Organic Cotton	Finishing (Prepare for ship)			N/A
1c	Finished Product Assembly	Organic Cotton	Finishing (Prepare for ship)			N/A
1c	Finished Product Assembly	Organic Cotton	Finishing (Prepare for ship)			N/A
1a	Material Production	Tencel Lyocell	Cut and Sew			N/A
1c	Finished Product Assembly	Tencel Lyocell	Finishing (Prepare for ship)			N/A
1a	Material Production	Linen	Cut and Sew			N/A
1c	Finished Product Assembly	Linen	Finishing (Prepare for ship)			N/A
1a	Finished Product Assembly	Spandex				N/A
1a	Finished Product	Polyester	Cut and Sew			N/A

Tier #	Tier Name	Fiber	Process	Material Name	Chemical	CAS RN
	Assembly					
1c	Finished Product Assembly	Polyester	Finishing (Prepare for ship)			N/A

APPENDIX B: Supply Chain Diagram—Tier Processes By Fiber

	Tier 4	Tier 3	Tier 2	Tier 1
Cotton	4a. Growing the cotton *4b. Picking the cotton (no chemistry)* *4c. Ginning the cotton (no chemistry)*	3a. Spinning cotton fibers into cotton yarn 3b. Knitting/Weaving into white cotton fabric	2a. Scouring & bleaching cotton fibers 2b. Dyeing white cotton fabric *2c.Chemical finishing treatments (excluded, MATE does not do)*	*1a. Cut & sew (no chemistry)* 1b. Garment washing & spot clean *1c. Prepare for ship (no chemistry)*
Linen	4a. Growing the flax *4b. Retting the flax (no chemistry; MATE uses non-chemical retting)*	3a. Spinning flax fibers into linen yarn 3b. Knitting/Weaving thread into unbleached "raw" linen fabric	2a. Scouring & bleaching raw linen fabric 2b. Dyeing white linen fabric *2c. Chemical finishing treatments (excluded, MATE does not do)*	*1a. Cut & sew (no chemistry)* 1b. Garment washing & spot clean *1c. Prepare for ship (no chemistry)*
Lyocell	4a. Responsible forestry (FSC/PEFC certified) 4b. Wood pulp creation	3a. Turning wood pulp into lyocell fibers (including bleaching) 3b. Spinning lyocell fibers into lyocell yarn 3c. Knitting/Weaving lyocell thread into lyocell fabric	2a. Scouring & bleaching lyocell fabric 2b. Dyeing white lyocell fabric *2b.Chemical finishing treatments (excluded, MATE does not do)*	*1a. Cut & sew (no chemistry)* 1b. Garment washing & spot clean *1c. Prepare for ship (no chemistry)*
Spandex	4a. Production of pre-polymer 4b. Chain extension reaction to create pre-polymer solution 4c. Diluting to create pre-polymer 'spandex' solution	3a. Solvent spinning/wet spinning of spandex fibers, adding finishing 3b. Wrapping of spandex fiber into spandex yarn 3c. Knitting/Weaving spandex fiber into spandex (blended) fabric	2a. Dyeing (blended) white spandex fabric *2b. Chemical finishing treatments (excluded, MATE does not do)*	*1a. Cut & sew (no chemistry)* *1b. Prepare for ship (no chemistry)*
Polyester	4a. Extraction of p-xylene and ethylene glycol from petroleum 4b. Polymerization of terephthalic acid and ethylene glycol 4c. Extrusion of polymer pellets	3a. Melt spinning (melting polymer pellets, extruding into fibers) 3b. Drawing and texturizing 3c. Knitting/Weaving polyester yarn into polyester fabric	2a. Scouring fabric prior to dyeing 2b. Dyeing white polyester fabric 2c. Mechanical finishing treatments 2d. Chemical finishing treatments (excluded, MATE does not do)	*1a. Cut & sew (no chemistry)* 1b. Garment washing & spot cleaning *1c. Prepare for ship (no chemistry)*

APPENDIX C: Restricted Substance List (RSL) Index

Applicable RSL Name	Product Focus	Summary	Link
American Apparel & Footwear Association (AAFA) Restricted Substance List	Apparel, Footwear, Home Textiles	This Restricted Substance List (RSL) is intended to provide apparel and footwear companies with information related to regulations and laws that restrict or ban certain chemicals and substances in finished home textile, apparel, and footwear products around the world.	https://www.aafaglobal.org/AAFA/Solutions_Pages/Restricted_Substance_List.aspx
Bluesign v13.0	Textiles, Leather Articles & Accessories	The Restricted Substances List (RSL) is an extract of the bluesign® System Substances List (BSSL) and contains consumer safety limits and recommended testing methods for the most important and legally restricted substances in textile/leather articles and accessories.	https://www.bluesign.com/en/downloads
Cradle to Cradle (C2C) Certified - Banned List of Chemicals	"Products" Including Apparel, Shoes & Accessories	The Banned List contains those chemicals and substances that are banned for use in Cradle to Cradle Certified™ products as intentional inputs above 1000ppm. These substances were selected for inclusion on the Banned Lists due to their tendency to accumulate in the biosphere and lead to irreversible negative human health effects. In addition, several substances were selected due to hazardous characteristics associated with their manufacture, use, and disposal.	https://www.c2ccertified.org/resources/detail/cradle-to-cradle-certified-banned-list-of-chemicals https://www.c2ccertified.org/resources/detail/cradle-to-cradle-certified-restricted-substances-list-rsl
German UBA List of Persistent, Mobile, and Toxic Substances (PMTs)	Any	According to the UBA (Germany Environmental Agency), the chemicals that have the highest likelihood of polluting and contaminating drinking water are substances that are mobile enough to travel in the water cycle through natural and artificial barriers and persistent enough to survive such a long journey. UBA has funded several research projects that have scientifically developed this list of criteria to identify persistent and mobile substances under REACH. Thus it is the combination of 2 intrinsic substance properties "Persistency" and "Mobility" that cause very high concern. (see link for more details).	https://www.umweltbundesamt.de/en/PMT-substances

Applicable RSL Name	Product Focus	Summary	Link
Green Science Policy Institute (GSPI) Six Classes - Antimicrobials	All Products	The Six Class Approach focuses on entire classes or groups of chemicals of concern, rather than phasing out problematic chemicals one at a time, in order to prevent "regrettable substitutions". Antimicrobials are chemcials used to kill or inhibit the growth of microbes. Antimicrobials of concern include halogenated aromatic compounds, nanosilver, and quaterny ammonium compounds (QACs or quats). Avoid products with triclosan, triclocarban, quats (often ending with '-onium chloride') or nanometals.	https://www.sixclasses.org/videos/antimicrobials
GSPI Six Classes - Flame Retardants	All Products	Flame retardants are chemicals that are supposed to slow ignition and prevent fires. They are used to meet flammability regulations. Flame retardants of concern include organohalogen and organophosphate chemicals such as polybrominated diphenyl ethers (PBDEs) and chlorinated tris (TDCPP).	https://www.sixclasses.org/videos/flame-retardants
GSPI Six Classes - Some Solvents	All Products	Solvents are a diverse class of chemicals that are used to dissolve or disperse other substances. Some solvents of concern include aromatic hydrocarbon solvents (e.g., toluene, xylene, benzene) and halogenated organic solvents (e.g., methylene chloride, perchloroethylene, trichloroethylene).	https://www.sixclasses.org/videos/some-solvents
Living Building Challenge (LBC) Watch List - Priority for Red List Inclusion	Building materials and finishes, including upholstery	The Living Building Challenge (LBC) Red List represents the "worst in class" materials, chemicals, and elements known to pose serious risks to human health and the greater ecosystem that are prevalent in the building products industry. The Watch List is a list of chemicals identified for potential inclusion on the LBC Red List, but have not been formally listed yet.	https://living-future.org/lbc/red-list/
LBC 4.0 Red List	Building materials and finishes, including upholstery	The Living Building Challenge (LBC) Red List represents the "worst in class" materials, chemicals, and elements known to pose serious risks to human health and the greater ecosystem that are prevalent in the building products industry. While there are other substances that could be added, the Red List focuses on substances with the greatest potential benefit if they were significantly curbed or eliminated from the building industry. The Red List is updated annually.	https://living-future.org/lbc/red-list/

Applicable RSL Name	Product Focus	Summary	Link
MADESAFE Banned / Restricted List	Home Goods, Clothing, Textiles, Etc	Products seeking the MADE SAFE (Made With Safe Ingredients™) seal are screened to ensure that over 6,500 Banned / Restricted List substances have been avoided or constrained, thereby eliminating the worst hazards commonly found in products used in our homes and daily routines.	https://madesafe.org/pages/why-made-safe
Oeko-Tex Eco Passport (RSL/MSRL)	Textiles & Leather process chemicals & chemical compounds	Leather and textile chemicals certified in accordance with the ECO PASSPORT have been tested for harmful substances in critical concentrations as listed in the ECO PASSPORT standard RSL/MRSL, which is updated annually to include new scientific findings or statutory requirements.	https://www.oeko-tex.com/en/our-standards/eco-passport-by-oeko-tex, & https://www.oeko-tex.com/en/our-standards/eco-passport-by-oeko-tex
UNEP - PIC Annex III (Rotterdam Convention)	Pesticides & Industrial Chemicals	The chemicals listed in Annex III include pesticides and industrial chemicals that have been banned or severely restricted for health or environmental reasons by two or more Parties and which the Conference of the Parties has decided to subject to the PIC procedure. There are a total of 54 chemicals listed in Annex III, 35 pesticides (including 3 severely hazardous pesticide formulations), 18 industrial chemicals, and 1 chemical in both the pesticide and the industrial chemical categories.	http://www.pic.int/TheConvention/Chemicals/AnnexIIIChemicals
WHO Pesticides - Extremely Hazardous and Highly Hazardous (Classes 1a and 1b)	Pesticides	A classification system to distinguish between the more and the less hazardous forms of selected pesticides based on acute risk to human health. Includes consideration of the toxicity of the technical active substance and also describes methods for the classification of formulations. There are 5 classifications, ranging from most extreme to least hazardous: 1a) extremely hazardous, 1b) highly hazardous, II) moderately hazardous, III) slightly hazardous, U) unlikely to present acute hazard. Toxicity based on LD50 for a rat (oral and dermal).	https://www.who.int/publications/i/item/9789240005662
Zero Discharge of Hazardous Chemicals (ZDHC) v2.0	Textiles	An RSL that focuses on sustainable fashion and eliminating harmful chemicals in the input, process, and output stages of chemical manufacturing. Divided into two chapters. Chapter 1: MRSL for Textiles and Synthetic Leather Processing. Chapter 2: MRSL for Leather Processing.	https://mrsl.roadmaptozero.com/
Endocrine Disruptor List II	Unspecified	This list contains substances that are currently under evaluation in an EU legislative process due to explicit concerns for possible endocrine disrupting properties. This could be due to a Member State or ECHA having included the compound on the CoRAP list (REACH), or due to an	https://edlists.org/th-substances-under-en-endocrine-disrupt

Applicable RSL Name	Product Focus	Summary	Link
		ongoing evaluation of endocrine disrupting properties under the Cosmetics Products Regulation. Pesticides and biocides which are concluded as endocrine disruptors in the scientific committees are placed on List II until legally adopted, at which time they are transferred to List I.	

APPENDIX D: Regulatory Hazard Lists (RHL) Index

Applicable Regulatory Hazard List	Product Focus	Summary	Link
California Department of Toxic Substances Control (DTSC) Candidate List	Chemicals of Concern	The primary purpose of the Candidate Chemicals List is for DTSC to identify potential Chemicals of Concern in Priority Products. This process includes evaluation of adverse impact and exposure criteria.	https://dtsc.ca.gov/scp/candidate-chemicals-list/
California Proposition 65	Carcinogens & EDs	Proposition 65 requires businesses to provide warnings to Californians about significant exposures to chemicals that cause cancer, birth defects or other reproductive harm. Proposition 65 also prohibits California businesses from knowingly discharging significant amounts of listed chemicals into sources of drinking water. Proposition 65 requires California to publish and annually update a list of chemicals known to cause cancer, birth defects or other reproductive harm. This list includes approximately 900 chemicals.	https://oehha.ca.gov/proposition-65/proposition-65-list
EU - Annex VI Carcinogenic, Mutagenic or Toxic for Reproduction (CMRs) List- Category 1 chemicals only	CMRs	Regulation on the classification, labeling and packaging of substances. EU - Annex VI CMRs: EU legislation subdivides CMR Category 1 into 1A and 1B. 1A stands for chemical substances for which there is scientific evidence based on humans that the substance is carcinogenic, mutagenic or reprotoxic; 1B stands for chemical substances for which there is scientific evidence based on animals that the substance is carcinogenic, mutagenic or reprotoxic. Not all CMR substances are restricted by REACH. Only CMR category 1A/1B substances listed in the table 3.1 of annex VI to CLP regulation are restricted by REACH.	http://www.chemsafetypro.com/Topics/Restriction/REACH_annex_xvii_restriction_CMR_substance_1A_1B.html
EU - GHS (H-Statements)	Hazardous Substances	Once the classification of a chemical has been determined, signal word, hazard pictograms, hazard statements and precautionary statements will be assigned. GHS hazard statement means a standard phrase assigned to a hazard class and category to describe the nature and severity of a chemical hazard. Each hazard statement is designated a code, starting with the letter H and followed by 3 digits. H2xx: Physical hazards; H3xx: Health hazards; H4xx: Environmental hazards. If any substance has been assigned with hazard statement code H340, H350 or H360, it will be restricted by REACH.	http://www.chemsafetypro.com/Topics/GHS/GHS_hazard_statement_h_code.html

Applicable Regulatory Hazard List	Product Focus	Summary	Link
EU - POPs (Persistent Organic Pollutants)	POPs	Persistent organic pollutants (POPs) are chemicals that persist in the environment, bioaccumulate through the food web, and pose a risk of causing adverse effects to human health and the environment. The POPs Regulation aims to protect human health and the environment with specific control measures that: prohibit or severely restrict the production, placing on the market and use of POPs; minimize the environmental release of POPs that are formed as industrial by-products; make sure that stockpiles of restricted POPs are safely managed; an ensure the environmentally sound disposal of waste consisting of, or contaminated by POPs.	https://ec.europa.eu/environment/chemicals/international_conventions/index_en.htm
EU - Priority Endocrine Disruptor	EDs	It is intended that the priority list of chemicals developed within the EU-Strategy for Endocrine Disruptors will be used to prioritize further detailed review of the information. However, it is important that the listings produced are not regarded as final and unchangeable: addition and removal of chemicals may be required in response to either developments in scientific knowledge or changes in chemical usage patterns.	https://ec.europa.eu/environment/chemicals/endocrine/strategy/substances_en.htm#priority_list
EU - R-Phrases	Any	Risk-phrase, sometimes abbreviated as R-phrase, refers to the labeling, via a phrase or sentence, of dangerous substances according to the risks they present. Dangerous substances can be classified according to the type of risk and each category has a code with an associated risk-phrase, a label with a standardized meaning in different languages.	https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Risk-phrase
EU - REACH Annex XVII Restricted Substances	Hazardous Substances & POPs	Some substances are banned by REACH annex XVII. These substances include Polychlorinated terphenyls (PCTs), asbestos fibers, pentachlorophenol and its salts and esters, and monomethyl-tetrachlorodiphenyl methane. Many of them are persistent organic pollutants (POPs).	http://www.chemsafetypro.com/Topics/EU/REACH_annex_xvii_REACH_restricted_substance_list.html
EU - SVHC Candidate List	CMRs & PBTs	Substances with the following hazard properties may be identified as SVHCs: Substances meeting the criteria for classification as carcinogenic, mutagenic or toxic for reproduction (CMR) category 1A or 1B in accordance with the CLP Regulation; Substances which are persistent, bioaccumulative and toxic (PBT) or very persistent and very bioaccumulative (vPvB) according to REACH Annex XIII; Substances on a case-by-case basis, that cause an	https://echa.europa.eu/substances-of-very-high-concern-identification-explained

Applicable Regulatory Hazard List	Product Focus	Summary	Link
		equivalent level of concern as CMR or PBT/vPvB substances.	
German FEA - Substances Hazardous to Waters	Aquatic Toxicity	This is a list of chemicals that fit a variety of chemical hazard profiles that should not enter the waters, whether due to aquatic toxicity or toxicity to humans who will use the waters. Requirements for assigning the four water hazard classes (WGK 0-3) to a chemical are detailed in section 3 of the "Guidelines for self classification" document at link.	https://pharosproject.net/hazard-lists/310
GHS - Australia	Hazardous Substances	Australia uses the GHS to classify hazardous chemicals. These classifications are based on defined criteria. Manufacturers and importers must determine if a chemical is hazardous. If the chemical is hazardous, manufacturers and importers must correctly classify the hazardous chemical. Focus is on chemicals, polymers, ingredients of products used in printing, plastics, mining, construction, paints, adhesives, consumer goods, cosmetics and more.	https://www.safeworkaustralia.gov.au/safety-topic/hazards/chemicals/classifying-chemicals/classifying-chemicals-australia
GHS - Japan	Hazardous Substances	Japan uses the GHS to classify hazardous chemicals. The Japan Industrial Standards is the framework through which GHS is applied in Japan.	https://www.cirs-reach.com/GHS/Japan_GHS_Implementation.html
GHS - Korea	Hazardous Substances	Korea uses the GHS to classify hazardous chemicals. This requires that chemicals be classified to align with GHS classification criteria. Additionally, chemical suppliers are expected to prepare safety data sheets and label containers according the the Korean Ministry of Employment and Labor's Public Notice No. 2016-19 - The Standard for Classification Labeling of Chemical Substance and Material Safety Data Sheet.	https://www.chemsafetypro.com/Topics/Korea/GHS_in_Korea_SDS_label.html
GHS - Malaysia	Hazardous Substances	Malaysia uses the GHS to classify hazardous chemicals. Under Malaysia's Classification, Labelling and Safety Data Sheet of Hazardous Chemicals Regulation, importers and producers of hazardous chemicals must prepare and submit a chemical inventory to the Director General.	https://www.cirs-reach.com/GHS/Malaysia_GHS_SDS_Labelling.html
GHS - New Zealand	Hazardous Substances	New Zealand uses the GHS to classify hazardous chemicals. The GHS is applied through New Zealand's Environmental Protection Authority.	https://www.epa.govt.nz/industry-areas/hazardous-substances/new-zealands-new-hazard-classification-system/

Applicable Regulatory Hazard List	Product Focus	Summary	Link
OR DEQ - Priority Persistent Pollutants	PBTs	The Oregon Department of Environmental Quality (DEQ) compiles a prioritized list of persistent bioaccumulative toxics that have a documented effect on human health, wildlife and aquatic life. Priority persistent pollutants are substances that are toxic and either persist in the environment or accumulate in the tissues of humans, fish, wildlife, or plants.	https://pharosproject.net/hazard-lists/54
OSPAR - Priority PBTs & EDs & equivalent concern	PBTs & EDs	OSPAR is a consortium of 15 European countries whose mission is to protect the North-East Atlantic. PBT (persistent bioaccumulative toxic) and endocrine disruptors (ED) are a subset of chemicals on the OSPAR List of Chemicals for Priority Action.	https://www.ospar.org/work-areas/hasec/hazardous-substances/priority-action
UNEP Stockholm Convention - POPs	POPs	This list uses data from 42 countries to record the presence of POPs in humans and the environment. At time of writing the list has 12 initial POPs and 14 new POPs that were adopted between 2009-2015.	https://www.unep.org/explore-topics/chemicals-waste/what-we-do/persistent-organic-pollutants/global-monitoring
US CDC - Occupational Carcinogens	Carcinogens	List of substances NIOSH considers to be potential occupational carcinogens.	https://www.cdc.gov/niosh/topics/cancer/npotocca.html
US EPA - Chemicals of Concern	PBTs	This lists the EPA's Toxics Release Inventory (TRI) chemicals that are persistent, bioaccumulative, and toxic (PBT) and are classified as chemicals of special concern, including lead and lead compounds, mercury and mercury compounds, dioxin and dioxin-like compounds.	https://www.epa.gov/trinationalanalysis/chemicals-special-concern
US EPA - IRIS Carcinogens	Carcinogens	The EPA's IRIS Program identifies and characterizes the health hazards of chemicals found in the environment. Each IRIS assessment can cover a chemical, a group of related chemicals, or a complex mixture. IRIS assessments are an important source of toxicity information used by EPA, state and local health agencies, other federal agencies, and international health organizations. This list is a subset specific to carcinogens.	https://www.epa.gov/iris/basic-information-about-integrated-risk-information-system
US OSHA Carcinogens	Carcinogens	List of carcinogenic chemicals that humans can be exposed to in the workplace.	https://www.osha.gov/carcinogens

Applicable Regulatory Hazard List	Product Focus	Summary	Link
US NIH - Report on Carcinogens	Carcinogens	The U.S. Department of Health and Human Services (HHS) 15th Report on Carcinogens (2021) is a congressionally mandated, science-based public health document which now includes 256 listings of substances — chemical, physical, and biological agents; mixtures; and exposure circumstances — that are known or reasonably anticipated to cause cancer in humans.	https://ntp.niehs.nih.gov/whatwestudy/assessments/cancer/roc/index.html
WA DoE - PBT	PBTs	The Washington State Department of Ecology developed a PBT Rule in 2006 (WAC 173-333) that established a process for identifying PBTs and developing chemical action plans (CAPs) to address their impacts. This is the list of PBT chemicals and chemical groups addressed by the WA State plan.	https://pharosproject.net/hazard-lists/24
US EPA - Priority PBTs (NWMP)	PBTs	The US EPA National Waste Minimization Program (NWMP) focuses efforts on reducing 31 Priority Chemicals (PCs) (or chemical classes) found in products and wastes by finding ways to eliminate or substantially reduce their use in production.	https://pharosproject.net/hazard-lists/25?sublist_id=111&tab=chemicals-list-panel
EC - CEPA Toxic Substances (Schedule 1)	PBTs	In determining whether a substance should be declared "toxic" under the Canadian Environmental Protection Act (CEPA 1999), the likelihood and magnitude of releases into the environment and the harm it may cause to human health or ecosystems at levels occurring in the Canadian environment are taken into account. If a substance is found to be toxic according to CEPA, the Ministers recommend that the substance be added to the List of Toxic Substances (CEPA 1999 Schedule 1). Preventive or control actions such as regulations, guidelines or codes of practice, are then considered for any aspect of the substance's life cycle.	https://pharosproject.net/hazard-lists/318?sublist_id=435&tab=chemicals-list-panel

APPENDIX E: Unique Chemical List

	Chemical (Listed Alphabetically)	CAS RN	Included in Analysis?
1	1,3,5-Triazine-2,4,6(1h,3h,5h)-Trione, 1,3,5-Tris[[4-(1,1-Dimethylethyl) -3-Hydroxy-2,6-Dimethylphenyl]Methyl]-	40601-76-1	
2	2-Methyl1-1, 5-Pentanediamine (Mpmd)	15520-10-2	
3	2-Oxo-3-(2,4,6-Trimethylphenyl)-1-Oxaspiro[4.4]Non-3-En-4-Yl 3,3-Dimethylbutanoate	283594-90-1	
4	2,4-Diamino-5-[4-[(2-Sulfoxyl Ethyl)Sulfonyl]Phenylazo]Benzenesulfonic Acid	27624-67-5	
5	3,6,9,12-Tetraoxahexadecan-1-Ol	1559-34-8	
6	3(2h)-Isothiazolone, 2-Methyl-	2682-20-4	
7	4-Chlorotoluene	106-43-4	
8	Acephate	30560-19-1	
9	Acetamiprid	160430-64-8	
10	Acetic Acid	64-19-7	
11	Acrylamide	79-06-1	
12	Alcohols, C16-22, Ethoxylated	69227-20-9	
13	Alcohols, C9-11-Iso-, C10-Rich, Ethoxylated	78330-20-8	
14	Alpha Amylase (Pancreatic)	9000-90-2	
15	Alpha-Endosulfan	959-98-8	
16	Ammonia	7664-41-7	
17	Azadirachtin	11141-17-6	
18	Barium Sulfate	7727-43-7	
19	Benzenesulfonic Acid, 2,2'-(1,2-Ethenediyl)Bis[5-[[4-[Bis(2-Hydroxyethyl)Amino]-6-(Phenylamino)-1 ,3,5-Triazin-2-Yl]Amino]-, Disodium Salt	4193-55-9	
20	Benzotriazole	95-14-7	
21	Bleach Plus Ammonia (Mixture)	7681-52-9	
22	Butanedioic Acid, Sulfo-, 1,4-Bis(2-Ethylhexyl) Ester, Sodium Salt	0577-11-7	
23	Calcium Carbonate	1317-65-3	
24	Cellulase	9012-54-8	
25	Cellulose	9004-34-6	
26	Chlorobenzenes	108-90-7	
27	Chlorpyrifos	2921-88-2	
28	Citric Acid	77-92-9	
29	Copoly(Ethylene Adipate)	24938-37-2	
30	Cypermethrin	52315-07-08	
31	Di Methyl Formamide (Dmf),	68-12-2	
32	Diethylene Glycol	111-46-6	
33	Dimethoate	60-51-5	
34	Dimethyl Acetamide	127-19-5	
35	Dimethyl Diallyl Ammonium Chloride	7398-69-8	
36	Dimethyl Sulfaoxide	67-68-5	

	Chemical (Listed Alphabetically)	CAS RN	Included in Analysis?
37	Disodium 8-Amino-5-{4-[2-(Sulfonatoethoxy)Sulfonyl]Phenylazo}Naphthalene-2-Sulfonate	250688-43-8	
38	Disodium Phosphite	13708-85-5	
39	Disperse Blue 1	2475-45-8	
40	Disperse Red 1	2872-52-8	
41	Disperse Yellow 3	2832-40-8	
42	Ethanol, 2-[2-(2-Butoxyethoxy)Ethoxy]-	143-22-6	
43	Ethylene Glycol	107-21-1	
44	Ethylenediamine (Eda)	107-15-3	
45	Fatty Acids, (C16-C18) And C18 Unsaturated, Isobutyl Ester	10024-47-2	
46	Fatty Acids, Castor-Oil, Caustic-Oxidized, Distn. Residues, Esters With 1,3-Butanediol	113669-95-7	
47	Fenvalerate	51630-58-1	
48	Glycine, N,N'-1,2-Ethanediylbis[N-(Carboxymethyl)-, Tetrasodium Salt	64-02-8	
49	Hexylene Glycol	107-41-5	
50	Huntite	19569-21-2	
51	Hydrogen Peroxide Stabilizer	Unknown	No
52	Hydrogen Peroxide	7722-84-1	
53	Hydromagnesite	12072-90-1	
54	Hydrotalcite	11097-59-9	
55	Imidacloprid	138261-41-3	
56	Lambda-Cyhalothrin (Iso)	91465-08-06	
57	Lignin Sodium Sulfonate	8061-51-6	
58	Magnesium Bisulfite	13774-25-9	
59	Magnesium Oxide	1309-48-4	
60	Magnesium Stearate	557-04-0	
61	Methacrol 2462	Unknown	No
62	Methylene Diphenyl Diisocyanate (Mdi)	101-68-8	
63	Mineral Oil	8042-47-5	
64	Monocrotophos	6923-22-4	
65	Multiprep Ss-400 Ingredient	Unknown	No
66	N-Methylmorpholine N-Oxide	7529-22-8	
67	Naphthalene	91-20-3	
68	Nitrate	14797-55-8	
69	Nitrogen	7727-37-9	
70	Octadecanamide, N-[2-[(2-Hydroxyethyl)Amino]Ethyl]-	141-21-9	
71	Optipol - Dap	Unknown	No
72	Ortho-Dichlorobenzene	95-50-1	
73	Oxalic Acid	144-62-7	
74	Oxygen	7782-44-7	
75	Ozone	10028-15-6	
76	P-Xylene	106-42-3	

	Chemical (Listed Alphabetically)	CAS RN	Included in Analysis?
77	Peg-10 Hydrogenated Tallow Amine	61791-26-2	
78	Phorate	0298-02-02	
79	Phosalone	2310-17-0	
80	Phosphonic Acid, [[(Phosphonomethyl)Imino] Bis[2,1-Ethanediylnitrilobis(Methylene)]]Tetrakis -, Sodium Salt	22042-96-2	
81	Phosphorus Oxide (P2o5)	1314-56-3	
82	Poe Fatty Alcohol Phosphoric Ester	Unknown	No
83	Poly (Oxy-1,2-Ethanediyl), Alpha- (Octylphenyl)-Omega-Hydroxy-, Branched	68987-90-6	
84	Poly-Dimethylsiloxane	9006-65-9	
85	Poly(Oxy-1,2-Ethanediyl), A-Isotridecyl-Ω-Hydroxy-	9043-30-5	
86	Poly(Oxy-1,2-Ethanediyl), A-Tridecyl-Ω-Hydroxy-, Branched	69011-36-5	
87	Polyethylene Ether Glycol	25322-68-3	
88	Polyethylene Glycol 4-(Tert-Octylphenyl) Ether	9002-93-1	
89	Polyethylene Glycol Mono(Octyl)Phenyl Ether	9036-19-5	
90	Polyethylene Terephthalate	25038-59-9	
91	Polyoxyethylene	9002-92-0	
92	Polytetramethylene Glycol	25190-06-01	
93	Polyurethane	9009-54-5	
94	Polyvinyl Alcohol	9002-89-5	
95	Polyvinyl Methyl Ether	9003-09-02	
96	Polyvinylpyrrolidone	9003-39-8	
97	Potassium Carbonate	0584-08-07	
98	Potassium Oxide (K2o)	12136-45-7	
99	Procion Navy H-Er 150%	Unknown	No
100	Procion Red H-E7b	Unknown	No
101	Procion Yellow H-E4r Ingredient	Unknown	No
102	Profenofos	41198-08-07	
103	Propyl Gallate	121-79-9	
104	Quaternary Ammonium Compounds, Di-C14-18-Alkyldimethyl, Me Sulfates	68002-58-4	
105	Quinalphos	13593-03-08	
106	Remazol Black B	17095-24-8	
107	Siloxanes And Silicones, Di-Me, [[[3-[(2-Aminoethyl)Amino]-2-Methylpropyl]Methoxymethylsilyl]Oxy]- And (C13-15-Alkyloxy)-Terminated	188627-10-3	
108	Sno White Byb Ingredient	Trade Secret	No
109	Soda Ash	497-19-8	
110	Sodium Acrylate	7446-81-3	
111	Sodium Chloride	7647-14-5	
112	Sodium Dithionite	7775-14-6	
113	Sodium Hydroxide	1310-73-2	
114	Sodium Sulfide	1313-82-2	
115	Sodium Thiosulfate	7772-98-7	
116	Strong-Inorganic-Acid Mists Containing Sulfuric Acid (See Acid Mists)	7664-93-9	

	Chemical (Listed Alphabetically)	CAS RN	Included in Analysis?
117	Sulfur Dioxide	7446-09-05	
118	Sulfuric Acid Disodium Salt	7757-82-6	
119	Terephthalic Acid	100-21-0	
120	Titanium Dioxide	13463-67-7	
121	Triazophos	24017-47-8	
122	Ultrawet Ws	Unknown	No
123	Water	7732-18-5	
124	Zinc Oxide	1314-13-2	

APPENDIX F: Key Toxicology Terms

Term	Unit	Definition
NOEC		No observable effect concentration: The lowest concentration without noticeable impacts to aquatic species endpoint(s).
Biodegradation half-life		Time required to reduce the concentration by 50% from any point in time by chemical degradation, indicating potential toxicity for aquatic organisms.
Biotransformation half-life (Fish)		Time required to reduce the concentration by 50% from any point in time by metabolism, indicating potential for toxicity in humans.
NOAEL		No observable adverse effect level: The lowest concentration without noticeable impacts to human endpoint(s).
$LogK_{ow}$		The ratio of the chemical concentration partitioned between water & octanol, indicating potential for bioaccumulation.

APPENDIX G: Combined ToxPi Scores

CAS RN	Chemical	ToxPi Score
298-02-2	phorate	0.747171
2921-88-2	chlorpyrifos	0.561777
91465-08-6	lambda-cyhalothrin (ISO); reaction mass of (S)-Î±-cyano-3-phenoxybenzyl(Z)-(1R)-cis-3-(2-chloro-3,3,3-trifluoropropenyl)-2,2-dimethylcyclopropanecarboxylate and (R)-Î±-cyano-3-phenoxybenzyl (Z)-(1S)-cis-3-(2-chloro-3,3,3-trifluoropropenyl)-2,2-dimethylcyclopropanecarboxylate (1:1)	0.558166
959-98-8	alpha-endosulfan	0.529827
6923-22-4	monocrotophos	0.507102
52315-07-8	Cypermethrin	0.497271
60-51-5	dimethoate	0.486015
51630-58-1	fenvalerate	0.45422
11141-17-6	Azadirachtin	0.42237
2310-17-0	Phosalone	0.370527
283594-90-1	2-oxo-3-(2,4,6-trimethylphenyl)-1-oxaspiro[4.4]non-3-en-4-yl 3,3-dimethylbutanoate	0.361923
79-06-1	Acrylamide	0.35973
41198-08-7	profenofos	0.347777
95-50-1	ortho-Dichlorobenzene	0.339833
107-15-3	Ethylenediamine (EDA)	0.326759
30560-19-1	acephate	0.321747
91-20-3	Naphthalene	0.317166
24017-47-8	triazophos	0.308892
7681-52-9	Bleach plus Ammonia (Mixture)	0.289171
106-43-4	4-Chlorotoluene	0.274255
108-90-7	Chlorobenzenes	0.249457
138261-41-3	imidacloprid	0.223507
138261-41-3	imidacloprid	0.223507
14797-55-8	Nitrate	0.220577

CAS RN	Chemical	ToxPi Score
1313-82-2	Sodium Sulfide	0.218747
40601-76-1	1,3,5-Triazine-2,4,6(1H,3H,5H)-trione, 1,3,5-tris[[4-(1,1-dimethylethyl) -3-hydroxy-2,6-dimethylphenyl]methyl]-	0.218126
7446-81-3	sodium acrylate	0.217886
7398-69-8	Dimethyl diallyl ammonium chloride	0.217675
7664-41-7	Ammonia	0.216857
1314-13-2	zinc oxide	0.203229
106-42-3	P-xylene	0.19677
7529-22-8	N-Methylmorpholine N-oxide	0.193017
15520-10-2	2-methyl1-1, 5-pentanediamine (MPMD)	0.178164
7727-43-7	barium sulfate	0.173622
4193-55-9	Benzenesulfonic acid, 2,2'-(1,2-ethenediyl)bis[5-[[4-[bis(2-hydroxyethyl)amino]-6-(phenylamino)-1 ,3,5-triazin-2-yl]amino]-, disodium salt	0.169261
95-14-7	Benzotriazole	0.167224
577-11-7	Butanedioic acid, sulfo-, 1,4-bis(2-ethylhexyl) ester, sodium salt	0.16651
2682-20-4	3(2H)-Isothiazolone, 2-methyl-	0.164092
22042-96-2	Phosphonic acid, [[(phosphonomethyl)imino] bis[2,1-ethanediylnitrilobis(methylene)]]tetrakis -, sodium salt	0.163284
64-02-8	Glycine, N,N'-1,2-ethanediylbis[N-(carboxymethyl)-, tetrasodium salt	0.158931
7558-79-4	Disodium Phosphate	0.146663
68-12-2	Di Methyl Formamide (DMF),	0.140932
13593-03-8	quinalphos	0.138991
11097-59-9	hydrotalcite	0.137364
67-68-5	dimethyl sulfaoxide	0.133403
17095-24-8	Remazol Black B	0.126399
143-22-6	Ethanol, 2-[2-(2-butoxyethoxy)ethoxy]-	0.119758
64-19-7	Acetic acid	0.115651
101-68-8	methylene diphenyl diisocyanate (MDI)	0.115538
9012-54-8	Cellulase	0.114672

CAS RN	Chemical	ToxPi Score
2475-45-8	Disperse Blue 1	0.114115
68002-58-4	Quaternary ammonium compounds, di-C14-18-alkyldimethyl, Me sulfates	0.110688
9000-90-2	alpha Amylase (pancreatic)	0.110606
13774-25-9	Magnesium bisulfite	0.108992
7772-98-7	Sodium thiosulfate	0.108441
7722-84-1	Hydrogren Peroxide	0.108317
7647-14-5	Sodium Chloride	0.107493
7775-14-6	Sodium dithionite	0.106138
77-92-9	Citric acid	0.104859
25322-68-3	polyethylene ether glycol	0.103303
100-21-0	Terephthalic acid	0.101263
13463-67-7	titanium dioxide	0.094909
497-19-8	Soda Ash	0.091651
107-41-5	Hexylene Glycol	0.075772
7757-82-6	Sulfuric acid disodium salt	0.07512
127-19-5	dimethyl acetamide	0.058173
7664-93-9	Strong-inorganic-acid mists containing sulfuric acid (see Acid mists)	0.052839
9/5/7446	Sulfur Dioxide	0.05216
107-21-1	Ethylene glycol	0.052145
111-46-6	Diethylene Glycol	0.047694
8042-47-5	Mineral Oil	0.044505
121-79-9	Propyl gallate	0.042451
557-04-0	magnesium stearate	0.03745
10024-47-2	Fatty acids, (C16-C18) and C18 unsaturated, isobutyl ester	0.03332
9002-92-0	Polyoxyethylene	0.026459
160430-64-8	Acetamiprid	0.014782
2872-52-8	Disperse Red 1	0.012882

CAS RN	Chemical	ToxPi Score
27624-67-5	2,4-diamino-5-[4-[(2-sulfoxyl ethyl)sulfonyl]phenylazo]benzenesulfonic acid	0.012785
1559-34-8	3,6,9,12-Tetraoxahexadecan-1-ol	0.012441
144-62-7	Oxalic Acid	0.008378
19569-21-2	huntite	0.006893
584-08-7	Potassium carbonate	0.006893
2832-40-8	Disperse Yellow 3	0.005712
141-21-9	Octadecanamide, N-[2-[(2-hydroxyethyl)amino]ethyl]-	0.005701