FASHION TAKES ACTION

A Feasibility Study of Textile Recycling in Canada

Commissioned by Environment and Climate Change Canada


Image: *Ikea*

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Fashion Takes Action

Fashion Takes Action (FTA) is Canada's non-profit fashion industry organization focused on sustainability. We work with industry and consumers in an effort to shift behaviour toward more positive social and environmental impacts. Our mission is to advance sustainability in the entire fashion system through education, awareness, research and collaboration.

Our Guiding Principles

FTA operates internally, externally and determines formal relationships with these Guiding Principles in mind. FTA is:

- Transparent
- Innovative
- Motivational
- Economical
- Inclusive

Previous Work Related to Textile Waste

In 2016, FTA set out to making fashion circular in Canada. We first introduced this topic at our annual World Ethical Apparel Roundtable (WEAR) in plenary sessions and two half day labs. The latter was facilitated by the Recycling Council of Ontario and attended by multiple stakeholders - retailers, municipalities, charities, industry associations, textile collectors, NGOs and academics. This was the first time such a diverse group participated in a multi-stakeholder discussion on this topic. The findings from these workshops formed the basis of what would eventually become the Ontario Textile Diversion Collaborative (OTDC).

In fall 2017 FTA secured funding from the Ontario Trillium Foundation's Collective Impact stream to convene a 4-day lab that would bring back the diverse stakeholders to address textile waste diversion through a lens of systems change. More than 40 stakeholders from across Ontario participated, with additional consultation from textile waste researchers in Nova Scotia, Montreal and Vancouver. The result of these labs was a draft theory of change and the identification of four main working groups: Policy & Regulation, Data & Research, Public Awareness and Local Recycling.

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Executive Summary & Key Findings

Textiles are made from fibres, which can be natural, synthetic or a combination of both; however, synthetics make up to 69.7 per cent of the global fibre demand, with polyester being the most popular fibre at a market share of 57.7 per cent (Sophia, SuetYin, Evonne, & Liesl, 2020). Despite the fashion industry's efforts to become circular, the amount of recycled polyester used is still very low (14 per cent), and feedstock mainly comes from PET plastic bottles instead of pre and post-consumer textile waste (Sophia et al., 2020). On the other hand, textiles in Canada account for 7 per cent of all plastics in Canadian landfills, and make up the third-largest category of plastic waste in absolute numbers after packaging and automotive (Deloitte, 2019). This raises the question of whether a textile recycling industry for synthetic fibres in Canada is feasible.

Looking at textiles through a waste management lens, there are many products made or partly made of fibres that are excluded from this study, such as technical textiles, furniture, carpets, area rugs, mattresses, disposable personal hygiene products and diapers. These products usually have their own waste diversion programs because they are often bulky, heavy, or difficult to handle in Residential waste collection, and there is little opportunity for reuse. Finally, they require unique recycling processes.

In 2018 about 58 per cent of all non-hazardous waste in Canada came from the Non-residential sector. The other 42 per cent was generated from the Residential sector (Statistics Canada, 2021).[1] In the Industrial, Commercial & Institutional (IC&I) stream, pre-consumer textile waste comes from fibre, yarn, or fabric mills and clothing manufacturing, which mainly results in a material loss during the manufacturing process, and materials from retailers with unsold, returned or damaged inventory. Textiles from pre-consumer sources are easier to recycle than post-consumer textile waste because the material is unused and therefore clean, and materials from textile mills or clothing manufacturers do not require disassembly to access the material. Hence it would be beneficial to start textile recycling with waste from the textile sector. However, based on survey results, it is impossible to determine the amount of pre-consumer textile waste because companies either do not track it, or it is too complicated for them to access this information. Still, survey results reflected an interest by the manufacturers and retailers to participate in a pilot program for textile recycling. In addition to pre-consumer textile waste, companies also produce post-consumer textile waste, such as linens from a hotel. However, there is no data on how much textile waste each sector has, since textiles are usually classified as 'other', and are not tracked as a standalone waste category. Thus, it is less likely that any survey will be able to gather this information. Instead, semi-structured interviews can be used to

[1] In 2018 all sources of waste for disposal was 25,733,021 tonnes. Residential sources of waste for disposal are 10,848,238 and Non-residential sources of waste for disposal are 14,884,782 tonnes (Statistics Canada, 2021).

determine common business practice and help us draw conclusions in conjunction with landfill waste composition data.

Regarding Residential textile waste, based on research and waste audits in Ontario, it can be estimated that the most conservative percentage of textiles ending up in the waste stream is 4.43 per cent, for a total amount of 480,576 tonnes Canada-wide (in 2018). This percentage reflects the six categories of textile waste determined in a workshop from OTDC with municipalities and textile collectors: clothing, home textiles, footwear, accessories, soft toys and others.

Not all of the material that ends up in the Residential waste stream requires recycling; most products are good enough for reuse. While some municipalities in Canada have established textile diversion programs, most textiles are being collected by charities that sell the material to local second-hand retailers to help fundraise their missions. Second–hand clothes that do not sell in Canada are sold on to graders that sort and grade the material before selling it to the global second-hand market. Based on the Ontario Dumpster Dive study, only 22 per cent of all textiles in the waste stream are available for recycling; the rest is good enough for reuse or so contaminated that it cannot be recycled. This situation is different in the industrial stream, where we estimated that all materials require recycling.

Applying this data and assumptions, we can estimate that 160,000 tonnes of textiles made from 100 per cent synthetic fibres and 200,000 tonnes from synthetic-natural fibre blends, are in the Canadian waste stream and require recycling.[2] Interestingly the use of the fibre types depends on the textile category. While natural fibres are dominant in clothing such as shirts, pants or towels, synthetic fibres are widely used in bedding or stuffed toys.

There is enough material to feed multiple textile recycling facilities in Canada, if the material can first be separated from the waste stream, and if there are sufficient recycling opportunities available in Canada. However, before any post-consumer textiles can be recycled, the material must be sorted according to reuse or recycling, and if for recycling, for which process.

A technical review was conducted to compare suitable technologies that can build up a textile recycling industry. Technologies were grouped into three pre-defined categories, or “classes”: sorting, mechanical recycling and chemical recycling. For each class, current projects and start-ups were identified, and a selection of detailed case studies was presented to offer in-depth information on processes, costs, feedstock, product characteristics and technological readiness. Although automated sorting technologies have been tried and tested on other waste streams, more work remains to be done to ensure their successful transfer to textile waste. The

[2] In the Canadian waste stream includes both the Residential and Non-residential stream

mechanical and chemical recycling sector is not yet consolidated, as various competing technologies are vying to demonstrate their viability, often on very specific feedstocks.

A comparative assessment was performed to outline the pros and cons of the solutions, presented in case studies. Automated sorting cannot replace the human eye for reuse markets but appears to be an essential step for any textile recycling operation. Overall, mechanical recycling can be achieved at a smaller scale and cost than chemical recycling solutions, but the range of outputs (products) is more limited. However, it must be considered that chemical recycling may require the use of harmful chemicals to deconstruct specialty textiles such as fire-resistant fabrics.

A preliminary business case was built for an open-loop mechanical recycling scenario for polyester waste which showed potential for economic viability. Work on this model must be continued at a pilot scale to gain more precision on some cost estimates and potential end markets.

When putting all findings together, considering feedstock, investment costs, and technology readiness, the most promising technology to start a textile recycling industry in Canada is mechanical recycling. The best way to get this recycling operation started is to conduct a pilot with a retailer or manufacturer. To make this pilot a success, not only the technology, but also potential end markets for the new products must be considered. There is a need for a platform that foster communication among stakeholders and brings them together around shared challenges and opportunities, so that critical information is exchanged and a vision for textile recycling in Canada can be created.

Finally, we have 22 recommendations which are outlined in detail in **Part Five**: Recommendations to Support a Textile. These are organized into three broad clusters: process-focused, product-focused, and system-focused. Highlights of our recommendations include:

1. **Textiles as designated waste material:** both the federal government and Canada's provinces must monitor textiles as their own waste type
2. **Communicate the Value of Textile Waste:** each province should establish textile diversion programs (similar to NS and BC), and it should be mandatory that municipalities report textile waste data to the province.
3. **Encourage Textile Waste Diversion Programs:** develop intermediate textile diversion programs for municipalities that are not yet prepared to divert all textiles. Intermediate textile diversion programs only divert specific textile product categories.
4. **Fund Textile Diversion Programs:** help to finance the establishment of textile diversion programs at the municipal level (this could include landfill bans).
5. **Foster a Textile Recycling Industry in Canada:** encourages brand owners to keep their material in Canada, and possibly implement an in-store take back program as a form of extended producer responsibility (EPR).

6. **Finance a Mechanical Textile Recycling Pilot:** support and invest in a number of mechanical recycling pilots and training workshops.
7. **Track Specific Import Data on Textiles and Clothing:** currently there are no data available as to the number of textiles imported into Canada.
8. **Funding a National Textile Diversion Working Group:** help to establish a national textile diversion working group that fosters a circular textile economy, with multiple stakeholders across the value chain.
9. **A Legislative Reform on the Duty Drawback:** explore how this drawback program can be modified to encourage more recycling of textiles.
10. **Review the Textile Labeling Act:** 'new material only' regulation must be adjusted so that all provinces may include recycled content.
11. **Conduct Further Research on Repair, Refurbish, and Upcycling:** fund further research on the potential for these methods to reduce textile waste to landfill.
12. **Canada-wide Action Plan on Zero Textile Waste:** further research to determine the barriers and challenges, and conduct pilots to develop possible solutions.
13. **Conduct Further Interviews and Landfill Audits:** interview other industry sectors to understand how they manage their textiles; waste audits to better understand volume and composition of textile waste generated by the IC&I sector.
14. **Encourage the Use of Reclaimed Fibres:** through procurement and tax/duty incentives for products made from recycled fibres.
15. **Support Post-Secondary Education for Circular Design:** make it mandatory for fashion design programs in Canada to adopt a circular approach to teaching design.
16. Fund Research on Mycoremediation to Reduce Textile Waste and Create Vegan Leather or other products: In particular, fund research with mycoremediation as a means to reduce plastic waste.

Glossary

Bioremediation: A branch of biotechnology that utilizes living organisms, such as microbes and bacteria, in the removal of contaminants, pollutants, and toxins from water, soil, and other environments.

Cellulosic Fibres: Are made from natural polymers and generated from plants such as cotton or flax. However cellulosic can also be dissolved from wood or plants and then forced through spinning jets. In this case a man-made cellulosic fibre is generated such as viscose rayon, or lyocell.

Closed-loop Recycling: Recycling processes that turn materials back into raw feedstock of equal quality. For textiles, this means the creation of recycled fibres and yarn. The chemical recycling of polyester creating new yarns would be considered closed loop, and the new product would be marketed as recycled polyester. In the textile and fashion industry, this process remains very rare. Focusing on the exact same raw component nevertheless restricts recycling options.

Destruction: A sorting and destruction process whereby branded and proprietary products, including those that pose a security risk, are disposed of securely.

Disposal: Methods of waste disposal in Canada are defined as landfill and incineration; disposal does not include recycling or composting.

Dispose vs Discard: Both terms mean throwing unwanted materials into the waste stream. The word “discard” mainly describes impulsive disposal. However, consumers often use the term “dispose” or “discard” interchangeably for anything they want to get rid of. For example, they dispose of or discard clothing in a donation bin. From a waste management perspective, however, this is not considered disposal or discard but donation.

Distressed Goods: Retailer inventory items which are never sold, not even on clearance (Kunz & Garner, 2011).

Distribution Channels: Businesses that are connecting the producer of a product with the end consumer by providing different services, such as retail stores, counselling, information etc. Distribution channels include wholesalers, retailers, distributors and others.

Down-cycling: The recycling of unwanted garments into other textile products of lower quality or into less valuable and/or non-recyclable products such as insulation materials. Although down-cycled insulation products might become a longer-lasting product than the original apparel product, the new product cannot be returned to the loop—no new textiles can be made from this material and therefore the lifecycle cannot be closed. Down-cycling is also known as open-loop recycling (compared to closed-loop recycling).

Duty Drawback: Often retailers have surplus/unsold/defective items and leftover garments, and if those garments are dumped at the landfill or exported for donation, the retailer receives the import duty back. If the material is being recycled, this is seen as use and the owner could not claim the import duty back. The back payment is usually done as an exchange process. This means the retailer is not getting money back, but when it imports new garments, those duties are compensated. This practice makes dumping garments more financially viable than recycling them.

Extended Producer Responsibility (EPR): A system in which a manufacturer or brand owner becomes responsible for their product's entire life cycle even after a consumer has bought it. EPR programs are designed to give producers a vested interest in ensuring a responsible end-of-life for their products.

Fast Fashion: The supply of clothing based on lowest production cost and fastest production time, often resulting in low-quality mass-produced apparel with short lifespans.

Felted Fabric: Felts belong to the category of non-woven fabrics and can be further classified as wool felts or needle felts. The consolidation of certain fibres through the application of heat, moisture, or mechanical action, which causes the interlocking, or matting, of fibres. Examples include wool, fur, and certain hair fibres. Wool can produce felting even when mixed with other fibres. In contrast almost any type of fibre can be used for the production of needle felts. Felts do not require an adhesive substance for their production.

Fibres: Large polymer molecules which lay alongside each other and are bonded together.

Fibre Blends: A mix of two or more textile fibres used to make fabric. The fibers can be blended or combined in various yarn and fabric structures. Blends often improve performance, and can be used to achieve special optical effects. Blending may also affect processing efficiency, yarn fineness, and cost.

Filament: A type of fibre that has an indefinite or extreme length, such as silk or man-made fibers which can be extruded to any length.

Jobber: A jobber operates similar to a wholesaler, but deals with end-of-line merchandise, often from previous seasons. Jobbers usually sell the material to markets where the brand does not conduct business –in order to protect the brand image. Jobbers usually pay low prices and often buy per pound.

Knitted Fabric: Made from either a single yarn or from many, looped continuously to produce a braided look. Knitted fabrics are classified as weft or warp knitted.

IC&I Sector Waste: Waste that is produced by the Industrial, Commercial and Institutional sectors. This includes household waste from multi-residential buildings. This waste ends up in the Non-residential waste stream.

Multi-family Homes: Also referred to as multi-unit residential buildings (MURBs), with more than six units each. In residential waste management, multi–family homes can provide a special challenge. First, these units produce a lot of waste per m^2 due to the high number of residents, second, these buildings often have different waste collection systems in place than the single-family waste collection programs rolled out by municipalities.

Non-woven Fabrics: A fabric that uses very short fibres that are felted or bonded together with heat, resin, chemicals, ironing, and/or needlepunching. This method is suitable for recycled fibres when they are too short to be woven or knitted; can be made from mixed fibres – both natural and synthetic - and used in agriculture, building, geo-engineering, acoustics, filtration textiles and reusable shopping bags.

Open-loop Recycling (or down-cycling): Processes by which textiles are deconstructed, shredded or otherwise processed and used as inputs for the manufacture of lower value products, such as insulation or fill.

Ontario Textile Diversion Collaborative (OTDC): This multi-stakeholder group had more than 40 members and created four working groups: Data, Policy & Regulations, Textile Recycling & Public Awareness. The group's mission was to get textiles out of landfills by making sure they are appropriately managed. The organization was funded by the Ontario Trillium Foundation and ended its operation with a final report and a webinar in 2019. The organization was under the umbrella of Fashion Takes Action.

Polyamide: A synthetic fiber artificially created through spinning, based on crude oil which mainly occurs as nylon.

Polymer: A class of natural or synthetic substances composed of very large molecules that are multiples of simpler chemical units called monomers, and when they are constructed in the form of long chains, they are called linear polymers. Polymers make up many of the materials in living organisms, such as proteins, cellulose, and nucleic acids.

Post-Consumer Textile Waste: Textile waste from items that have been in use, and are no longer wanted. May originate from households as well as industries (hospitals, work sites, etc.)

Pre-Consumer Textile Waste: Pre-consumer textile waste occurs before the consumer takes ownership for a textile product. Textile waste that is mainly created during textile and garment manufacturing (i.e., leftover yarns, offcuts, trims, rejects), or finished garments that are produced but can't be sold due to various reasons (i.e., damaged, returned, excess inventory).

Recycling: A process of recovering resources by converting materials that would otherwise end up in waste into usable materials that are either more valuable (upcycling), of same value (closed-loop recycling) or lower value (down-cycling). Recycling is an important part of waste prevention and reduction. An integrated waste management strategy incorporates the three core waste management techniques: Reduction, Reuse and Recycling, known as the 3 R's. Composting is a specialized part of recycling.

Regenerated Fibre: New fibre is regenerated with innovative chemical recycling technology by using discarded textile material or PET plastic bottles.

Reverse Logistics: The coordination and planning of how to get products back from consumers, or from retail locations, in order to extract the maximum value of collected products, through reselling, recertifying (repair), or recycling the returned products into new products.

Sectors in the Clothing Industry:

Textile Manufacturing: The textile mills (name for textile manufacturing facilities) buy fibres, spin the fibres into yarn, and weave or knit the yarn into fabrics. There are multiple processes involved to produce, embellish, and improve fabrics.

Clothing Manufacturing: Clothing manufacturers buy fabrics and accessories and produce garments (apparel).

Service Producing Sector: This sector consists of Wholesalers, Jobbers, and Retailers.

Textile Sorter and Grader: Inspects and grades textiles to define their value and determine whether the product can be resold and in which market, or if it requires recycling. A textile sorter and grader is not necessarily a textile recycler; however, many sorting and grading facilities do ragging, and some do other mechanical recycling process. In this case, a sorter and grader also functions as a recycler.

Spinning: A process in which an extruded liquid polymer filament is continuously drawn and simultaneously solidified to form a continuous fibre. It uses a twisting technique where the fibre is drawn out, twisted, and wound onto a bobbin. There are three fundamental processes for the manufacturing of man-made fibres: melt spinning, wet spinning, and dry spinning.

Spun Yarns: Are made from staple fibres such as cotton and wool, or from broken or cut man-made fibres. Spun yarns are produced by placing a series of filaments together to form a continuous assembly of overlapping fibres, usually bound together by twist.

Up-cycling: Transforming fabric scraps or unwanted garments into new garments or other textile products of high quality. See down-cycling in contrast.

Waste Diversion: Shifting materials away from disposal (landfill or incineration) by using waste management strategies. Waste diversion requires collection and processing of the material. A charity that collects material is not necessarily diverting the material.

Waste Management Approach: An approach that determines how waste is handled to make best possible use of it. This approach seeks to determine the best solutions for waste minimisation: recycling, composting, energy recovery, or landfill.

Woven Fabric: Made by using two or more sets of yarn interlaced at right angles to each other to form a whole, producing a wide variety of fabrics.

List of Abbreviations and Acronyms

IC&I	Industrial, Commercial, and Institutional Sector
NIR	Near-Infrared Radiation
NS	Nova Scotia
OTDC	Ontario Textile Diversion Collaborative
PA	Polyamide
PC	Product Category
PET	Polyethylene terephthalate
RFID	Radio-frequency identification
TPA	Terephthalic acid

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Context of Study

In 2018 Canada launched an Ocean Plastics Charter as part of its G7 presidency to encourage other governments, businesses and organizations to join efforts and develop strategies to combat plastic waste on land and within oceans. Critical areas of strategy development include consumer awareness initiatives, product design, collecting systems, recycling activities, and research and monitoring. Since 2019 the Environmental Ministers have been working on an action plan to implement the Canada-wide Strategy on Zero Plastic Waste (Statistics Canada, 2021b).

When most people think of plastics, packaging or daily use articles come to mind. Some might link plastics to building or construction materials or to electronic equipment, but only a few will connect plastics with textiles. However, seven per cent of all plastics in Canadian landfills are textiles, and they accounted for 235kt of waste disposed nationwide in 2017 alone. This makes textiles the third-largest sub-category of plastic waste in absolute numbers after packaging 1,524kt (47 per cent) and automotive 309 kt (nine per cent) (Deloitte, 2019). The connection between plastics and textiles raises the question of what textiles are and how they are currently managed so that such a high amount of material ends up in landfills. What possibilities currently exist to make economic use of this wasted material?

To better understand textile waste in the Canadian context and its contribution to plastic waste, Environment & Climate Change Canada commissioned Fashion Takes Action to conduct this study that profiles the possibilities and pre-feasibility of a local textile recycling industry.

Organization of Study

The research has been organized into five parts. The first part includes a literature review to introduce and define textiles, describe global fibre consumption and provide an overview of textile sorting and recycling methods.

The second part describes textile waste sources, diversion and collection programs, and maps out the role of key stakeholders such as consumers, charities, second-hand retailers and graders, before the amount of textiles in the waste stream is estimated, for both the Residential and IC&I sector, and finally, the volume of synthetic materials that require recycling.

In the third part, textile waste from the Non-residential sector was explored through a survey developed for fibre & yarn mills, textile and apparel manufacturers, and clothing brands and retailers. A statistical method was then used to analyze the data. Furthermore, semi-structured interviews were conducted with key stakeholders in the industry to better understand the barriers and opportunities for textile recycling in Canada. A list of these interviews is presented **Appendix A:** Semi-Structured Interviews with Key Stakeholders.

The fourth part is a technical review that evaluates the various sortation and recycling processes' requirements and feasibility (i.e., chemical, mechanical, or hydrothermal) through global market research on existing technologies. A survey was developed and phone interviews conducted to successfully compare the different technologies and determine the requirements to establish a large-scale textile recycling operation in Canada. A critical aspect of this analysis was to assess how the conditions necessary to enable recycling vary between textiles. Finally, using the most promising technology, an initial feasibility study was conducted to demonstrate the business case, with recommendations for further research through a pilot study.

The fifth part pulls together all of the findings and provides a number of recommendations to best address textile waste in Canada. These are presented in three categories: process-focus, product-focus and system-focus.

Scope of Study

The scope of this study includes pre-consumer textile waste from the Non-residential waste steam and post-consumer textile waste from the Residential waste stream. The pre-consumer textile waste comes from fibre & yarn mills, textile manufacturers, apparel manufacturing and the clothing retail sector.

This study looks at the following post-consumer textile waste categories: clothing, home textiles, accessories, footwear, and stuffed toys which are produced by private households and multifamily homes (if they are managed by municipalities). This study does not further explore post-consumer textile waste from industry for example, bedding generated from hotels and hospitals. The study estimates the volume and composition of the potential feedstock of pre- and post-consumer textile waste, provides a technical review and comparative analysis of sortation and recycling processes (mechanical and chemical), describes the material flows and key stakeholders in the value chain, but does not look into possibilities of upcycling, repair or composting of textiles. Finally, this study presents recommendations to support a new textiles economy for Canada.

As there is a significant lack of data on textile waste, this study conducted numerous research projects to gain primary data; however, results might be limited in regards to geographic reach, availability of data and information, and willingness of participants to respond to surveys. In order to stay within the timeline and budget of this project, various assumptions have been made to guarantee this study's overall success at meeting its core objectives. These assumptions are communicated throughout the report.

Part One: Background

Definition of Textiles

All textiles are made from fibres constructed from linear polymers that lie alongside each other and are bonded together. Textiles differ in the forming of materials, which can be either from natural or synthetic polymers. Natural fibres are based on natural polymers and are divided into vegetable fibres (from cellulose), animal fibres (from protein) and cellulosic man-made fibres, which are artificially formed through spinning, and are based on naturally occurring cellulose polymers. Synthetic fibres are also artificially created through spinning, but are based on petroleum polymers (such as polyester) or crude oil (such as polyamide, which mainly occurs as nylon) or natural gas (such as acrylic). Fibres based on natural cellulose (such as cotton, flax or hemp) or protein (such as wool and silk) and artificial cellulosic fibres (such as modal, viscose, known as rayon in the U.S., or lyocell, known as Tencel in the U.S.) have the potential to biodegrade in a landfill and release greenhouse gases contributing to climate change, while synthetic fibres do not biodegrade at all. Tests from Li, Frey, and Browning (2010) have shown that polyester fabrics may display slight initial signs of degradation, but will remain intact in a composting environment. Much like other plastic, textiles made of synthetic fabrics such as polyester or nylon will indefinitely occupy landfill space; for this and many other reasons, such as reducing the impacts of virgin material and resource extraction, it is desirable to keep both natural and synthetic textiles out of landfills.[3]

Fibres are spun into yarns (spun yarns or filaments), and the yarns are woven, knitted, felted, or bonded into a fabric. Many modern fabrics are made of a blend of natural and synthetic fibres, which have certain benefits including improved performance in use, clothing comfort, aftercare, the fabric's look, and reduced production costs (Eberle et al., 2004). Materials are also blended to combine the benefits of each fibre. Organic fibres like cotton are commonly mixed with synthetic fibres, such as polyester. For example, socks are often made of 80 per cent cotton and 20 per cent polyester to combine the comfort of cotton with polyester's strength. Fabric blends have become extremely popular and very common.

Textiles made of fibre blends can be produced either in the yarn stage when different fibres are spun into one yarn which is then woven into fabric, or in the fabric stage when fabrics are woven or knitted with varying types of yarn (Eberle et al., 2004). The numerous possibilities for fabric blends, complicate research into recycling of blended textiles. It is unclear as to what extent, if any, fabric blends are able to biodegrade in landfills. While further research is required, it is

[3] Landfilling is still the common waste management method in Canada.

likely that only the organic portion biodegrades under a reasonable timeframe, while the synthetic part will not.

Fabrics are being further treated for their aesthetics or their functionality; such treatments include bleaching, dyeing, printing, water repellent, stain or flame retardants and more. However, if textiles are chosen for their functional characteristics other than appearance, they are called functional textiles. For example, in sports and leisurewear many textiles have functions such as moisture transport, thermal regulations or UV protection.

Fabrics are then cut and sewn to make clothing, home textiles or technical textiles. While everyone is familiar with its use in clothing, textiles can also be used for household items such as towels, table cloths, bedsheets, curtains, area rugs, carpets, umbrellas, furniture, flags, mattresses, or even tents. Miscellaneous uses include the production of containers for storage or packaging, such as rice bags or fruit nets or for cleaning devices.

Not many people are aware of technical textiles. Technical textiles are used, for example, in the medical field for bandages, wound dressing, or surgical wear to protect against bacteria, radiation or even electrostatic charge; this means these textiles also fulfil functions and are therefore often referred to as functional textiles.

Technical textiles are also used in transport and recreation, such as sails, balloons, kites, and parachutes. Further, technical textiles are needed for industrial purposes as protective gear against high or low temperatures worn by workers in cool-rooms or by firefighters, in agriculture to cover and protect plants (agrotextiles), in scientific processes for filtering, for construction and engineering projects, as insulation material, or for drainage (geo-textiles).

In other words, textiles are everywhere. Due to the versatility of fabrics, they can be used for many applications depending on the different fibre qualities treatments and production methods. Consequently, textiles are not a homogeneous product group.

Figure 1 provides an overview of the three textile categories (clothing, home, and technical textiles) and gives product examples.

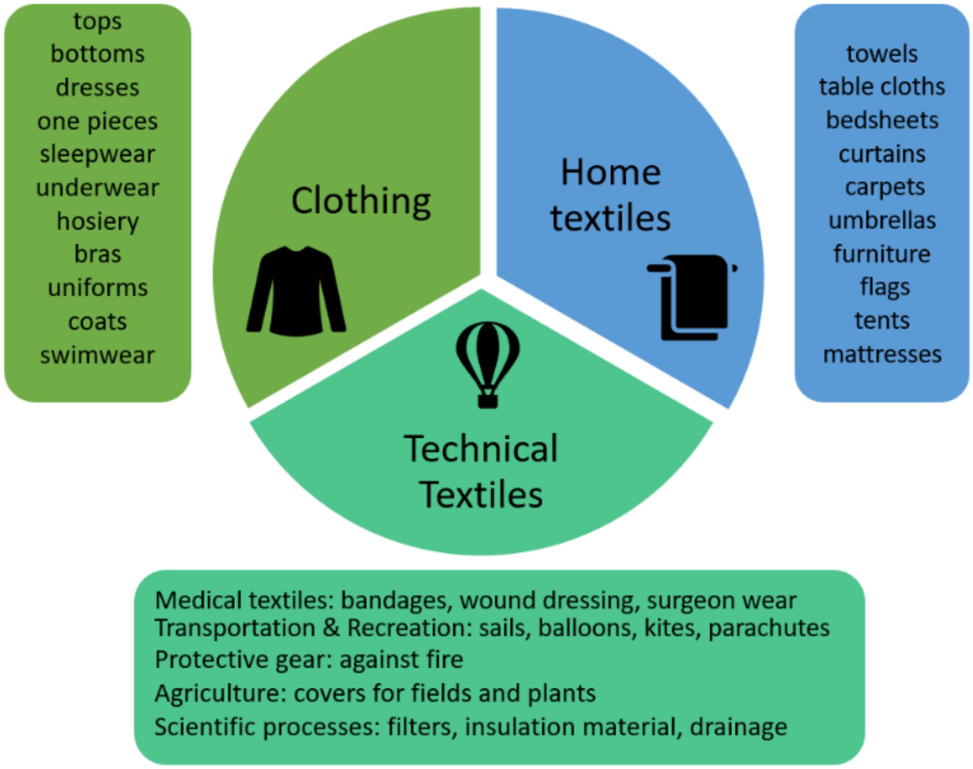


Figure 1: Categories of textiles with product examples

Looking at textiles through a waste management lens, there are many products made or partly made of fibres that are excluded from this definition, such as furniture, carpets, area rugs mattresses or disposable personal hygiene products and diapers. These products usually have their own waste diversion program because they are often bulky, heavy, or difficult to handle in Residential waste collection. Some of these items are collected by Habitat for Humanity others have little opportunity for reuse. For example, many organizations have sanitary concerns with mattresses if the organization is not explicit specialized in collection of them. Finally, these items require unique recycling processes.

In fact, the definition of textiles in waste management is heavily influenced by the charities that collect unwanted textiles to sell to second-hand markets in order to fundraise for their missions. In this case, the textiles category includes shoes and bags, which were traditionally made of leather and not of fibres, but due to their high resale value, they are collected under "textiles". Today, most shoes are made of some fibre material and the sole and outsole are often made of plastic foam. Thus, shoes are a combination of different material types that make them difficult to recycle, but the recycling process for a shoe is different from that of a garment. For the definition of textile waste, a baseline was developed in a workshop from the Ontario Textile Diversion Collaborative (OTDC) with municipalities, charities, and private collectors. Six categories were identified: clothing, home textiles, accessories, footwear, stuffed toys, and other. Furthermore, the group decided to use the more common terms from the textile industry and preferred home textiles over household textiles. Likewise, the term accessories are chosen to describe bags and gloves, rather than durable goods which is used in the Nova Scotia textile waste audit (Jensen, 2018).

Global Fibre Consumption

Although more than 40 different fibres exist (Eberle et al., 2004), the global fibre demand is driven by polyester. In 2017 polyester production was approximately 53 million mega tonnes (mt), a market share of more than 50 per cent (Textile Exchange, 2018). This number increased to 57.7 million mt and 52.2 per cent in 2019, making polyester the number one fibre globally. With polyamide and other synthetic fibres such as spandex (also referred to as lycra or elastane), acrylic or acetate, synthetic fibres accounted for 69.7 per cent of the global fibre production in 2019 (Sophia et al., 2020). These numbers illustrate that most textile products are made of a type of plastic from polyester, a material blended with polyester, or some other synthetic materials (see **Figure 2**).

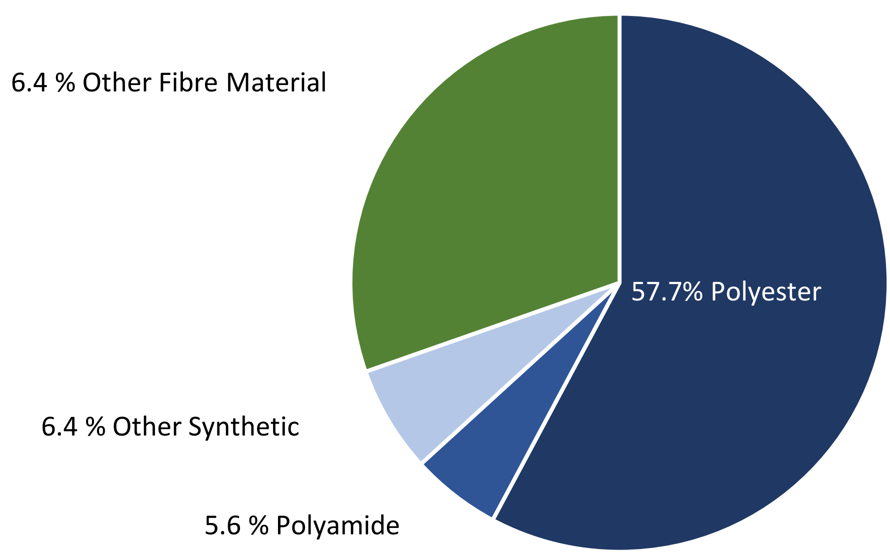


Figure 2: Global synthetic fibre production in 2019, compiled from (Sophia et al., 2020)

While the global fibre demand is continuously increasing, a positive development within this industry is the increased use of recycled polyester in clothing production. In 2019, 14 per cent of worldwide polyester production was recycled polyester, or polyethylene terephthalate (PET) mainly made from PET plastic bottles. This number could have been higher if China had not released an import ban in January 2018 on different types of solid waste that caused a shortage of plastic bottles available for recycling (Sophia et al., 2020). Recycled polyester can also be produced from pre- and post-consumer textile waste, but this remains a niche market and is not commonly practiced. In Canada, Loop Industries (Terrebonne, Quebec) developed and patented a technology to depolymerize PET plastic and polyester fibre, including plastic bottles, packaging, carpets, and textiles of any colour base building block monomers (Industries, 2021).

Furthermore, the former company Victor Innovatex, since purchased by Duvaltex in Quebec, developed an Eco-Intelligent® polyester in 2003. This product is based on recycled plastic pellets with their partner Unifi (North Carolina) and contains a mix of post-consumer and/or pre-consumer recycled material.

Even more challenging than polyester fibre recycling is the recycling of polyamide fibres. Despite the difficulty, the company General Recycled based in Vancouver, BC, is already recycling polyamide fibres and has built a second facility in Val-des-Sources, Quebec. While the company's primary focus is on aramid fibres – a specific type of polyamide fibre extensively used in fire-resistant garments – they are also looking at nylon and polyester fibres. The company's main reason for using aramid over nylon fibres is the comparatively low price for virgin nylon fibres compared to aramid fibres. Nevertheless, this means that a closed-loop recycling process for polyamide fibre exists and is available in Canada.

As outlined above, 6.4 per cent of all synthetic fibres fall into the 'other' category. This group includes fibres such as elastane and acrylic. Although a couple of companies are working on the chemical recycling of these fibres (Textile Exchange, 2018), it is unknown at this time if companies in Canada are involved in this kind of fibre recycling.

Sorting Textiles

Before anything can be recycled, it is necessary to evaluate the possibility to reuse the product and keep it in use for as long as possible. This is particularly important for clothing since garments are highly underutilized. On average, consumers wear their garments only a handful of times before they dispose of them. For example, according to a survey of two thousand women in the U.K., the average clothing item was worn an average of only seven times before being discarded (Maybelle, 2011). This low garment utilization means there are great opportunities to resell and further reuse garments, as long as the material is being separated from the waste stream. Notably, before used textiles can be resold, they require a sorting or grading process based on quality and product type.

Another reuse option is to use the garment for its fabric value, and upcycle it into a new garment. This means that parts of one garment are used and mixed with parts of another garment. There are a number of designers and small brands in Canada upcycling to develop new products, for example, Nudnik in Toronto, who uses second-hand clothes and deadstock to produce their line of children's clothing.

If the material is not appealing enough for upcycling, recycling is required to divert the fibre material from disposal. Recycling can be done mechanically or chemically, depending on the desired output. Based on the recycling process, the material must be further sorted by fibre material or colour. Finally, not every garment or textile product can be reused, upcycled or recycled. The material may be contaminated with oil and paint, contain mould, or have a strong odour which requires a costly cleaning process. In that case, recycling is not feasible. It is difficult to collect such materials since, during the collection phase, these materials could contaminate the other collected materials. Examples of such products are used pet articles such as beds, clothes or toys. These materials have no commercial value if they are used and have strong odour. **Figure 3** provides an overview of the different sorting options according to garment, fabric or fibre value.

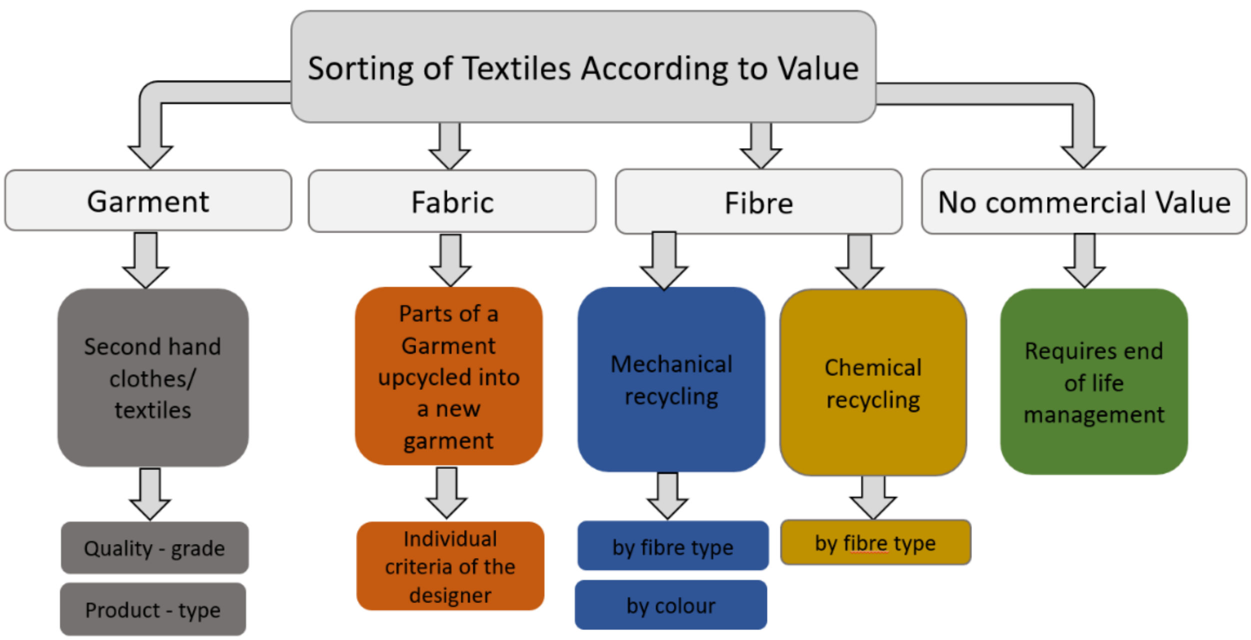


Figure 3: Sorting textiles according to value

Recycling Textiles

Theoretically, all textiles can be recycled in some way (Stall-Meadows and Goudeau, 2012); the questions are where and how. Textile recycling starts with separating the fabric from other solid parts of the products. For example, to recycle a chair's fabric, the textile material must be separated from the framework's wood or metal. For a garment, this means accessories such as buttons or zippers must be removed. Once there is an individual textile material, the recycling process can start.

Companies that sort and grade used clothing that is not suitable for reuse, divide them into pieces to be sold as cleaning and wiping rags. This ragging process downcycles the product and is only applicable for natural fabrics like cotton that have high absorption rates; thus, synthetics are not well suited. This technique is widely practiced in Canada and is part of many graders' operations, for example, Canadian Clothing International Inc. in Scarborough, Ontario.

The other option for mechanical recycling is shredding, in which fabrics are pulled apart and the fibres are shortened as a result. During this process they also lose their strength, and if they are made into new yarn, the resulting quality is lower. However, such shredded materials can be used for "non-woven" fabrics, made directly from fibres without creating a yarn or the need for a weaving or knitting process. The company Jasztex in Montreal is known for its non-woven fabrics, made into insulation material, blankets, or filters (Jasztex, 2012). Another company that innovatively transforms shredded denim material is the U.S.-based company Shear Composites. The company bonds the shredded fibres with a bio-based resin to create sheet material or compression moulded items to produce furniture, countertops and work surfaces, plates, and even jewellery (Shear Composites, 2021). It is currently unknown if a similar company exists in Canada.

The chemical recycling process depends on the fibre material. Natural cellulose-based fibres, can undergo a particular procedure that extracts and dissolves the cellulose. The process generates a pulp that can be respun into a yarn. In this case, a cotton fibre could not be chemically recycled back into a cotton fibre, but would become a regenerated man-made cellulosic fibre. This situation is different for synthetic fibres since they are already man-made fibres; the fibre material can be dissolved, turned into a pellet or chip, and spun into the same fibre type. However, every fibre requires its own recycling process, even if the forming materials are the same. For example, cotton and linen fibres consist of natural polymers, but the chemical recycling process is still different. Therefore, most companies have focused their recycling research on polyester, which has a market share of 52 per cent, or cotton, which has a market share of 25 per cent (Textile Exchange, 2018).

Various global start-ups work on chemical closed-loop recycling processes, such as Evrnu, Circ, Worn Again and Re:newcell, the latter which claims to have the largest cellulose recycling plant globally. While Evrnu started as a company that specialized in cotton recycling, they have extended their portfolio to include synthetics. Worn Again and Circ (formerly Tyton Bio Sciences) started with polyester fibre recycling and expanded their portfolio to recycle fibre blends. Further information about these companies can be found in Part Four: Examples of Operators and Manufacturers. All start-ups claim that recycled fibres require less energy and greenhouse gas emissions than producing virgin fibres.

However, chemical closed-loop textile recycling (not from plastic bottles) is still in its infancy. It is much easier to work with an untreated material than a dyed garment treated with various unknown chemicals, and worn by a consumer. Hence chemical closed-loop textile recycling is better suited to start with pre-consumer textile waste from manufacturing facilities rather than post-consumer textile waste. Once the technical challenges are overcome, the next hurdle is economic feasibility since reclaimed fibres must compete in price with virgin fibres. In an interview, Luke Henning, Chief Financial Officer of the Startup company Circ, claimed that the company will mix their reclaimed fibres with virgin fibres, not in an effort to increase product quality, but rather, to produce a reclaimed fibre material that is competitive in price (Weber, 2021). **Figure 4** provides an overview of the different textile recycling options.

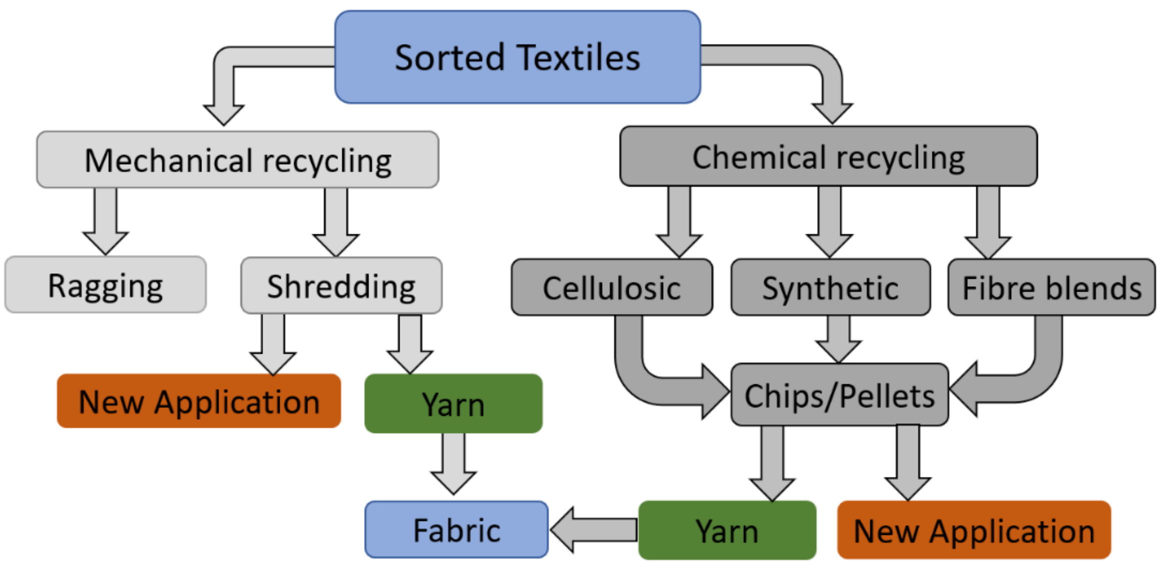


Figure 4: Overview of mechanical and chemical textile recycling options

Part Two: Textile Waste

Sources of Textile Waste in Canada

In Canada, textile waste can come from either Residential or Non-residential sources. Residential non-hazardous waste disposal consists of solid waste produced by all residences, including waste picked up by the municipalities, or waste that is self-hauled to depots, transfer stations, and disposal facilities.[4] Non-residential non-hazardous solid waste includes waste generated by all other sources not included in the residential waste stream. Therefore, Non-residential waste includes all waste from multi-unit residential buildings and the Industrial, Commercial and Institutional (IC&I) sector. Waste from the IC&I sector comes from manufacturing, commercial operations, shopping centres, restaurants, offices, and institutional materials such as schools, hospitals, government facilities, seniors' homes, and universities (Statistics Canada, 2021a). The other Non-residential waste generation sector is waste resulting from demolition, land clearing and construction (DLC) which is not considered in this analysis. The sources, the collection systems, and waste policies differ between Residential and Non-residential waste and therefore, both streams must be analyzed separately. **Figure 5** reflects the sources of textile waste only explored in the study.

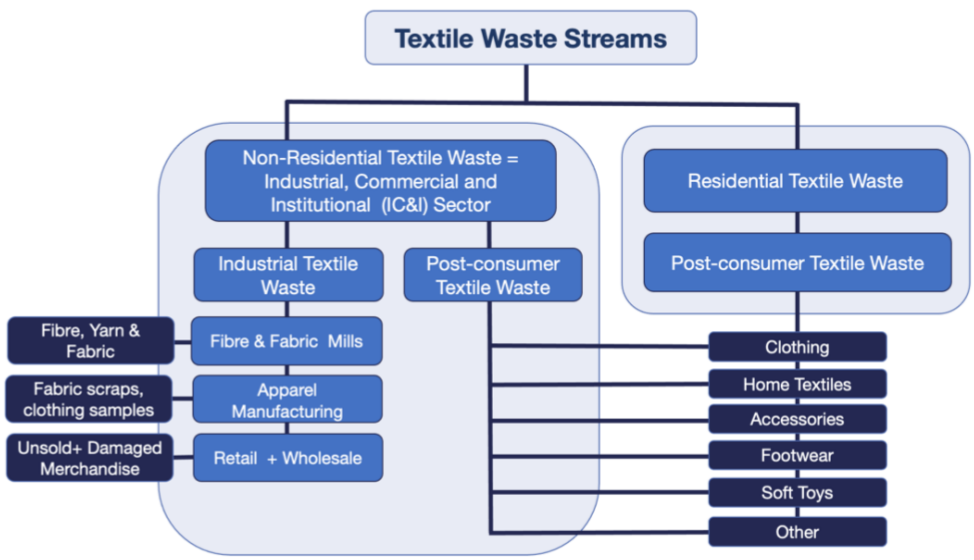


Figure 5: Waste streams and categories of textile waste adopted from Weber (2021)

[4] Waste can be picked up by municipalities either through their own staff or contracting private firms.

Common Methods of Residential Textile Waste Collection

Prior to 2016 there were no "province or territory-wide diversion programs for textiles [in Canada]" in place (Giroux, 2014b, p. 33) for Residential textile waste. This situation has since changed, as some progressive municipalities have textile diversion programs in place, while others are interested in starting, or are piloting textile waste diversion programs. The interest comes from an awareness that textiles are often the most significant single waste group remaining in the waste stream, after organics. Furthermore, municipalities recognize that textiles can have a higher sales value than some of the materials diverted in a blue box program; and finally, municipalities are often contacted by textile collectors eager to partner up, collect and manage the materials for them. The service that textile collectors can provide means that municipalities do not need to invest in infrastructure for textile diversion programs.

As a result, an increased number of municipalities see textiles as low hanging fruit for waste diversion and have partnered up with one or multiple charity organizations to set up semi-private textile collection systems. Semi-private means the charities collect and further resell the textiles, but a municipality might also encourage its residents to donate their textiles to their charity partner. Municipalities might also support their partners by providing space, for example, for a collection depot next to a landfill site, or with locations where the charity partner could set up textile collection bins. In the Greater Toronto Area, the city of Markham took it one step further and branded over 150 textile collection bins with their logo, placed across the municipality and ran the programs through licensed charity partners. For more information about Markham's Textile Diversion program see the case study in **Appendix B:** Markham Textile Recycling Program Case Study.

Less commonly practiced is that municipalities collect, manage and resell their textile themselves, as in the city of Colchester, Nova Scotia. Other regional districts, such as Metro Vancouver, do not want to start collecting textiles, nor do they want to partner up with a particular charity or collector. They argue that they cannot compete with a charity in collecting textiles, nor can they undermine textile collectors' competition. Nevertheless, they developed a 'Think Thrice' campaign to educate its residents about textile waste diversion (Storry, 2021).

There is also no standard method in place as to how to collect these textiles. Some municipalities introduced curbside pickup where residents receive a designated plastic bag collected on a predetermined date. The town of Aurora, Ontario has implemented such a system. The plastic bags are preferred because they prevent the material from becoming wet, which can cause mould, thus making the material unusable. Other municipalities argue that curbside pickup is too expensive and prefer collection bins. Using bins also has the advantage of being accessible 24 hours a day, 7 days a week.

So far, only the city of Markham, Ontario has released a ban of textiles in landfills, in 2017. However, many charities would support further bans as the following statement from a Goodwill (Great Lakes) representative shows: "we would absolutely support a municipal landfill ban and Goodwill would like to collect and manage the materials. We want to be that partner for municipalities, and we want to find a seamless alternative solution for what consumers are doing today. Making it as easy as possible for them when these bans come into play" (Habash, 2021).

However, while some charities might support textile bans, municipalities are more concerned about the material that is not good enough for reuse and requires recycling. Some municipalities, such as Toronto, are concerned about even using the word recycling in connection with textiles and are concerned that textiles could end up in the blue box and cause contamination in their Materials Recovery Facilities (MRF). While the city encourages their citizens to donate their clothes, it also tells them to throw items not suited for donations into the garbage. This message leaves the citizen with the decision of whether an item is good enough for reuse or not. With this messaging, textile collectors will ultimately collect less (Weber, 2015).

Four aspects have allowed municipalities to underestimate the problem of textile waste diversion and the amount textile collectors collect: 1) the degree to which local residents are willing to bring their unwanted clothing to one of the recycling boxes or donation stations (Laitala, 2014), 2) the vague communication from many textile collectors as to what materials can be donated, 3) the volume of textile waste that comes from an increase in consumption, and 4) the quality of the textile material collected. This fourth aspect includes the vulnerability of second-hand markets for used clothing as a commodity, and the amount of material that is not good enough for reuse, thus requiring recycling infrastructure to improve diversion. The latter element is often overlooked because most textile collectors only collect the material and sell it by the pound without examining its quality (Weber, 2015).

In summary, there is no standard method for municipal textile diversion programs, nor can it be assumed that a municipality has a textile diversion program in place. Regardless, textile collectors will advertise and install their collection bins in an attempt to gather the unwanted material. Whether or not municipalities are involved in textile waste diversion, they are positioned between the consumers and textile collectors. Therefore, to fully understand the issue of textile waste, it is necessary to explore how consumers are managing their unwanted garments and what textile collectors do with the collected material. First, the consumer standpoint is addressed, followed by the role of textile collectors, second-hand retailers, and sorter and graders.

HOW CONSUMERS MANAGE THEIR UNWANTED TEXTILES

A representative study conducted in Ontario in 2015 found that donating clothes is an accepted social norm. This implies that people know they should donate their clothes, with 91 per cent of participants claiming that they have donated clothes at some time. Most consumers admit they have no barrier to donating clothes, and estimated that they donate nearly 60 per cent of all their unwanted garments. Nearly half (49 per cent) of the participants dispose of unwanted garments because they think their clothes have become too inferior to donate.

The main barriers for clothing donations mentioned by participants are the accessibility of bins, and the required time needed to bring unwanted clothes to a donation location. Nine per cent of participants declared that they throw all their unwanted clothes into the garbage and admit they have never considered doing something else with them (Weber, 2015). To put this number in context, it means that roughly 1.3 million people in Ontario throw all of their unwanted clothes into the waste bin. Hence, garments have a high potential to end up in the garbage, but for years the per centage of textiles in Canada's waste stream was unknown.

For two years, the Ontario Textile Diversion Collaborative (OTDC) and its member municipalities tried to determine the volume of textiles in Ontario's waste stream, without success. Two factors which made it impossible to determine this data were: 1) the municipalities had no textile waste data because most do not identify textile waste as a separate category in their waste composition studies. and 2) the methodologies used to collect and report the data, and the varying time frames when textile waste audits were conducted were so different, that a comparison and consolidation of data was impossible.

The Role of Textile Collectors, Second-hand Retailers, Sorters and Graders in the Management of Used Clothes

In Canada, used textiles are collected either by for-profit companies or charities. Charities that only collect (not sell textiles to a private entity) include Diabetes Canada and Kidney Clothes. The latter's mission is to raise money for those that suffer from kidney disease, and they do this through the collection of reusable and resaleable clothing and household goods which are then sold to their main customer Value Village (VV) by the pound. VV is a for-profit company that works with many charities that collects and sells used clothes at its second-hand stores across Canada. Different textile collectors use various collection methods, with Kidney Clothes known for its convenient home pickup service. In contrast, Diabetes Canada mainly collects through donation bins. However, VV will also accept donations directly from its customers at its retail locations. Once VV receives the product, employees will do a rough pre-sorting of the merchandise in their stores. About half of the donated material goes into the store for sale, while the other half is not considered good enough for their customers and is sold to a sorter and grader. In this process, very little goes to waste on Canadian soil (Shumpert, 2021).

Thrift customers who shop for vintage or used clothes know what they want, and popular pieces can sell in a matter of hours or days. If a garment is still on the sales floor after two weeks, it is less likely that it will sell, so the second-hand retailers will sell these materials on to a grader. About 30 per cent of the material will be sold to end consumers, with the remaining 70 per cent sold to a grader by the pound (Ontario Textile Diversion Collaborative, 2018). Second-hand retailers make a higher profit when the material is sold in store, rather than by the pound to a grader. However, they still rely on selling their leftover materials to a grader, even if the price is a fraction of the sales price in the store. Graders buy the material from second-hand retailers and sort it according to various criteria, then sell it globally to other markets – usually whoever pays the most. Graders have hundreds of categories for sorted materials, and each grader knows its customers best (Rivoli, 2009). Once the material is sorted and graded, it is pressed into bales and then shipped abroad. In seldom cases, unsorted bales are also being sold, because this decreases the price significantly. International buyers have different requests; however, it is difficult for outsiders to determine a valuable product on the second-hand market overseas. For example, bras are an item that Canadians might question whether to donate, but according to textile exporters, there is a demand on the international second-hand market for these items, particularly if they are in good condition and the elastic strap is still functioning.

Most charities report that the amount of materials they collect is increasing each year (Ontario Textile Diversion Collaborative, 2018). However, collecting more unwanted material does not automatically support their business, which is mainly dependent on two things: 1) the labour costs and expenses for collection of the materials (e.g., the licences to place bins or to operate collection vehicles), and 2) the achieved price per pound for the collected textiles, which connects directly to the quality of the materials. Hence, charities are concerned about the quality of the donated products and their associated collection costs.

Some graders offer additional services such as the removal of price tags or laundering the items; others might downcycle some of the materials through ragging. If a Canadian textile recycling industry can ever be developed, it could be placed at the sorters and graders, since they choose whether a textile requires recycling or can be sold for reuse. They have the power to decide whether a garment stays in the country or is being sold abroad, and they might even decide to not sort the textiles in Canada but rather to ship overseas for sorting where the labour is cheaper. In recent years, the prices for used clothing as a commodity have dropped, putting the industry under pressure, and as a response, graders have sought options to grade the materials offshore. Graders play a central role in the management of used textiles as they own the product and can decide what to do with it.

We interviewed Tony Shumpert, Vice President of Reuse & Recycling at Savers/Value Village who believes that North American graders have the greatest opportunity when it comes to textile recycling. Shumpert stated: “The reason being is that the graders that are operating in Canada are already separating, or grading, the material into various categories for reuse, recycling and waste to landfill. It is their business to determine what is reusable and what is not. A thrift retailer such as Value Village would never spend the human resources to sort out materials based on fibres, which is what is required for recycling. Whereas the grader is in a different situation, already handling each item and assessing it, so the only calculation they must consider is whether recycling is cost neutral or slightly better for the non-reusable (or non-sellable) textiles. Some may even consider recycling because of its environmental benefits. In terms of automated sortation, it also makes sense for the sorters and graders in North America to invest in this, given the high labour cost to sort textiles when compared to that of overseas markets where the labour is one tenth the cost in North America. If automated sortation can mitigate the cost burden of manually sorting by fibre composition, then it might be something for sorters and graders to consider" (Shumpert, 2021). This raises the question of what the barriers are for textile sorters to get started with textile recycling.

To gain further insight from a sorter's perspective, we spoke with Navi Sahsi, Director at Canam International Textile Recycling. Sahsi indicated an interest in developing a local textile recycling facility to better manage items not suitable for reuse. He also affirmed the high labour cost associated with sorting and grading textiles in Canada, based on the fact that roughly 50 per cent of what his facility buys annually, is shipped overseas to be sorted and graded at a tenth of the cost (Sahsi, 2021).

Firstly, sorters and graders in Canada have a high interest in having little to no waste since they pay the waste handling fees associated with discarding materials that are not fit for reuse. Although there is no official data on the volume of textile waste managed by sorters and graders, it can be estimated based on our interviews that it is 5-10 per cent. Since textile sorters and graders have waste material that requires recycling, it becomes a question as to the barriers that are preventing them from beginning this process. At this point, there is no comprehensive research as to all the barriers, but based on workshops conducted by OTDC, the textile sorters who attended stated that they lack the equipment to recycle the material and there is a lack of end markets for the recycled materials (Ontario Textile Diversion Collaborative, 2017).

Unfortunately, sorters and graders are typically shy. Since many people disagree that used clothes should be sold to developing countries, sorters and graders often hide behind charities and second-hand retailers. This may have worked in the past, but there has been a recent increased pressure for more transparency as to where the materials end up.

The charity organization Goodwill Industries in the Ontario Great Lakes, for instance, uses a variety of platforms to create employment opportunities for people in need. It collects resaleable clothing and household goods and sells them in their stores. Furthermore, it operates a centre where they sell products by the pound to private people and small businesses, and where the organization bales its donations for further resale. They recently partnered with an Ontario college to conduct research on upcycling, and have been producing face masks throughout the COVID-19 pandemic. The charity is now considering development of their own sorting facility, and they are exploring opportunities to recycle the unusable excess material. A recycling facility could provide the opportunity for charities to expand their business model. However, the challenges lie in how to get this textile recycling system started, what end products could be made, and how these products can be marketed. This example shows that a potential textile recycling industry could also be established in conjunction with some of the charity organizations.

SECOND-HAND MARKETS OVERSEAS

Once sorted and graded, the material is baled and ready for export. Each bale has a unique composition of articles, and buyers of used clothing in developing countries are cautious about who and where they buy from.

The price of bales may vary depending on the type and quality of the garment. Furthermore, prices are not static and instead vary according to supply and demand. For example, the sorting company Canadian Textile Recycling Limited displays prices that vary between CAD$0.30 and CAD$1.50 per lb (660 – 3,300 CAD$/tonne). Rivoli (2009) reports that a 1,000-lb bale might contain up to 3,000 articles of clothing – and each one is different. The total value of used clothing that was exported from Canada to other countries around the world in 2017 is CAD$173M (Government of Canada, 2021).

In recent years there have been various concerns that western countries are dumping their unwanted clothes in developing countries, leading to environmental pollution and destroying the local textile industry. We interviewed Dr. Anika Kozlowski, a fashion professor and researcher at Ryerson University in Toronto, who has done extensive research in Ghana on textile waste, to hear her perspective. Dr. Kozlowski reports: “Seeing winter clothing in Africa is quite common, from the West coast to the East as they litter the landscape and are found in abundance in their landfills. The narrative that African countries are only provided with clothing they need is utterly false. It has become a dumping ground, as one only needs to visit to see the vast amount of apparel waste accumulating at a rate far greater than any African country can effectively deal with.” However, this response contradicts others who were interviewed that claim no used clothing buyer would purchase bales from sources they do not trust, or that are not suited for their market. Rivoli (2009) reports that problems are also caused when used clothes are donated to developing countries as a form of humanitarian relief following a crisis. More research is necessary on how these unsuitable materials end up in developing countries, and if these materials are actually from Canada or other countries.

This study aims not to rectify nor define either opinion, but instead views used clothing as a commodity, acknowledging that garments will be sold to global second-hand markets as long as it makes economic sense for the graders. If the grader can make as much or more money from recycling the material than from selling the used clothes, a localized recycling system can work.

But in order for this to happen, textiles first need to be removed from the waste stream, and then collected for recycling – all at the lowest possible cost.

In short, the collection, sortation and sales of used clothes is big business. In 2019, Canada exported approximately $130.54 million USD worth of used clothing, making Canada the eleventh largest exporter of used clothing globally (Sabanoglu, 2020). What is not commonly known is that Canada also imports used clothing at times of the year when used clothing donations are low, so that sorters can keep their facilities in operation.

Given the research findings from textile collectors, second-hand retailers and graders, it can be determined that a correlation exists between an increase in the diversion of used textiles, and an increase in demand by the reuse sector. It therefore does not make sense that the materials go into landfill, and yet our used clothing capture rate varies to such a degree that used clothing is imported from countries such as the U.S. to be processed further in Canada. This shows promise that government intervention to increase textiles recovered from disposal could stimulate growth in the reuse sector.

Textile Waste Data

With some exceptions, the majority of municipalities in Canada have no textile diversion program in place, and more critical is that they do not know how much textile waste is in their waste stream. In Ontario, for example, textiles are not a designated waste material, which means municipalities are not required to divert textiles from the waste stream, nor do they track the volume of their textile waste. Adding another category for textile waste to an existing waste audit costs money, hence there is little justification for this if it is not a requirement. This situation is common across Canada.

An apparel waste study in the Greater Vancouver Area looked at 28 regions, 13 of which had no data on textile waste. Whereas for the other 15 regions, the data provided was from 2006 – 2016, with only two regions having data from 2016, and three from 2015. This lack of data reveals that if textiles are audited, it is not common practice. Moreover, only three jurisdictions separated clothing from other textiles. The Vancouver area research had a final estimate of 5 per cent for textiles overall and 2 per cent for clothing waste, but with limited primary data (Storry & McKenzie, 2018). This lack of data is a Canada-wide problem and is not unique to the Greater Vancouver Area. As a result, many assumptions have been made. Canada’s Ecofiscal Commission confirms, there are “significant deficiencies in solid waste management data in Canada. In most cases, Canadian waste management data are several years old and may be outdated” (Canada's Ecofiscal Commision, 2018, p. 48).

While data is sparse on textile waste in the Residential waste stream, there is even less data available from Non-residential sources. Textiles are most often included in the "other" waste category. Because textiles are not a separate waste source, they are rarely mentioned in waste composition studies. One exception is the waste audits conducted in Nova Scotia (NS).

In 2017, NS audited seven landfills across the province to determine what materials end up as waste. While the waste auditors described the textile waste category as strikingly large, it needs to be considered that NS is highly efficient in their waste diversion efforts, having banned organics and paper/fibres years ago (Jensen, 2018). However, there are still some organics in the waste stream because these bans have not been well enforced. According to Statistics Canada (2008) the overall disposal rate in the Residential waste stream in NS was 45 per cent lower than the Canadian average, and The Conference Board of Canada (2014) confirms: "Nova Scotia earns an 'A' grade, with the lowest amount of waste generated per capita among all provinces". This performance must be considered when looking at textile waste data from NS because an equivalent rate of textiles in NS would be approximately half the rate for example, in Ontario. The high diversion rate in NS makes the other waste categories larger from a per centage perspective.

Of the IC&I waste stream in NS, textiles accounted for 5.8 per cent in contrast to 12.7 per cent of the Residential waste stream. Interestingly, the per centage of textiles in the IC&I waste stream was significantly lower than in previous years. In the Non-residential waste stream, the per centage of textile waste was 10.4 per cent in 2012, and 10.1 per cent in 2011 (Jensen, 2018). Using an average from all three studies, textiles in the Non-residential waste stream account for 8.77 per cent, and 13.40 per cent in the Residential waste stream (**Table 1**).

Table 1: Overview of textile waste (%) in Nova Scotia

Waste Sectors	2011	2012	2017	Average over three waste audits
Residential waste stream	11.2	16.3	12.7	13.40
Non-Residential (IC&I) waste stream	10.1	10.4	5.8	8.77
Average textile waste across sectors	10.65	13.35	9.25	11.08

According to Bob Kenney, Recycling Development Officer Sustainability and Innovation, Air Quality and Resource Management from Nova Scotia Environment (NSE) (2021) the reason for the low per centage of textile waste in 2017 from the Non-residential, or IC&I sector, compared to the Residential stream, is due to sample size. The collected data over the three waste periods are larger and therefore the results are more accurate. A company generates more waste than a household, thus a sample selection from the IC&I sector does not reflect as many different waste sources as a sample from the Residential waste stream. Furthermore, samples from the IC&I sector depend more on the specific landfill site and the particular companies. Therefore, waste audits from the IC&I stream have higher variabilities in the composition of the waste than Residential audits. The idea to take the average per centage of all three waste audits from the IC&I sector - 8.77 per cent – is supported by Mr. Kenney.

Regarding Residential waste, Kenney (2021) suggests staying with the lower per centage of 12.7 per cent in 2017 because Nova Scotia Environment funded the Association for Textiles Recycling (AFTeR) to organize itself and to divert more textiles from disposal.[5] The decreased per centage of textile waste in 2017 might reflect the successful work of AFTeR. Since Nova Scotia's disposal rate is almost 50 per cent lower than the Canadian average, the 12.7 per cent of Residential textile waste would equal 6.35 per cent Canada-wide. Residents of NS are heavy consumers of used clothes, and second-hand retailers Frenchy's and Guy's Frenchy's Imports, bring large amounts of used clothes from other countries into the province. Since residents have no stigma against used clothing, there is some overconsumption of cheap second-hand clothes, which eventually end up in the Residential waste stream (Kenney, 2021).

In summary, while textile waste data does exist from the Greater Vancouver Area and Nova Scotia, it is not logical to extrapolate the waste produced from one province to another. Since every province has its own reality of waste management, population and industry, the amount and composition of Residential and Non-residential textile waste may vary significantly between provinces. Furthermore, none of the data provides information about the quality of the material that ends up in the waste stream, nor the potential for reuse or recycling. To gain further data about the quantity and quality of textile waste in Ontario, the Dumpster Dive study was conducted.

Textiles in the Residential Waste Stream in Ontario

Although it would be desirable to know the per centage of textile waste across all jurisdictions in Canada, such data does not exist. Nevertheless, some insights can be provided into the quantity and quality of textiles from Ontario's Residential waste stream through a Dumpster Dive study conducted by Fashion Takes Action, Seneca College and environmental consultants, AET Group Inc.

[5] AFTeR has its own Strategic Planning, municipal outreach, etc.

AET group was chosen by the non-profit organization Stewardship Ontario in partnership with the Continuous Improvement Fund to conduct all their waste audits for 2019/2020 to control the programs' effectiveness and efficiency. Stewardship Ontario carefully chose the municipalities for these waste audits to represent the Province of Ontario (ON). Hence, the municipalities differ in size and include large urban, medium urban, rural, regional, and a Township. Furthermore, the municipalities also differ in their waste management programs in that some collect waste weekly, and others bi-weekly, while residents of the Township must bring their waste to a depot. Interestingly the audits included not only single-family homes (a traditional part of the Residential sector) but also multi-family homes which are part of IC&I sector yet are managed by municipalities on request by property owners. In agreement with Stewardship Ontario and each municipality, AET group separated all textiles from the waste stream and pre-sorted the material according to the following categories: clothing, home textiles, shoes, accessories, soft toys and other. AET group removed materials that were so heavily contaminated that they were unacceptable for further analysis. Although an annualization method with 4 rounds of waste audits was planned to reflect seasonal variations, only three could be conducted due to COVID-19. The textile waste audits from spring 2020 had to be cancelled because of a regional lockdown. The collected data ranges from July 8, 2019 to March 14, 2020, representing waste snapshots over ten months of a year, from ten representative municipalities in Ontario. More than 2,846 single family households and 35 multi-residential complexes were sampled in 36 waste audits reflecting a waste generation period of 19,370 days. Out of 36 audits, 11 took place in the summer months, 12 in fall and 13 in winter. In total, we collected and analyzed nearly 11,000 pieces of textiles, slightly over 1,800 kg, filling a transporter each season. Results indicated that the average per cent of textile waste per season was the highest in fall (4.72 per cent), followed by summer (4.41 per cent) and winter (4.15 per cent). This slight difference is comparable with used clothing collection drives, which are also typically highest in fall (Ontario Textile Diversion Collaborative, 2018). If we take the average of textile waste over the entire 10 months, we can assume that in Ontario, the per centage of textile waste in the waste stream is 4.43 per cent.

In the 2018 Waste Management Industry Survey for Business and the Government Sectors, Statistics Canada reports that Ontario oversees more than a third of the amount of Residential waste in Canada (36.69 per cent), and as such plays a major role as a waste generator. However, when comparing the textile waste data from Ontario (4.43 per cent) with the Greater Vancouver Area (5 per cent) and the calculated number from NS (6.35 per cent), Ontario has the lowest per centage. The lower per centage of textiles in Ontario's Residential waste stream makes sense since Ontario's overall waste diversion rate is lower than in NS or BC. Given that we want to evaluate whether there is enough textile waste available as feedstock for a recycling industry, we will use the most conservative number from Ontario of 4.43 per cent, as an estimate as to the amount of textiles in Canada’s waste streams.

Applying textile waste data from these audits, it is estimated that a total amount of 176,343 tonnes of textile waste in Ontario and 480,576 tonnes Canada-wide were sent to disposal in

2018. This waste is expensive to manage, and a missed opportunity to utilize materials that can either be resold and directly bring in revenue or create value through resource recovery to satisfy the increased global fibre demand (Ellen MacArthur Foundation, 2017; Giroux, 2014a). It is necessary to note that if all provinces in Canada would release and enforce a ban on textiles, not all 480,576 tonnes of textiles would be available for recycling. It is also important to remember that Canada is importing used clothes, particularly from the U.S., to sort and grade the material.

CALCULATING THE FIBRE MATERIALS AVAILABLE FOR RECYCLING

The Dumpster Dive study determined the per centage of each product category (PC) in the waste stream. Each item was graded according to whether it was good enough for reuse, needed recycling, or had to go to waste because it was too contaminated. The same grading system was used for all items, regardless of whether the product was a bedcover or a pair of underpants. In other words, the grading system did not consider potential end markets for these products. This method was used because in a real-life scenario, each grader has its customers and end markets. The overall per centage of the materials that were good enough for reuse is 64 per cent; that required recycling was 22 per cent; and that were so contaminated they could only be considered waste at 14 per cent (i.e., cleaning rags). However, each PC has a different rate of materials that require recycling.

Once each PC was determined, and the per centage within each of materials that required recycling, the fibre type was considered. It is necessary to differentiate between natural fibres, synthetic fibres or fibre blends because each fibre type requires different recycling processes. Articles made of cotton, flax, linen, hemp or wool were classified as natural fibres. Polyester, nylon, acrylic and spandex were summarized as synthetic fibres; and fibre blends were all materials that have a mix of natural and synthetic fibres. If a product is a fibre blend of polyester and nylon, it would still be categorized as synthetic fibre, although it is a blended material. This definition is unusual for fibre blends, but it was used to address the different recycling requirements. The final calculations were based on clothing, bedding, and towels, because these product categories can be recycled with similar technologies, whereas shoes or bags for example, require different technologies.

Results indicate that diverting the Product Category clothes, and the subcategories bedding and towels from the Residential waste stream would reduce the per centage of textile waste Canada-wide by 57.8 per cent or in absolute numbers, by approximately 280,000 tonnes (based on 480,576 total tonnes of textile waste in Canada's Residential landfills). Of the diverted materials, approximately 60,000 tonnes will require recycling. From this material, roughly 11,000 tonnes are synthetic fibres, and 17,000 tonnes are fibre (**Table 2**).

Textiles in the Non-residential Waste Stream

In 2018 about 58 per cent of all non-hazardous waste in Canada came from the Non-residential sector accounting for 14,884,782 tonnes. The other 42 per cent (10,848,128 tonnes) was generated from the Residential sector (Statistics Canada, 2018). However, there is a data gap on how much textile waste is generated from each sector and industry, and what product categories or fibres are ending up in a landfill. This study cannot close this research gap, however various surveys were conducted with the textile and clothing industry to gain more insights from the IC&I sector. This is described in the Survey Results section. To bridge this data gap and to arrive at an estimate for the Non-residential sector, the same waste composition was assumed for the IC&I sector as for the Non-residential waste stream, based on the Dumpster Dive study in Ontario.

Applying the conservative estimate of 4.43 per cent textile waste in the Residential waste stream to IC&I waste leads to an estimated amount of 659,396 tonnes of textile waste disposed of annually in Canada. To calculate the potential of the different fibre types available as recycling feedstock, the assumption must first be made as to the per centage of material that is available for either reuse or recycling. It is important to note that these assumptions must be made because there is no data available. In this case, it is assumed that all the textile waste from the IC&I sector requires recycling.

The per centage of the different fibre types was applied as in the Residential waste stream, which are 50 per cent natural fibres, 22.4 per cent synthetic fibres and 27.6 per cent blended fibres. The per centage of synthetic fibres is assumed to be higher in the Industrial stream than Residential because of the higher amount of home textiles, but there is no proof for this logic. Hence this is a conservative estimate so as not to overestimate the amount of synthetic fibres, especially given that the focus of this study is on recycling solutions for synthetics. Finally, the total fibre material that could be available for recycling was calculated according to the textile material diverted from the waste stream (**Table 2**).

Table 2: Overview of the fibre material that requires recycling in tonnes, per Product Category Canada-wide.

Product Category (PC)	% in Waste Stream	Absolute Volume (t) in Canada's Landfills (all fibres)	Synthetic (%) Require Recycling	Absolute Volume (t) of Synthetics Require Recycling	Blends (%) Require Recycling	Absolute Volume (t) of Blended Fibres Require Recycling	Total Synthetic & Blend (%) Require Recycling	Absolute Volume (t) of Synthetics & Blends in Canada's Landfills Require Recycling
Clothing	**42**	**201,842**						
Tops	37	74,682	16	1,314	28	2,300	44	3,614
Bottoms	27	54,497	12	785	44	2,877	56	3,662
Dresses	3	6,055	38	69	0	0	38	69
One-piece	4	8,074	28	68	30	73	58	141
Sleepwear	3	6,055	34	103	0	0	34	103
Underwear	6	12,111	4	155	45	1,744	49	1,899
Hosiery	11	22,203	17	491	52	1,501	69	1,992
Bras	1	2,018	67	135	28	57	95	192
Uniforms	1	2,018	19	96	81	409	100	505
Coats	6	12,111	40	484	33	400	73	884
Swimwear	1	2,018	19	96	73	368	92	464
Bedding	**12**	**58,150**	**40**	7,908	33	6,524	73	14,432
Towels	**4**	**17,781**	**11**	1,702	2	309	13	2,011
Total Residential (Clothing, Bedding, Towels only)	57.8	277,773		**13,406**		**16,562**		**29,968**
Total Non-Residential (all textile categories)	100	659,396	22.4	147,705	27.6	181,993	50	329,698
Total Residential & Non-Residential				**161,111**		**198,555**		**359,666**

INDUSTRIAL TEXTILE WASTE

Textiles in the Non-residential waste stream come from companies that produce textiles or textile products, and from companies that consume textile products. These products are identified as post-consumer textile waste. An example of the latter would be a hospital that provides bedcovers or towels for its patients. Additionally, there are companies that produce textiles and products for apparel, furniture, carpets, and even hot air balloons, as well as those companies selling these products. However, this study's focus is on companies that belong to the textile industry, and those that manufacture or sell cloth. For this study, the textile industry was chosen because textile waste is part of these companies' operations. Likewise, they can play a key role in textile recycling since they produce fibre, yarns and fabrics and there might be an opportunity to produce reclaimed fibre material. Clothing manufacturers and retailers that produce textile waste on a regular basis are also included. At first, the connection between fashion retailers and textile waste might not be evident, but unsold merchandise, damaged or stained products, and returns, are all contributing to what is considered pre-consumer textile waste. The difference between pre- and post-consumer textiles is that pre-consumer materials are unused and therefore clean when they go to waste, in contrast to the materials from post-consumer waste, which may be stained, dirty or contaminated. This makes a significant difference when it comes to recycling and can have far reaching effects. The following example will explain why it is important to make this distinction.

Until the beginning of 2020, Ontario had the Reg. 218/01: Upholstered and stuffed articles in place. This regulation mainly requested that any stuffing or lining materials for an article such as the filling of a pillow, or a part of a mattresses or any upholstered products, or even the lining of a winter coat, could only be filled or made with new materials – in other words, that had not been previously used. Recycled materials were not allowed. This regulation, better known as New Materials Only Regulation, prohibited for example, that shredded textiles from post-consumer textile waste could be used in Ontario in any kind of stuffing. However, the offcuts from a manufacturing facility which are "unused" - could have been used. While in the meantime the regulation has been loosened, it is still in place in Quebec and in Manitoba. The industry is slowly engaging with this new opportunity, with Canada Goose for example, now making some of their coats with recycled down. A photo of a New Material Only Label is provided in **Figure 6.**

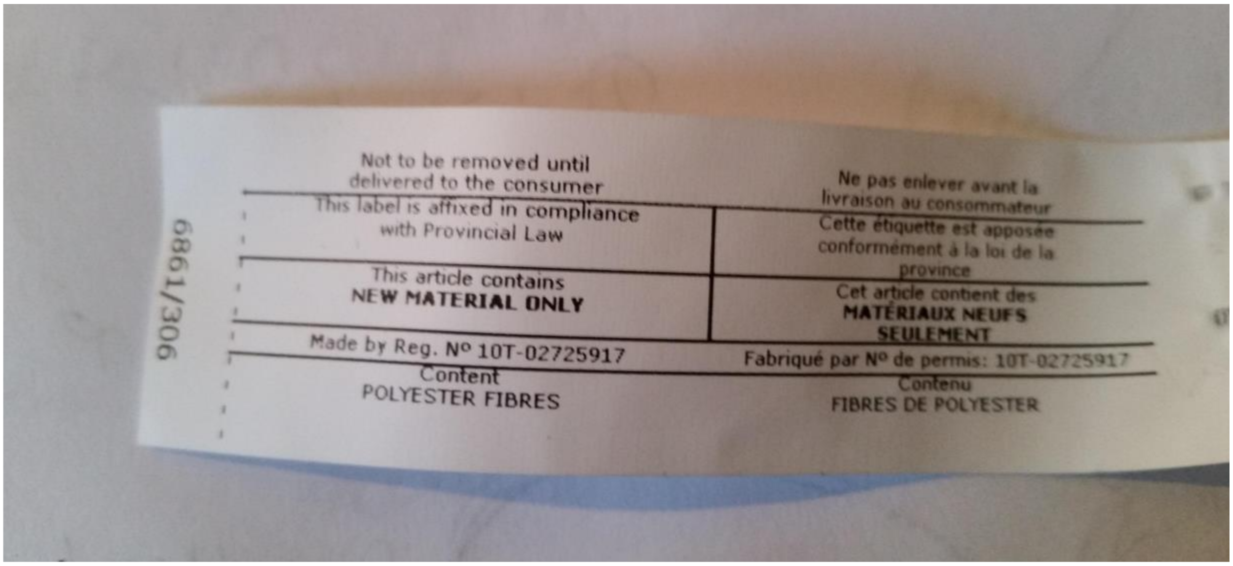


Figure 6: A "new material only" label from a garment

Part Three: Pre-consumer Textile Waste

In this section, clothing retailers, textile mills, textile product mills, and clothing manufacturers are described to get a better idea about the scope of these industry sectors.

Clothing Retailers

According to Statistics Canada (2021a) there were 19,021 clothing stores in Canada in 2019 with 99.1 per cent of them having less than 99 employees. Most of these retailers sell mainly new clothing. However, the number of stores that will remain in business once the pandemic is over is unknown. Although the overall increase in e-commerce grew by 70.5 per cent during the pandemic, there is no doubt that Canadian retail apparel sales had a disastrous year with sales falling 23.6 per cent in 2020 (Trendex, 2021). It is not clear how much inventory will be left once the sector goes back to full operating hours, nor how the retailers will manage their waste. In fact, this information was not available before the pandemic, and now with the new uncertainty, the challenge has become even greater. To get a sense of how much inventory was unsold before the pandemic, the Retail Council of Canada and the Canadian Apparel Federation were contacted, but even these industry associations had no data to share, and instead estimated the per centage of unsold merchandise to be between 10 and 15 per cent. Regardless of how high this number is, the question remains as to what retailers are doing with the leftover material.

Some retailers have reverse logistics in place, where stores can return the materials to distribution centres, and then may sell the product on to a jobber. In some cases, brands also sell their unsold merchandise to off-price retailers such as Winners, or the items will show up in an outlet shopping mall or liquidation centre. Another possibility for a retailer to dispose of distressed goods is to donate the material to a charity, and in return the retailer might receive a tax receipt.[6] Some charities also “de-brand” the merchandise which means they remove labels, logos, or trademarks so that the recipient does not know what brand they receive – this is mainly done for marketing reasons to protect brand image, or in case of security, for example to avoid the misuse of uniforms. The next option is to hire a reverse logistics company to sort, de-brand and manage the material in the most appropriate way. An established reverse logistics company in Canada is Debrand, located in BC, and handles the unsold inventory of brands such as Lululemon and Aritzia (Debrand, 2018). Debrand’s co-founder claims: “No brand wants to see its label going into landfill, but there is a cost associated if brands want to have their unsold inventory properly managed” (Eleiter, 2021). Debrand’s customers do not rely on making a profit from the recycled materials, instead Debrand is paid ahead of time for their service. This gives

[6] Retailer inventory items which are never sold, not even on clearance (Kunz & Garner, 2011).

the company the opportunity to recycle the material, for example by sending it to a shredder. Eleiter reports: “In one year, we send between 1M and 1.5M pounds to recycling channels (all in the U.S.) and 90% of this are textiles, 95% of which are synthetic” (Eleiter, 2021). There is a lack of textile recycling options in Canada, and often the material is being sent to the U.S. for shredding and further processing, at a cost. Hence, textile shredding costs money and is not a source of revenue, as there is a lack of creative applications for the recycled materials, and finally established end markets for these products (Ontario Textile Diversion Collaborative, 2017). Eleiter further outlines: “There is a need in Canada for textile recycling. If we want to become more circular and we want to encourage nearshore manufacturing then we need to be able to access the inputs and outputs locally. We need to start by looking at current feasible, financially viable solutions that have end markets that Canada can support” (Eleiter, 2021).

Another development that increased the need for reverse logistics is the growth of online retailing. Since the pandemic, overall e-commerce sales increased by 70.5% in 2020, and was according to Trendex: “the only bright spot for Canadian apparel retailing” (Trendex, 2021, p. 1). This means retailers have to deal with an increased amount of merchandise being returned from customers, because the merchandise does not suit their needs. Eleiter (2021) explains: “The issue right now is the mass shift of consumerism and the way they shop - they return 40% of what they buy in some cases. Distribution centres are inundated with returns, and they are already busy fulfilling outbound shipments for online orders. Now, they must also deal with these returns, and there is no efficient way for these items to be managed, which is the solution we are trying to fix. In addition, the retailers need to be better at asking customers why they are returning the product, and that the reason for asking this is to keep it out of the landfill. Once we know the reason, we can easily determine a reuse or recycling channel for our retail clients (**Figure 7**). All the constraints are in the backend. We ask the retailer, based on historical trends, what is most likely resalable or repairable - if they say a hole and it can’t be repairable it will automatically be sent to recycling. Each customer is going to have their own preference and profile for each grading channel. It can get really specific with donation partners. But if the items fall under a certain manufacturer’s suggested retail price, they say to just recycle it”.

The last option is to send everything to a landfill, which might cost a small amount, but is often the easiest option, and allows the retailer to claim the import duty drawback. If a retailer has no reverse logistics in place, the store manager must decide what to do with the material. An often-practiced method is to cut and destroy the material, and put it in the garbage for waste management to pick up. It is unclear how store managers handle those materials in their inventory, nor how they will appear in their accounting records. There is no official data on the number of companies that are practicing this method, but the “practice of destroying and disposing of unsold goods is apparently widespread in the retail world” (Forani, 2020). However, some cases are made public, most recently in April 2021 at a SoftMoc store in Toronto. Prior to that Carter's OshKosh in January 2020, where the public was outraged via social media to learn unsold merchandise that was in perfectly good condition, was cut up and put in the garbage. This might explain why no clothing company chooses to openly discuss this.

Unfortunately, there is no data available on how much inventory ends up in each channel. To better understand how much money the Canada Border Services Agency (CBSA) paid for duty drawback, a request was made to the Information Act by the OTDC in 2019. The Agency reported that CBSA refunded $8,019,662 through the Drawback Program between April 1, 2018 and March 31, 2019, for clothing that was deemed obsolete or surplus goods, and that met the legislative conditions established in section 109-111 of the Customs Tariff. The legislation's conditions require that the material is not to be used in Canada (see **Appendix C:** Access to Information Act Annex). However, this amount might also include merchandise that is imported and warehoused in Canada, on route to a final destination where it is being sold, for example to the U.S. In other words, it is unclear both how many pounds of material, or the total value of the material is going into the landfill. We do know that the import duty for clothing and shoes is between 17.5 and 18.5 per cent, which is significantly higher when compared to other sectors. Furthermore, we can claim that this legislation undermines textile recycling, or the reuse of these products through charitable donations in Canada, since these more environmentally friendly options are deemed as 'use in Canada.

Therefore, companies that recycle their textiles or donate locally cannot claim this import duty back. This aspect of the regulation is not sustainable, as it incentivizes companies to take the easier and cheaper route of dumping their unsold merchandise. Ironically, the Canadian Apparel Federation recognized that many of its members are not aware of the duty drawback and so hosted a webinar after the first COVID -19 lockdown: "How to Use the CBSA Duty Deferral Program".

In conclusion, the duty drawback program provides an incentive for importers to landfill their unsold merchandise, instead of reusing or recycling the materials. Many retailers do not even know about the opportunity to get the import duty drawback, and a significant portion of retailers do not even know how much unsold merchandise they have. While some retailers who lack reverse logistics may put their unsold inventory in the garbage, others pay for the recycling of their materials, but still require a reverse logistics partner to manage the inquiry. While the increase of online retailing has increased the need for reverse logistics, growing pressure for circularity has opened new interest in recycling opportunities which Eleiter (2021) summarizes as follows: “The textile recycling industry is at a crossroads as there is a demand by the manufacturers, brands, and retailers for circularity - in the past 2 years it has become prominent, there is an appetite for it but zero infrastructure to support it”.

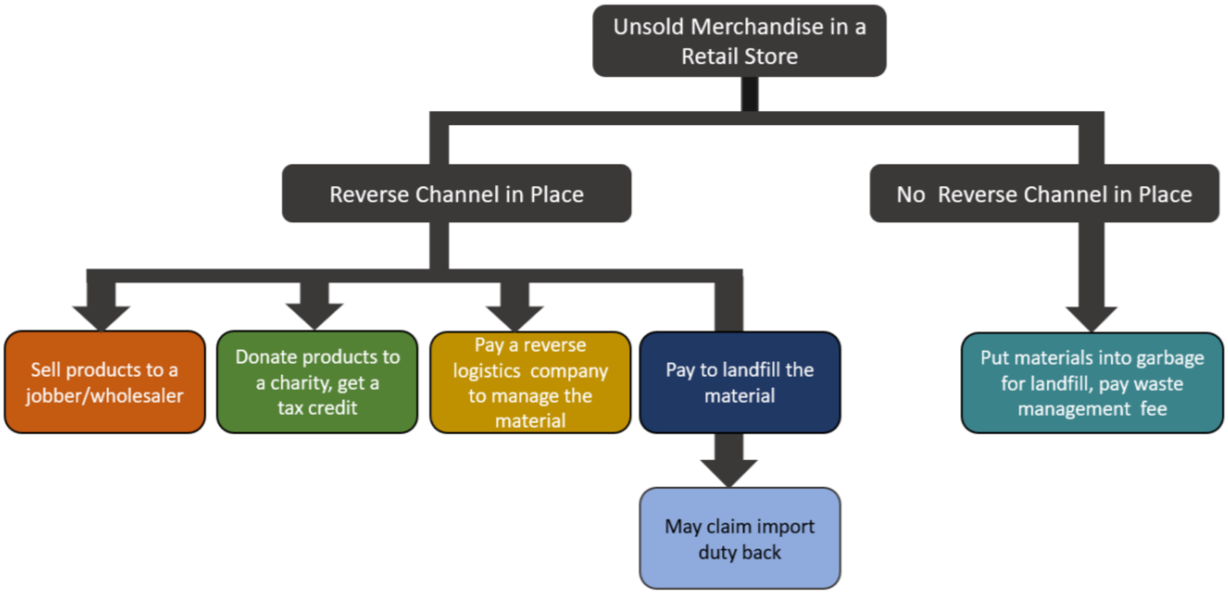


Figure 7: Channels for unsold merchandise in clothing retail

Textile Mills, Textile Product Mills and Clothing Manufacturers

After the removal of the import quota on imported textile and clothing products in 2005 the Textile mills (NAICS code 313), Textile product mills (NAICS code 314) and Clothing manufacturers (NAICS code 315) in Canada experienced an increase in international competition, and finally a major decline.[7] In only eight years, from 2001 to 2009, sales in Textile mills dropped by 64.52 per cent, Textile Product mills dropped 32.23 per cent, and Clothing manufacturers by 72 per cent (Statistic Canada, 2018). In 2020 these industry sectors contributed approximately 0.1 per cent to the Canadian Gross domestic product (GDP) (Statistics Canada, 2020). However, over the last year sales have been stable, and today Canada has a small but highly specialized textile industry that produces technical textiles and niche products, with little remaining of the traditional textile markets for clothing and home textiles (Statistic Canada, 2018).

Statistics Canada reports that in 2019, of 593 known Textile mills, 92 per cent have less than 99 employees. The statistics further show that Canada has 1,045 Textile Product Mills with 98 per cent of the establishments having less than 99 employees; and finally, 3,453 Clothing

[7] North American Industry Classification System (NAICS) Canada 2017 Version 3.0

Manufacturers, with 97.2 per cent of the facilities having less than 99 employees (Statistic Canada, 2018).

While this overview provides an idea on the size of these industry sectors, it does not describe how much material these manufacturing facilities produce. Data is available for the export value of the produced material, but this only allows a comparison of exports and imports to define a possible trade deficit or surplus. It does not provide any information about the quantity in meters, or the number of garments produced. Furthermore, there are no price indications per piece or meter, and no information about the used fibre qualities. This makes it difficult to make any assumptions about the potential textile waste, and it does not indicate if there are any shifts towards sustainability, for example using reclaimed fibres. The same lack of data applies to all imported textiles and clothing, hence the only option to gain any information and to better understand pre-consumer textile waste is to conduct a survey.

Survey: Pre-industrial Textile Waste

A survey was developed in order to better understand the volume and composition of textile waste generated by these industry sectors. The survey questions are summarized in **Appendix D:** Survey Questions. In order to identify Canadian organizations involved in the Canadian apparel industry, an environmental scan was conducted and a database was then created. The purpose of this database was to: 1) establish an estimate of the number of organizations that make up the Canadian apparel industry, and 2) form a participant pool for the survey. During our conversations with experts, we recognized that one survey would not be sufficient to gain enough insights into the different sectors, simply because their operations are too different. Therefore, three survey categories were developed depending on organization type: 1) yarn and fabric mills, 2) clothing manufacturers, 3) clothing retailers. While clothing retailers are distributed across Canada, the textile production industry is located mainly in Quebec and Ontario. The survey was thus offered in English and French to accommodate both official languages. Due to the lack of a national database of Canadian textile and apparel companies, a team of 5 researchers was hired to build a comprehensive list of these organizations. These were identified through contacts with various other fashion stakeholder groups such as the Toronto Fashion Incubator, Fashion Takes Action's contact list and google searches using the following terms to identify Canadian clothing and textile organizations: "Canadian Clothing or Manufacturers", "Canadian Designers", "Canadian Brands", "Canadian Retailers", "Canadian Yarn" and "Canadian Fibre Mills".

The survey was shared through industry associations such as the Retail Council of Canada and Mmode, as well as to apparel groups on social media platforms (i.e., Facebook and LinkedIn) and FTA's own contacts. Despite several attempts to reach the Canadian Apparel Federation, whose members are mainly manufacturers, we had no response. As a result, 494 organizations were contacted within the Canadian clothing and textile industry by phone to explain the research study and invite them to participate in the survey. See **Appendix E:** Canadian Textile Mills & Manufacturers Surveyed for a list of these 494 organizations.

SURVEY RESULTS

Out of the 494 organizations invited to conduct the survey, 99 participants (68 in English and 31 in French) participated in the survey; this is a 20 per cent participation rate. Despite substantial efforts to motivate participation by companies, the response rate was low. The low and incomplete response rate has impacted the generalizability of the data collected and the assumptions that can be made regarding the Canadian clothing and textile industry. **Table 3** shows the participation and the completion rate.

Table 3: Participation and completion rate of the different industry sectors

Industry Sector - Respondent Self Identification	Invited to Participate	Partially Completed	Completed Survey
Fibre, Yarn, Fabric Mills	29 (6%)	9 (19%)	2 (4%)
Clothing Manufacturers	212 (43%)	9 (19%)	41 (79%)
Retailers	253 (51%)	29 (62%)	9 (17%)
Total	494 (100%)	47 (100%)	52 (100%)

Fibre, Yarn, and Fabric Mills

Out of 29 mills invited to participate, only 11 attempted the survey and 2 mills fully completed the survey. While the Canadian Textile Industry is known to use natural, artificial, and manmade fibres and filaments (Statistics Canada, 2018), the two participants only use natural fibres and had negligible amounts of textile waste. Based on the survey results, representative data regarding textile waste from fibre, yarn and fabric mills could not be inferred due to the low response rate.

Clothing Manufacturers

Clothing manufacturers made up the largest portion of respondents at 50 per cent. Data collected for this group was largely demographic as none of the clothing manufacturers responded to questions regarding their textile waste. The lack of responses in this particular section of the survey suggests they likely do not quantify their textile waste. However, the higher response rate when compared to the other sector participants indicates there is an interest in this topic.

Clothing Retailers

Retailers made up 38 per cent of respondents, with 38 partially or fully completing the survey, however the majority of responses were incomplete. When questioned as to whether they knew their annual volume of excess inventory, 82 per cent responded to the question (31 participants). Of the participants, 40 per cent indicated that they had annual revenues over $10m, and 32 per cent indicated they had over 1000 employees, suggesting sales of a significant volume of textile-based products. In this group of respondents, 17 per cent stated that their excess inventory was either sent to landfills or incinerated. A further 25 per cent stated their excess inventory is disposed of in three streams: 1) landfill/incineration, 2) resell at retail, and 3) donate to charity. outlines the excess inventory management of the 31 respondents. It is important to note that respondents checked all answers that applied, highlighting that brands and retailers use more than one approach to manage excess inventory.

Table 4: Excess inventory management by retailers

Excess inventory management	Number of participants (multiple options selected)
Donate to charity	15
Resell at retail	10
Landfill/Incineration	6
Pay for collection/recycling	4
Sell for collection/recycling	4
Other/Don’t know	10

Due to a low response rate regarding the volume and composition of pre-consumer textile waste, a secondary survey with brands and retailers was conducted to collect more targeted data on how this merchandise is managed. We had 16 respondents and **Table 5** provides a characterization of these participants and their willingness to participate in a textile recycling pilot.

Table 5: Retailer participants of secondary survey

Business Size	Number of employees	Number of participants	Willingness to participate in a Textile Recycle Pilot
Micro-sized Enterprise	Less than 50	4	3
Large Enterprise (10+ million revenue)	500-999	3	3
Large Enterprise **(10+ million revenue)**	1000+	9	6
Total		16	12

We identified six large (over 1000 employees) and three mid-market large size brands and retailers (500-999 employees) with revenues over CAD $10 million who are interested in participating in a textile recycling pilot program. Three micro-sized brands and retailers indicated a willingness to participate as well. This pool of participants has good representation from the various business-size sectors in the Canadian apparel industry.

When retailers were asked how they managed returned or damaged garments in the second survey, patterns emerged based on company size. Donation and disposal (landfill or incineration) were the two most popular responses. However, these options were not used in isolation, but in combination with other management strategies such as repair or employee sales. **Table 6** breaks down the management options that were available to the retailers for returned/damaged garments, along with the number of participants who use them, and the company size. The data shows us that companies with 1000+ employees tend to use a combination of management strategies for returned/damaged garments. The most common management approaches are disposal and use of a third party for donation/export, with some repair and employee sales. The use of these two approaches by larger companies, is likely due to their ease and low cost. Smaller firms prefer repair as a first option, then donate or recycle. Repair is far easier to facilitate for a smaller company than a larger one.

Table 6: Management of broken/damaged goods by retailers

Management of returned/damaged garments	Number of participants (size)
Recycle the product	1 (less than 50) 1 (500-999) 1 (1000+)
Use of a third party either for export or donation	2 (500-999) 1 (1000+)
Repair and donate	3 (less than 50) 1 (1000+)
Dispose of (landfill) plus a combination of another option (e.g., repair, employee sale)	4 (1000+)
Return to vendor	1 (1000+)
Does not know	1 (500-999)

Results from the two surveys for retailers demonstrate that the two most popular approaches for excess merchandise (unsold and damaged) are: 1) donation or third-party collection, and 2) landfill/incineration.

Overall, results of the surveys suggest that the majority of Canadian companies who manufacture and/or sell textile-based products in the clothing industry do not know the volume of textile waste they produce. All but one respondent has preferred options for managing textile waste, with some indication of a preference for diversion strategies. Further research would be required to draw any deeper correlations.

Additional Research on Textile Mills

We contacted Accelerating Circularity, a U.S based not-for-profit organization, who were working on a similar survey to ours, to learn more about their results. The organization shared identical difficulties, and emphasized that their data's unknowns and assumptions are significant, but could nevertheless determine that the average working loss from Textile and Textile Product mills was between 5-7 per cent. Furthermore, the organization found out that the average per centage of waste sent to landfills from Textile mills was 5 per cent - the lowest of all manufacturing facilities (compared to Textile Product Mills and Clothing Manufacturing). While this data is from the U.S, it can be assumed that it is similar in Canada because the material loss in production is less dependent on the geographic area, but rather on the technology used to optimize production. Interestingly, the organization recognized that fibre, yarn, and thread mills are largely vertically integrated and must be seen as one waste source, which could be why there is relatively little waste (Brown, Coulter, Magruder, & Twogood, 2020, pp 51-52).

To gain more insight into the waste from fabric mills, we contacted Duvaltex in Quebec, a company that did not participate in our survey, but agreed to an interview. The company is North America's largest contract textile manufacturer, mainly producing fabrics for the commercial sector, hospitality, institutional, and healthcare markets. The company owned Teknit, Guilford of Maine, and acquired Victor Innovatex and True Textiles a few years ago. It is fully integrated, which means it is spinning its yarn and buying yarn. The company is known for its Eco – Intelligent Recycled Polyester Fibre (see **Part One:** Global Fibre Consumption). Duvaltex is trying to optimize processes to use post-consumer materials and transfer them to 100 per cent post–consumer biodegradable polyester fabrics. It has a product line from ocean waste and has a closed loop production and recycling program for textile trims in collaboration with its fibre suppliers.

According to our phone interviews, and the 5 per cent estimated material loss by Accelerating Circularity, we can assume there is minimal yarn and fibre waste produced by this sector, which is likely why there was little interest in the topic and a low response rate to the survey. However, if there is fabric waste or deadstock, these companies are likely to donate it or sell at a low price.

We interviewed a Canadian luxury outerwear manufacturer and retailer, who indicated that end rolls and pieces that are not used in production are diverted from waste and donated to their initiative that provides materials to Inuit parka makers. However, they did not have the material waste analysis for the remaining scraps from their cutting facilities in Canada available, but exhibited an openness to participate in contributing an analysis to help recycled fabric initiatives:

"Given that we are proudly a Canadian brand known around the world and that our parkas are manufactured here, we would welcome the opportunity to explore domestic sourcing of recycled fabric if that was made available and met our standards."

– Confidential brand

Part Four: Technical Review

This technical review aims to provide a comprehensive view of the available recycling options for various types of textile waste. The technologies are grouped into pre-defined categories, or ‘’Classes’’ (**Table 7**):

- Sorting / fibre separation technologies
- Mechanical recycling
- Chemical recycling (including hydrothermal technologies)

A selection of case studies is presented below for all classes. The information contained in each case study is a close transcription of information gathered via e-mail or phone interviews with promoters, manufacturers, and operators of the various technologies. Additional information from publicly available data is included to provide supplementary information.

Sorting & Fibre Separation Technologies

CATEGORIES AND DEFINITIONS

Table 7: Technical process definitions of various technologies

Technology	Technical process definition
Manual Sorting	Manual sorting is the most common method. This method can only be used to separate textiles using parameters that humans can detect by sight and touch, namely: • Colour - limited range, as presented and not necessarily the original colour of the dye • Fabric - limited range, such as leather, wool, cotton, denim • Quality - if the textile has been worn, damaged, repaired, soiled, etc. • Style - shirt, dress, socks, child, etc. • Brand - especially for jeans • Unusual - vintage, wedding dress

Semi-automated **or** **Automated sorting**	Near-infrared (NIR) spectroscopy	This technology sorts textiles by colour and fibre composition by measuring the absorption of near-infrared rays by the fabric in wavelengths between 700 and 2500 nm. Infrared light is directed towards the material; the fabric absorbs certain wavelengths and reflects others. The reflected wavelengths form a different spectrum for each fibre and each mixture of fibres. The spectra obtained are then compared with those of a database, making it possible to match spectra with materials. The textile supply upstream of the optical detection system can be done either manually or automatically. The optical detection system determines the nature of the fibre. The textiles can then be separated using a pressurized air jet or other automated means.
	RFID Tags *	The RFID tag is a small wireless chip with a radio circuit in which digital data is encoded. The code is initially generated by the manufacturer and may include information on the material's nature. There are mainly two types of RFID tags: tags with their own power source are called active tags and those that do not are called passive tags. Passive tags are activated using radio frequency (RF) scanning of the reader.
	Bar codes *	A 2D barcode label can also carry information about the fabric to instruct a sorting process. In this case, the black and white pattern of the label is read by the camera and decoded by a computer. Work is needed to identify the most suitable data format for the barcode and verify that the labels will remain machine-readable at the end of the textile use phase.

* Important Note: RFID Tags and Bar Codes are not currently used in recycling. See details in Comparative Assessment.

EXAMPLES OF OPERATORS AND MANUFACTURERS

Table 8: Examples of operators and manufacturers

Technology	Company	Country
Manual Sorting	Certex	Canada
	Wiseman Exports	Canada
	East-West Textilrecyclint Kursun GmbH	Germany
	SOEX	Germany
Near-infrared (NIR) spectroscopy	Swedish Innovation Platform for Textile Sorting (SIPTex)	Sweden
	Valvand Baling Systems (distributor of FiberSort technology)	Belgium
	Pellenc (manufacturer)	France

MARKET DATA

- Market: Manual sorting makes it possible to differentiate reusable clothing from residual textiles that will be reused as a cloth or felt or end at the landfill. Automatic sorting divides mixed textile streams to provide a uniform flow to mechanical and chemical recyclers. Collaboration between these actors is necessary.
- Reuse: According to Statistics Canada, the majority will be sorted and resold to retailers in developing countries, which imported CAD$21M worth of used clothing from Canada in 2017. Material not suitable for reuse will be turned into wipers and rags or shredded and reprocessed as insulation material or for padding car seats by mechanical recyclers.

Case studies

Case study summaries include, where applicable and information was available, the technical aspects of a given firm's recycling process, their Technology Readiness Level or TRL (detailed in **Appendix F:** Technology Readiness Level Chart), current and future waste handling capacities (in tonnes per year), energy requirement, number of employees required to operate the facility, accepted material inputs, critical contaminants, outputs of the technology, environmental impacts, quantity of material sold, sales trends in 2020, technology patented, estimated acquisition cost, and reference.

East-West (Manual Sorting)

Table 9: East-West (Manual Sorting)

EAST-WEST TEXTILRECYCLINT KURSUN GMBH (Germany)	
TECHNICAL PROCESS DESCRIPTION	
Technical aspects of their recycling process	• Pre-sorting: After delivery, the textiles are placed on a conveyor belt allowing the textiles to be lifted hydraulically. They use more than 16 stations for preliminary manual sorting and separation. Individual sort tables are loaded automatically using a robot on a sky track. The staff differentiates and selects quality pieces, such as shirts and pants, and puts them in the corresponding wells, opening under automatic control. • Sorting: The textiles are transported via conveyors to the sorting complex made up of 36 tables and another automated distribution system. The staff manually sorts out textiles and shoes according to 450 criteria to reuse the highest possible per centage. The criteria include quality, materials, as well as certain criteria specific to the receiving country.
Technology Readiness Level	TRL9: in commercial function since 1989

Current and future capacities	More than 12,000 tonnes per year
Energy required	NA
Number of employees required to run the facility	The company operates more than 3,000 recycling banks for used textiles in Germany and employs 170 people at their head office. Worldwide, over 500 people work for the company: in South America, West and East Africa, and Southern and Eastern Europe.
INPUT & OUTPUT SPECIFICATIONS	
Accepted material (inputs) that can be processed by this technology	Mix of residual textiles (clothing, towels, scarves, etc.) and shoes
Critical contaminants	If the clothes are very dirty, too damaged or contaminated with unknown substances, they cannot be reused as second-hand clothes, but they could become insulation material or get turned into cleaning rags.

Output of this technology and their function	• 50 per cent non-reusable textiles
	  ○ 20 per cent transformed into rags
	  ○ 20 per cent transformed into insulating material
	  ○ 10 per cent used in energy recovery
	• 50 per cent distributed worldwide for reuse

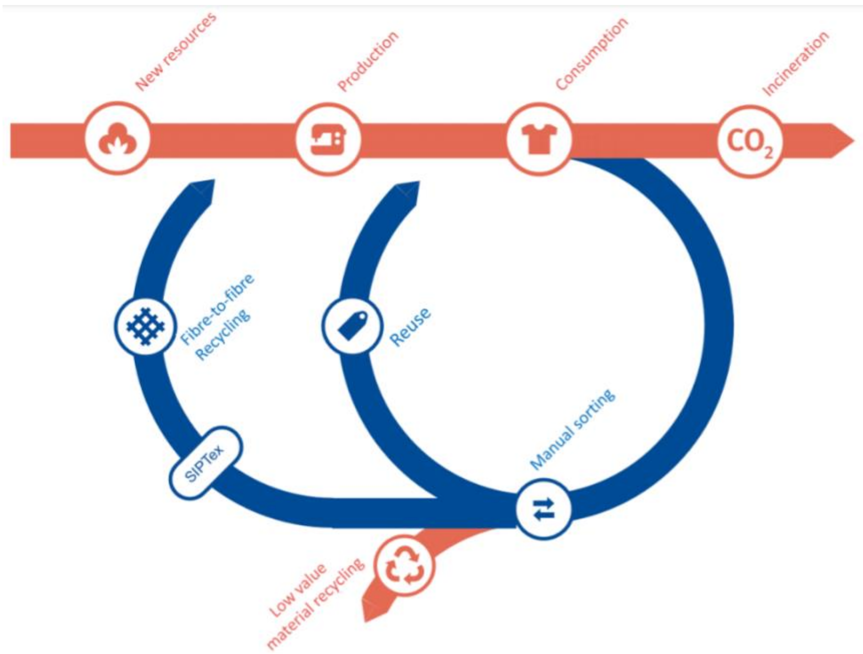
Environmental impacts	NA
MARKETS	
Quantity of material sold annually	12,000 tonnes of used textiles

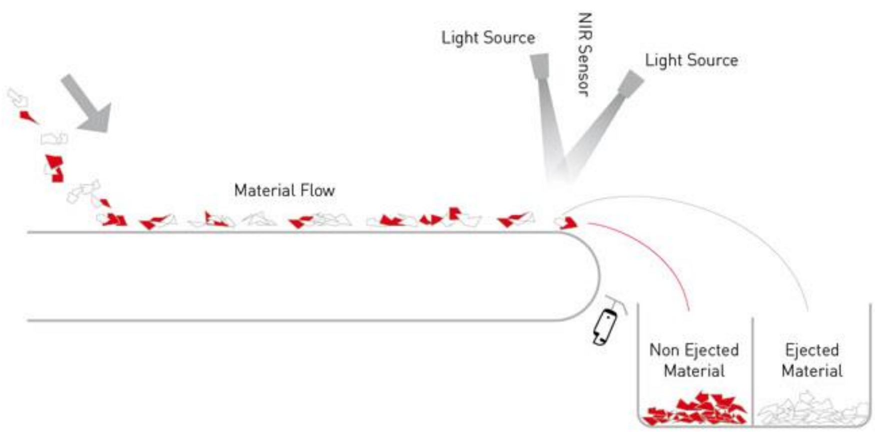
Sales trend in 2020 (increase, decrease or stable) and why	12.5 million euros per year
BUSINESS DEVELOPMENT INFORMATION	
Technology patented	NA
Estimated acquisition cost	NA
REFERENCES	
(East-West Textilrecycling Kursun GmbH, 2021; European Business, 2021; Hosen, 2021)	

SIPTex (NIR Sorting)

Table 10: SIPTex (NIR Sorting)

SIPTex (Finland)	
TECHNICAL PROCESS DESCRIPTION	
Technical aspects of their recycling processes	Manufactured by Staedler and Tomra, the system in use at SIPTex can be programmed to sort 3 different streams simultaneously by fibre and/or colour. More than 4 optical sorters are installed: 3 for sorting residual materials and 1 for the cleaning step to ensure quality control. Each optical sorter consists of a digitization unit and an automated sorting system using compressed air to lift up or push down items on separate conveyor belts. The digitization unit comprises a near infrared camera that can identify items based on materials and/or colour according to their spectral signature, and a programmable controller to command the sorting system downstream.





Technology Readiness Level	TRL 9 First large-scale automatic textile sorting plant commissioned in Fall 2020
Current and future capacities	4.5 tonnes per hour, or more than 24,000 tonnes per year.
Energy required	NA
Number of employees required to run the facility	4

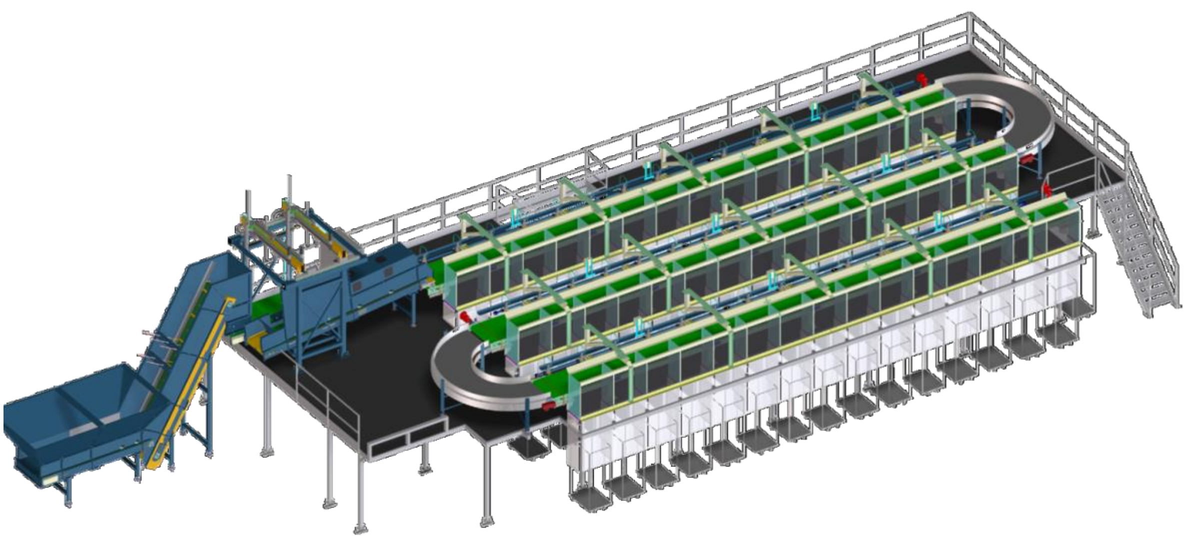
INPUT & OUTPUT SPECIFICATIONS	
Accepted material (inputs) that can be processed by this technology	The material arrives in three separate streams: • pre-sorted post-consumer materials, such as hotel linens and other waste from commercial cleaning operations • manufacturing waste (end-of-roll, scraps, clips) • bulk post-consumer waste left-overs (re-usable items have been removed) All material must be clean and dry. For now, there is a focus on these fibres: • Cotton • Wool • Polyester • Acrylic • Polyamides • Viscose
Critical contaminants	For now, there is a focus on materials that do not contain: • Multi-layer materials, such as a jacket with a lining. The textiles are scanned on one side and therefore a lining can contaminate the final product. • Balls of yarn and longer objects that are rolled up • Upholstered materials, such as pillows and down comforters • Elastic sheets, since they tend to tangle • Carpets and curtains • Textile that are soiled by paint or oil • Flame-retardant treated material
Output of this technology and their function	In Sweden, there are a couple of facilities that recycle on a larger scale, including Renewcell and IKEA. Chemical processes place specific demands on fibre content, therefore Siptex is expected to contribute primarily to this type of recycling. Other recycling processes that are targeted are

	mechanical recycling and low-value recycling (such as upholstery).
Environmental impacts	NA
MARKETS	
Quantity of material sold annually	Maximum capacity of the facility: 24,000 tonnes/year
Sales trend in 2020 (increase, decrease or stable) and why	New facility, no numbers available yet
BUSINESS DEVELOPMENT INFORMATION	
Technology patented	No. Sysav have no plans of expansion (as a municipal-owned company), and their facility Siptex is a result of Swedish textile research and collaboration through the entire value chain.
Estimated acquisition cost	7.5 million euros
REFERENCES	
(Eagle Vizion, 2021; Lätt, 2021; Sysav, 2019, 2021)	

Valvand (NIR Sorting)

Table 11: Valvand (NIR Sorting)

Valvand Baling Systems (Belgium)	
TECHNICAL PROCESS DESCRIPTION	
Technical aspects of their recycling processes	When equipped with robots specifically designed for the sorting of textiles, the theoretical speed is 1 part per 3 seconds per robot. It is possible to add up to four robots on a single production line. The NIR sorting technology can now separate textile fibre into 45 different kinds of stream and increasing the number of categories is under consideration. In addition, the technology can separate items into 20 different colours, and it can extend to more options.



Technology Readiness Level	TRL6 This technology currently operates mainly through pilot projects.

Current and future capacities	The Fibersort optical sorting technology allows, in theory, to separate 1 part per second, which represents 900 kg of textiles per hour. With a manual feeding, the speed is rather 1 piece of textile per 6 seconds.
Energy required	NA
Number of employees required to run the facility	NA
INPUT & OUTPUT SPECIFICATIONS	
Accepted material (inputs) that can be processed by this technology	All kinds of textiles can represent possible inputs for this technology depending on the fibres and colour. However, some textiles are easier to sort than others: textiles that do not contain mixture of fibres, for example.
Critical contaminants	• Infrared light can only penetrate thin textiles. Often textiles are too thick and only the top layer is analyzed. This is an obstacle for textiles whose two surfaces are not made of the same kind of fibres. • Textiles made from fibre blends are more difficult to sort, while pieces made from pure materials (100 per cent cotton, for example) perform well in sorting. The average sorting accuracy is estimated at 60 per cent. • Some materials resemble each other chemically (such as cotton and viscose, both of which are mostly cellulose). It is therefore more difficult to differentiate between textiles which contain a mixture of the two kinds of fibres. • The colours of dark dyes can also interfere with spectroscopic analysis because they absorb most of the wavelengths emitted. Black textiles can still be identified. • Treatments applied to textiles, such as coating or waterproofing, may affect the quality of the detection process. Since these coatings are present in small amounts, on the surface of the fabric, they make the determination of the fibre more ambiguous.

Output of this technology and their function	This technology can mainly be used by textile recycling companies that require the sorting of different fibres for their own use.
Environmental impacts	NA
MARKETS	
Quantity of material sold annually	NA
Sales trend in 2020 (increase, decrease or stable) and why	NA
BUSINESS DEVELOPMENT INFORMATION	
Technology patented	Patent Pending
Estimated acquisition cost	NA
REFERENCES	
(Circle Economy, 2021b, 2021c; Valtech Group, 2020; Valvan Baling Systems, 2021)	

Pellenc (NIR sorting)

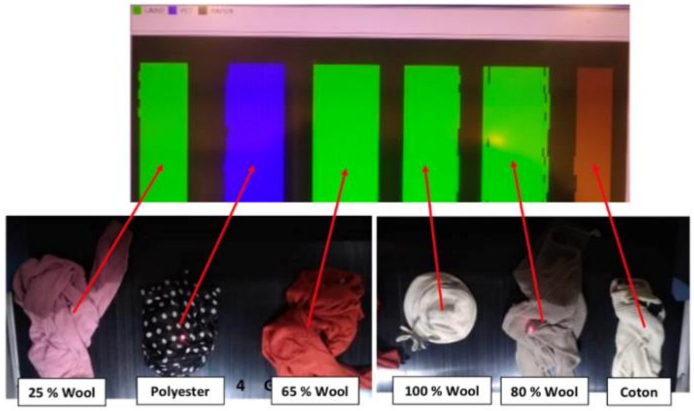
Table 12: Pellenc (NIC Sorting)

Pellenc ST (France)	
TECHNICAL PROCESS DESCRIPTION	
Technical aspects of their recycling processes	The optical sorter Mistral+ is capable of sorting material, but also colour sorting on both unground and shredded material. It is a multi-material sorting machine for sorting and recycling centers.

Tests were carried out recently with a partner in Europe. The aim of the test was to determine if it was possible to separate textiles mainly composed of cotton or polyester. The results of those tests are presented in **Appendix G**: Pellenc ST Test Results.

These various sorting tests first of all illustrate that a cotton vs. polyester separation is almost perfect under the conditions of these tests, namely unused, clean and dry objects, but also by passing them one by one. Regarding mixed cotton / polyester textiles, they are still, in these same conditions, capable of setting a border to separate the “majority cotton” or the “majority polyester”. Tests 3 and 4 show that it is possible to put the 50 per cent cotton / 50 per cent polyester textiles in either of the fractions (cotton or polyester). However, it also reveals that settings need to be readjusted in order to enable the sorting of mixed textiles (cotton or polyester) with other elements such as viscose or elastane in small quantities (less than 20 per cent).

NIR spectra analysis for various materials:



Technology Readiness Level	TRL6 for textile but TRL9 for plastics Test currently underway in Europe for textile.
Current and future capacities	5 tonnes per hour
Energy required	14 kWh for the current capacity (including optical sorter)
Number of employees required to run the facility	NA
INPUT & OUTPUT SPECIFICATIONS	
Accepted material (inputs) that can be processed by this technology	Many achievable possibilities. It all depends on customer needs, even zippers are detectable in induction. Their current test was to determine the possible separation of textiles mainly composed of cotton or polyester.
Critical contaminants	NA
Output of this technology and their function	This technology can mainly be used by textile recycling companies that require the sorting of different fibres for their own use.

Environmental impacts	NA
MARKETS	
Quantity of material sold annually	NA
Sales trend in 2020 (increase, decrease or stable) and why	NA
BUSINESS DEVELOPMENT INFORMATION	
Technology patented	Yes.
Estimated acquisition cost	CAD$400,000
REFERENCES	
(MetalTech Systems, 2016; Pellenc ST, 2020)	

Mechanical Recycling

CATEGORIES AND DEFINITIONS

Table 13: Categories and definitions

Technology	Technical process definition
Open-loop recycling	The result of a process where textile fibres are pulled apart and loosened. Can be associated to low-value recycling, also called downcycling, which produces a material of lesser value than the original. Bulk fibres or shreds are used today for felting, upholstery, bulk fibres and non-woven

	applications whenever the fibre is too short to be woven or knitted into a new fabric.
Closed-loop recycling	Following defibration, a spinning process can be used to manufacture new yarn or thread from recycled fibres. During spinning, the carding is drawn, spun and twisted to produce the yarn. Often, longer virgin fibres are used as carrier fibres and mixed with shorter recycled fibres to achieve the extraction of yarn of sufficient quality.

EXAMPLES OF OPERATORS AND MANUFACTURERS

Table 14: Examples of operators and manufacturers

Type	Company	Country
Open-loop recycling	Jasztex	Canada
	Leigh Fibers	United States
	Le Relais	France
Closed-and open-loop recycling	Centre Européen des Textiles Innovants (CETI)	France
Closed-loop recycling	General Recycled	Canada

MARKET DATA AND COMPETING COMMODITIES

- Virgin vs. recycled fibre: While it might be assumed that recycled polyester is cheaper than virgin polyester, the reality is it is 30 per cent more expensive. Waste collection is not free, processing is complex, and on the other hand, the price of crude oil is not high enough to compensate. Recycled polyester fibres are currently made from waste water bottles. (GAYASKIN, 2020)
- Applications vary considerably depending on the type of fibre used:

  - Recycled denim can be used to produce high-quality construction materials, such as fire-proof insulation panels (ex: Blue Jeanious by Jasztex).
  - Cotton and other fibres with similar absorbing properties can be readily repurposed as wipers and rags for industrial application. This remains the most significant recycling possibility in North America for garments that are not suitable for reuse.
  - Shoddy fibres can be produced from mixed materials, for example post-industrial scraps, thrift stores' apparel waste or certain material grades from grader-sorters. These fibres can be used in upholstery applications whenever regulations or market specifications allow it.
  - Post-consumer waste from the IC&I sector fibres may be used in the manufacture of emergency blankets, subfloors (ex: Velpedi by Jasztex), automotive insulation, etc.
  - Polyester fibres may be used in filtration and heating, ventilation, and air-conditioning (HVAC) applications.
- The industrial capacity review conducted as part of the MUTREC project (CTTÉI, 2020) identified three recycling operations in Québec with the ability of shredding and fraying textile waste. Theses stakeholders may be interested in trying alternative post-consumer feedstock. Furthermore:
  - A recent survey identified 10 organizations that mechanically recycle cellulosic fibres in the United States (Accelerating Circularity, 2020).
  - A market study done by Circle Economy (Circle Economy, 2021a) identified 7 mechanical recyclers located in Canada and the United States. Of this total, two produce recycled yarn (cotton, cotton/polyester blend or wool). An open-loop recycler, Leigh Fibers, boasts a capacity of 136,000 tonnes/year.
- Volume and Price: The table below shows the relationship between volume and value of post-consumer textiles by fibre grade. Future recycling technologies can change demand and value (van Duijn, 2021; WRAP, 2019).

Table 15: The relationship between volume and value of post-consumer textiles by fibre grade

Suggested grades	Textiles available for Fibertsort (tonnes)	Prise range per kg (euros)
100% Cotton	240,570	0.10 to 0.30
100% Polyester	29,160	0.05 to 0.15
100% Viscose	4,374	0.05 to 0.15
100% Wool	2,430	0.30 to 0.60
100% Acrylic	8,262	0.05 to 0.15
Other pure fibres	6,318	0.05 to 0.15
Other blends	98,658	0
+80% Wool blends	5,346	0.20 to 0.40
Cotton/poly blends	9,.882	0.05 to 0.15

CASE STUDIES

CETI (Open-loop Recycling)

Table 16: CETI (Open-loop recycling)

Centre Européen des Textiles Innovants (CETI) (France)	
TECHNICAL PROCESS DESCRIPTION	
Technical aspects of their recycling processes	The pilot in use at CETI allows to model small-scale production and recycling processes for the textile industry. From waste to yarn: • Cutting (50x50mm) • Fraying (~25mm) • Carding (5g/m²) • Open-end spinning (from 10Nm to 70Nm) From waste to non-woven: • Cutting (50x50mm) • Fraying (~25mm) • Carding • Airlay • Meltblown • Spunbound The clothes are first sorted by colours and fabric types before being cut. After cutting, the heavier parts (i.e., buttons and zippers) are separated from the rest by density. The fabrics are then frayed in an apparatus composed of 8 cylinders. The fibres obtained from this process are approximately 7 mm long and cannot be spun directly, they are therefore blended with longer virgin cotton fibres. The recycled and virgin fibres are homogenized to obtain a uniform colour. The fibres are then carded to form a cotton ribbon which can then be spun. The equipment in use for the CETI mechanical recycling project was supplied by LAROCHE.

View of the fraying pilot line

Technology Readiness Level	TRL8
Current and future capacities	100 kg per hour
Energy required	NA
Number of employees required to run the facility	3
INPUT & OUTPUT SPECIFICATIONS	
Accepted material	Textile waste (old clothes, manufacturing waste, facial masks)
Critical contaminants	• Metals and plastics due to fire risk • Textiles with coating for yarn production • The fibres that are recycled are too short to be able to be spun directly, so they must absolutely be mixed with a certain per centage of virgin fibres, which are longer. A minimum of 30 per cent virgin fibres are required.

Output of this technology and their function	The recycled yarn formed by this technology can be reused in the manufacture of new fabrics and clothing. The recycled fibres could also be used in the manufacture of veils and non-woven mattresses.
Environmental impacts	NA
MARKETS	
Quantity of material sold annually (kg or lbs)	110 tonnes per year
Sales trend in 2020 (increase, decrease or stable) and why	Increase in sales due to COVID-19. CETI produces nonwoven for FFP2 Masks.
BUSINESS DEVELOPMENT INFORMATION	
Technology patented	No. They would envision an expansion to Canada.
Estimated acquisition cost	Non-woven: 16 million euros Upcycling platform • Pilot line: 2.5 million euros • Industrial line: 5 million euros
REFERENCES	
(CETI, 2019, 2021)	

General Recycled (Closed-loop Recycling)

Table 17: General Recycled (Closed-loop recycling)

General Recycled (Canada)	
TECHNICAL PROCESS DESCRIPTION	
Technical aspects of their recycling processes	General Recycled is a company specialized in the recycling of work clothes from aramid fibres. These fibres offer superior resistance to wear and fire-protection. The main steps involved in the process are: • Collection & shredding of aramid garments • Fraying and creating recycled aramid yarn • Weaving recycled aramid fabric • Knitting recycled aramid fabric • Converting and dying of recycled aramid fabrics
Technology Readiness Level	TRL9
Current and future capacities	Approximately 400 kg per hour
Energy required	NA
Number of employees required to run the facility	NA
INPUT & OUTPUT SPECIFICATIONS	
Accepted material (inputs) that can be processed by this technology	The line was designed to recycle Meta- and Para-aramid garments and fabrics. The line could theoretically shred garments and fabrics that are cotton or polyester/cotton, or nylon garments, since the cutting systems are sufficiently strong to fray tougher fibres such as aramid.

	General Recycled is open to an open-loop recycling program with others fibres than aramid.
Critical contaminants	The output needs to meet certain standards, dealing primarily with flash fire and electrical arc flash standards. Any non-fire-resistant fibres such as polyester, or cotton, into our fibre blend are therefore not allowed at the moment. In the case that non fire-resistant products were produced, then the tolerance to contaminants would be quite high.
Output of this technology and their function	General Recycled produces recycled meta and para-aramid yarn, fabric and garments, that meet North American certification for flash fire and electrical arc flash protection. The garments can take multiple forms from base layers to outerwear, including non-woven applications, insulation, cut-proof protection etc.
Environmental impacts	NA (new facility)
MARKETS	
Quantity of material sold annually	NA (new facility)
Sales trend in 2020 (increase, decrease or stable) and why	An increase in sales is expected as it is the only company in the world recycling non-biodegradable fibre/fabric/garments in a closed-loop system.
BUSINESS DEVELOPMENT INFORMATION	
Technology patented	Yes, at this point in North America only. The EU and Asian marketplaces require some product changes which are being addressed at the moment. Third party licenses will eventually be allowed.
Estimated acquisition cost	Not for sale.

REFERENCES
(Estrie Plus, 2020; General Recycled, 2021; TechniTextile, 2021)

Chemical Recycling

CATEGORIES AND DEFINITIONS

Table 18: Categories and definitions

Technology	Technical process definition
Dissolution	Dissolution uses solvents to separate the main fibre, usually cotton, from unwanted elements. This technology uses solvents such as methyl-morpholine oxide (NMMO) can turn cellulose fibres into a liquid pulp. Once dissolved, the pulp can be used in the viscose process to make manmade cellulosic fibres.
Depolymerization	Depolymerization makes it possible to return further upstream, to the monomers, by breaking the bonds of the polymers and of the synthetic fibres by chemical or enzymatic hydrolysis, by methanolysis (with an alcohol) or by glycolysis. Several synthetic polymer fibres (polyamide, polyester, polyurethane and acrylic) can be treated that way.
Hydrothermal processing	It uses subcritical water—water heated under pressure to temperatures above its boiling point—to extract a cotton-containing pulp or break chemical bonds in polyester. Under the right conditions, it can be efficiently used to separate fibres from mixed-fibre textiles by dissolving one component while leaving others unaltered.

EXAMPLES OF OPERATORS AND MANUFACTURERS

Table 19: Examples of operations and manufacturers

Type	Company	Country
Dissolution	Infinited Fiber	Finland
	Re:newcell	Sweden
	Evrnu	United States
	Phoenxt	Germany
	SaXcell	Netherlands
Dissolution and Depolymerization	BlockTexx	Australia
	Worn Again	United Kingdom
	Resyntex	Slovenia
Hydrothermal	Circ	United States
	Hong Kong Research Institute of Textiles & Apparel (HKRITA)	China

MARKET DATA AND COMPETING COMMODITIES

- Virgin vs recycled fibre: Chemical recyclers have the capability to generate 100 per cent recycled fibre. Considering the low cost of virgin fibre, however, some have reported having to blend virgin fibre in their final product in order to be competitive.
- Dissolution and depolymerization products: residual textile waste could be transformed into raw materials for the chemical industry (Resyntex, 2021a)
    - Proteins, derived from wool – for use in wood-based adhesives
    - Glucose, derived from cotton – for conversion to bioethanol
    - Monomers from polyamide – recycled back into polyamide (PA)
    - Monomers from polyester – recycled into polyethylene terephthalate (rPET).

- Competition and Demand: The Overview of Current & Potential End-Markets for Fibersorted Materials presented in **Appendix H:** Overview of Current & Potential End Market for Fibersorted materials - Textile to Textile Recycling, offers a global overview of recyclers currently in development and in operation (Circle Economy, 2021a). Some are a competition for a future installation in Canada, while others could be interesting collaborators.
    - Number of chemical recyclers in North America: 7
    - Technological maturity: Pilot and scale plants
    - Inputs: Some of these recyclers process PET from water bottles and not textiles, in order to produce recycled polyester
    - Examples of chemical recyclers: Evrnu, Loop Industries, Circ., Premier Fibers, Unifi.

CASE STUDIES

Infinited Fiber (Dissolution)

Table 20: Infinited Fiber (Dissolution)

Infinited Fiber (Finland)	
TECHNICAL PROCESS DESCRIPTION	
Technical aspects of their recycling processes	Infinited Fiber receives sorted cotton waste, which is shredded and chemically pre-treated in acid and alkaline solutions to remove any non-cellulose fibres (like polyester, dyes, textile treatment chemicals, etc.) and to soften any elastane. The remaining cellulose mass is treated with urea in a carbonation process to create cellulose carbamate powder. This powder is dissolved in hydrogen peroxide to create a cellulose liquid, which is filtered to remove any remaining impurities (including the softened elastane) and wet-spun into filament fibres. These are then cut to create staple fibres. The resulting bundles of staple fibres are washed, opened and dried, and are then ready to move to yarn manufacturers to be spun into yarn or to nonwovens manufacturers for their applications.

Technology Readiness Level	TRL7: Pilot facilities
Current and future capacities	150 tonnes per year (pilot facility).
Energy required	From cradle to gate (i.e., to the creation of ready, regenerated fibres), the direct energy consumption per tonne of fibres is approximately 8,8 MWh
Number of employees required to run the facility	Their pilot facilities currently employ around 12 people.
INPUT & OUTPUT SPECIFICATIONS	
Accepted material (inputs) that can be processed by this technology	Cellulose-rich textile waste. For efficiency purposes, the requirement is a minimum of 80 per cent cellulose content vs. 20 per cent non-cellulose fibres. Their technology can also be used to turn any other cellulose-rich waste (used cardboard, agricultural by-products like wheat or rice straw) into the same unique textile fibre.
Critical contaminants	• Max 20 per cent non-cellulosic material like polyester. • The process can handle lower feedstock qualities, but more contaminants end up in a waste-stream rather than being regenerated into new textile fibres, adding inefficiency to the fibre regeneration process. • For elastane the max content is about 1-2 per cent as this is a very difficult material to remove.
Output of this technology and their function	Cellulose carbamate fibre, a unique, high-quality textile fibre with the soft and natural look and feel of cotton, but unique characteristics (like higher dye uptake, naturally occurring antibacterial properties). The fibre can be used on its own for 100 per cent regenerated yarns/fabrics and clothing, and it also blends easily with other textile fibres. The fibre has also been tested with great results for suitability for non-woven applications (such as wipes, women's hygiene products, diapers, etc.).

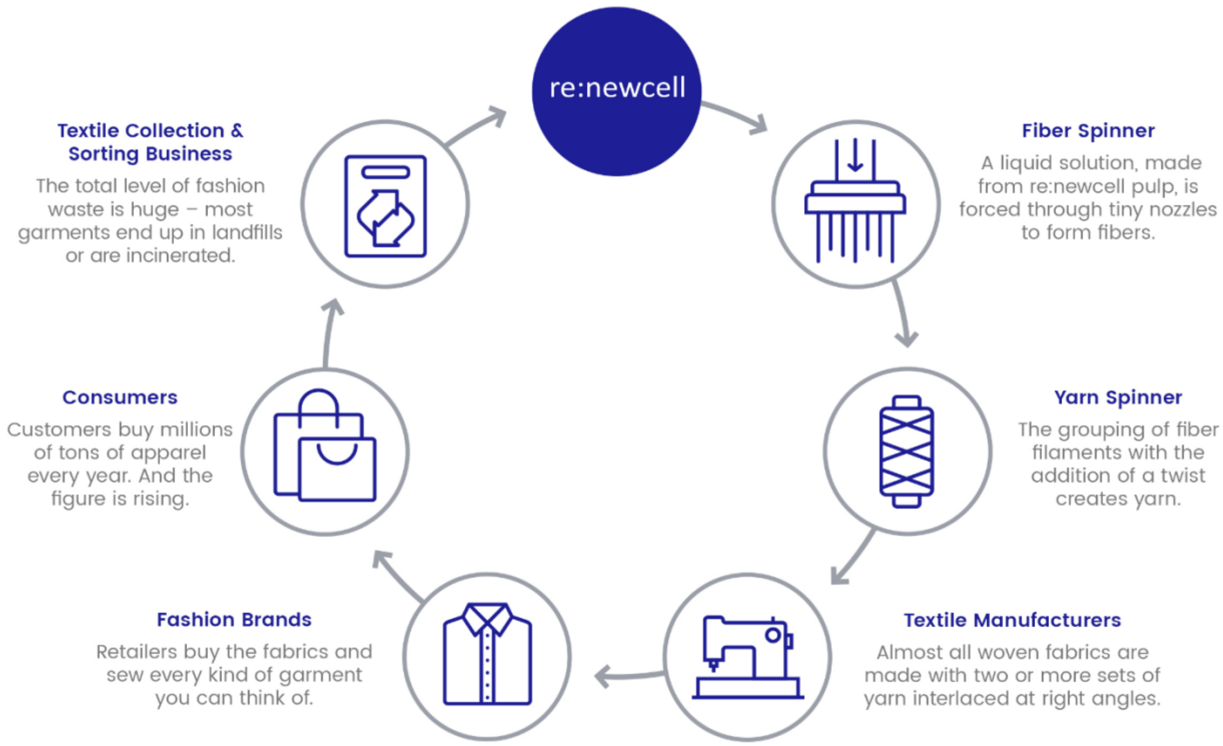
	Cellulose carbamate fibre is a biodegradable, circular material that contains no microplastics. Textiles made with it can be recycled at end-of-life together with other textile waste in the same process.
Environmental impacts	Carbon footprint of production varies greatly depending on factory source of energy. A recent LCA indicates that the environmental performance of industrial cellulose carbamate fibre production would be at an acceptable level when compared to conventional textile fibres like cotton and viscose. Direct water consumption is around 54 m^3/tonne of fibre created (cradle to gate calculation). Compared to the most common man-made cellulosic, viscose, a major benefit of cellulose carbamate fibre is that its production does not use the toxic nerve poison carbon disulfide used in viscose production; this has been replaced with the naturally occurring compound urea. The solid waste created in the process consists of the non-cellulosic impurities that are removed from the feedstock (textile waste). This is currently used for energy production. The by-products created in the process that cannot be used again are sold as raw material for other industrial processes.
MARKETS	
Quantity of material sold annually	NA (Pilot facility)
Sales trend in 2020	NA
BUSINESS DEVELOPMENT INFORMATION	
Technology patented	Yes. The business strategy is to license the technology to existing viscose or pulp mills which could be retrofitted, and to stakeholders interested in setting up a new production.

Estimated acquisition cost	**New industrial facility: 220 million euros** **Retrofitting e.g., an existing viscose factory:** • **Fibre production modules: 20-30 million euros** • **Carbamation investment: 35 million euros**
REFERENCES	
(*Infinited Fiber Company*, 2021)	

Re:newcell (Dissolution)

Table 21: Re:newcell (Dissolution)

Re:newcell (Sweden)	
TECHNICAL PROCESS DESCRIPTION	
Technical aspects of their recycling processes	The clothes are mechanically treated to separate the buttons and zippers. The textile remains are then shredded, discoloured, and degraded into a cellulose slurry, for which no virgin material is needed. Textiles undergo a chemical treatment that removes dyes as well as polyester, nylon and other synthetic compounds that could be found in textile inputs. The pulp thus obtained is a pulp suspended in water. This pulp passes through an apparatus used in the manufacture of paper, to remove the water and to form a product which resembles sheets of cardboard. These sheets are sent to textile factories; they dissolve the pulp and pass it through a die to form new fibres. These fibres generally form a finished product of viscose or lyocell.



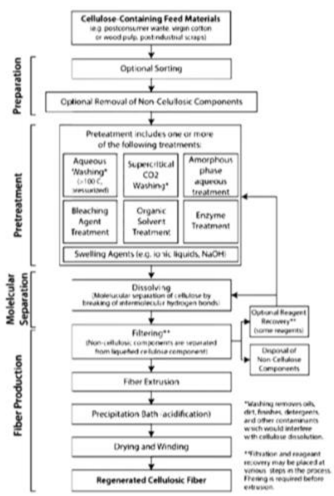
Technology Readiness Level	TRL8 The technology is currently operating on an industrial scale in the town of Kristinehamn.
Current and future capacities	In 2017, the first pulp production plant opened in Kristinehamn; it can produce 7,000 tonnes annually. The production at this plant is a demo that can potentially be upscaled to 30,000 tonnes in the future. Re:newcell's ambition is to increase the company's recycling capacity to 250,000 tonnes by 2026.
Energy required	NA
Number of employees required to run the facility	NA
INPUT & OUTPUT SPECIFICATIONS	

Accepted material (inputs) that can be processed by this technology	Re:newcell does not collect or sort post-consumer textiles, but collaborates with collection and sorting companies. The post-consumer textile stream must have a cellulose (cotton or viscose) content of over 98 per cent.
Critical contaminants	Non-cellulose compounds are considered as contaminants and should be removed from the inputs to not interfere with the process. For example, polyester is considered a contaminant and must be removed.
Output of this technology and their function	Circulose® is the branded dissolved pulp product of Re:newcell. This product is a pulp from which brands can produce yarn then garments.
Environmental impacts	The production plant runs on 100 per cent renewable energy, from wind and hydro energy. This process produces wastewater that is contaminated with COD and BOD, which is cleaned in a wastewater treatment plant. Besides wastewater, dust production also is an important by-product.
MARKETS	
Quantity of material sold annually	7,000 tonnes of Circulose per year
Sales trend in 2020 (increase, decrease or stable) and why	NA
BUSINESS DEVELOPMENT INFORMATION	
Technology patented	Yes
Estimated acquisition cost	NA
REFERENCES	
(Remington, 2021; Renewcell, 2021; TIME, 2021)	

Evrnu (Dissolution)

Table 22: Evrnu (Dissolution)

Evrnu (United States)	
TECHNICAL PROCESS DESCRIPTION	
Technical aspects of their recycling processes	Products made with the NuCycl process by Evrnu can be disassembled to the molecular level and regenerated multiple times into new clothing, home and industrial textiles with extraordinary performance and environmental advantages. The technology uses repolymerization to convert the original fibre molecules into new high-performing renewable fibres (see process diagram below).



Technology Readiness Level	TRL5 Preliminary LCA performed but technology is still in R&D.
Current and future capacities	1 tonne of dissolved pulp from post-consumer garments per day
Energy required	Preliminary data indicates that Evrnu pulping takes less energy than wood pulping. Fibre energy demand varies depending on the solvent systems (ex: viscose, lyocell).

Number of employees required to run the facility	NA
INPUT & OUTPUT SPECIFICATIONS	
Accepted material (inputs) that can be processed by this technology	Materials containing cellulose, which may include post-consumer waste clothing, residual fabrics and / or various biomass materials.
Critical contaminants	A pre-treatment is available to remove these contaminants: • Chemical dyes • Dirt, grease, soils and deodorants • Buttons, zippers and fasteners
Output of this technology and their function	Cellulose molecules that can be used in textile and garment industries, and other industries.
Environmental impacts	Bench scale achieved: 38 L of direct water use per kg of fibre
MARKETS	
Quantity of material sold annually	Not commercial yet
Sales trend in 2020 (increase, decrease or stable) and why	Not commercial yet
BUSINESS DEVELOPMENT INFORMATION	
Technology patented	Evrnu creates and licenses fibre formulations.
Estimated acquisition cost	Not commercial yet
REFERENCES	
(Evrnu, 2021a, 2021b, 2021c; FLYNN, 2015; FLYNN & STANEV, 2016; Impact Hub, 2018)	

Blocktexx (Dissolution and Depolymerization)

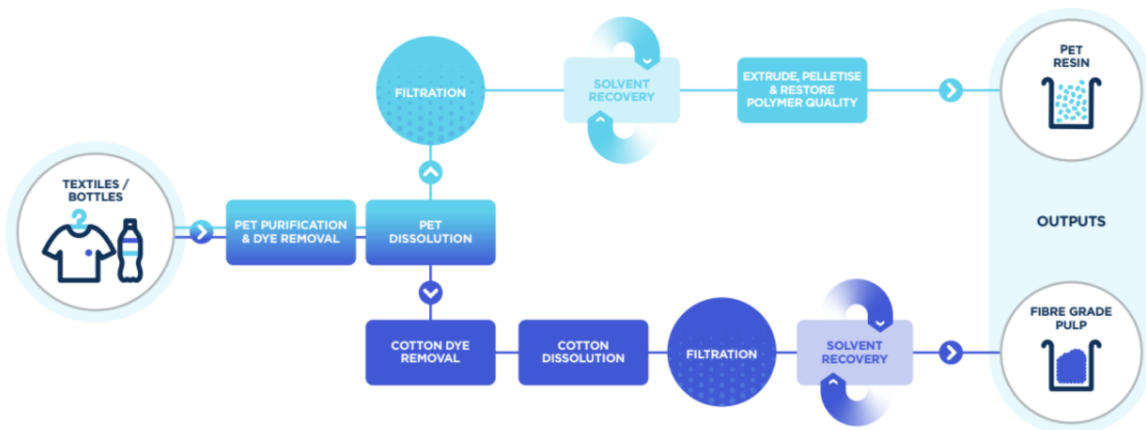
Table 23: Blocktexx (Dissolution and depolymerization)

BlockTexx (Australia)	
TECHNICAL PROCESS DESCRIPTION	
Technical aspects of their recycling processes	BlockTexx owns proprietary technology S.O.F.T.™ that separates polyester and cotton materials such as clothes, sheets and towels of any colour, and conditions them back into high-value raw materials of PET and Cellulose for reuse as new products for all industries. Textiles are washed, shredded and then placed in a reactor which removes the cotton from the polyester. Polyester fibres can then be melted into PET pellets and cellulose slurry can be dried into a powder form if required. The plant aims to be zero waste with the recovery of all liquid wastes.
Technology Readiness Level:	TRL7: The start-up just completed a small commercial pilot in January 2019.
Current and future capacities	The future facility will process 1 tonne of textiles per hour, thus 10,000 tonnes per year.
Energy required	NA
Number of employees required to run the facility	NA
INPUT & OUTPUT SPECIFICATIONS	
Accepted material (inputs) that can be processed by this technology	BlockTexx technology targets commercial textiles (laundry, prisons, healthcare), workwear and specific branded clothing lines where the polyester/cotton ratio is known. The technology can be used for textiles from charities but requires an additional sorting process to determine polyester versus cotton ratios.

Critical contaminants	When they receive shirts and jackets from uniform suppliers or retailers for separation and recycling, they must remove all the trims, including buttons and zips, so the downstream outputs of recycled polyester and regenerated cellulose are not contaminated (a lot of buttons are made out of nylon, which would contaminate the polyester).
Output of this technology and their function	The recovered PET is polymerized to create virgin-quality S.O.F.T.™ branded rPET plastic pellets and polyester fibre suitable for use in textiles, packaging, building products. The recovered cellulose is processed to create S.O.F.T.™ branded cellulose powder for use in many industries such as textile, pharmaceutical and food.
Environmental impacts	NA
MARKETS	
Quantity of material sold annually (kg or lbs)	Not commercial yet.
Sales trend in 2020 (increase, decrease or stable) and why	Not commercial yet. BlockTexx also plans to build a marketplace for recycled textiles.
BUSINESS DEVELOPMENT INFORMATION	
Technology patented	BlockTexx owns proprietary technology S.O.F.T.™ (Separation of fibre technology)
Estimated acquisition cost	NA
REFERENCES	
(BlockTexx, 2021a, 2021b; Circular, 2021; Powell, 2019; Recycling Technology, 2020)	

Worn Again (Dissolution and Depolymerization)

Table 24: Worn Again (Dissolution and depolymerization)

Worn Again (United Kingdom)	
TECHNICAL PROCESS DESCRIPTION	
Technical aspects of their recycling processes	Polyester fibres are soaked in a solvent to leach out small molecules of contaminants, such as dyes. Other polymers, such as polyurethane and cellulose acetate, are also washed during this step. After washing, the polyester/cotton blend saturated with solvents is heated to a high temperature to dissolve the polyester and transform it in solution. Cotton remains in its solid form. Cotton and polyester are then separated by filtration. The solvent is removed from the PET mixture. The solid cotton fibres are dissolved using a new ionic liquid. Viscose paste can be processed in several ways. Currently, a wood pulp is produced and can be used as a raw material for cellulosic fibre spinning processes, such as viscose and lyocell.
	
Technology Readiness Level	TRL5
Current and future capacities	Batches of 10 kg per hour at the current pilot facility. The next step will be to design a demo facility running at 5,000 tonnes per year and in longer term, industrial plants able to run at 50,000 tonnes per year.

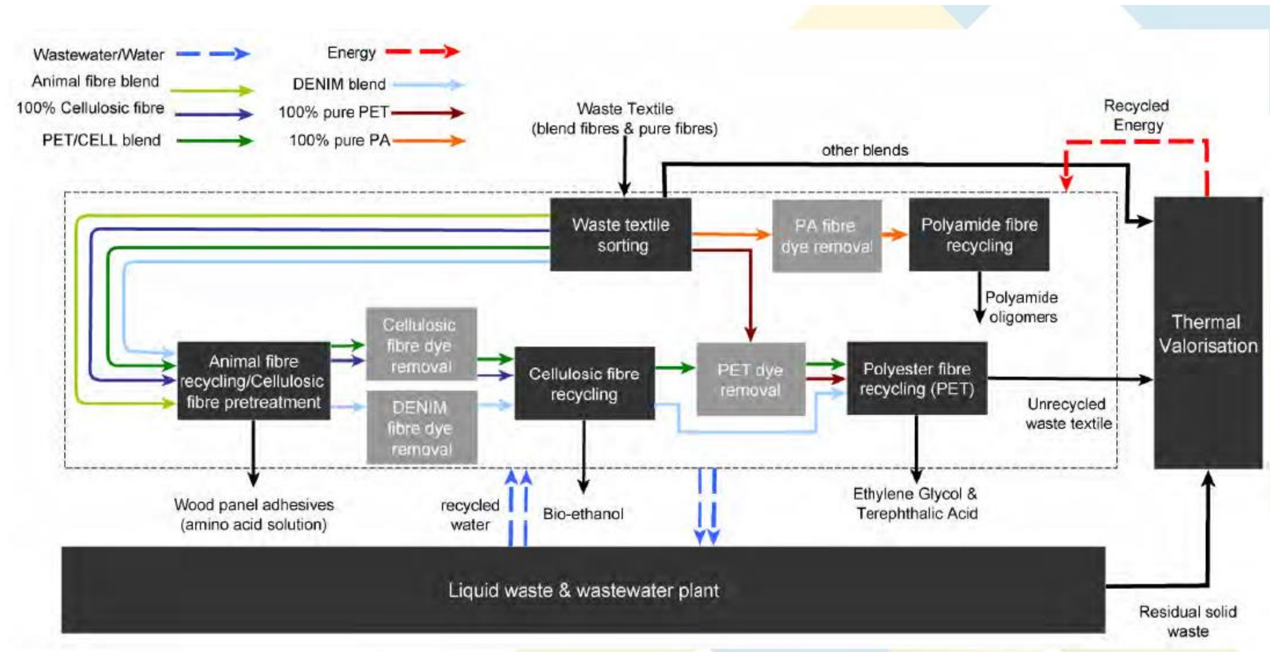
Energy required	NA
Number of employees required to run the facility	Currently at pilot plant: 2
INPUT & OUTPUT SPECIFICATIONS	
Accepted material (inputs) that can be processed by this technology	Textiles made of pure polyester and polyester/cotton or polyester/cellulose blends. The process is also able to run separately with PET bottles and plastic packaging.
Critical contaminants	No tolerance for metals - max tolerance of 10 per cent of other materials (such as: wool, acrylic, nylon, elastane, PU, etc.)
Output of this technology and their function	PET pellets and cellulose pulp go back as new circular raw materials into the textile manufacturing supply chain to manufacture new products.
Environmental impacts	NA
MARKETS	
Quantity of material sold annually	Not commercial yet.
Sales trend in 2020 (increase, decrease or stable) and why	Not commercial yet.
BUSINESS DEVELOPMENT INFORMATION	
Technology patented	Yes, at industrial scale their business model is based on technology licensing. Once at industrial scale, they want to license the technology worldwide. The expansion in specific countries will depend on the potential commercial plant operators to license their technology.

Estimated acquisition cost	Not to share yet.
REFERENCES	
(Bothwell, 2020; Fashion Network, 2021; Kart, 2021; Worn Again, 2021)	

Resyntex (Dissolution and Depolymerization)

Table 25: Resyntex (Dissolution and depolymerization)

Resyntex (Germany)	
TECHNICAL PROCESS DESCRIPTION	
Technical aspects of their recycling processes	RESYNTEX is a research consortium that aims to produce secondary raw materials from unwearable textile waste. Its goal is to design a complete value chain, from textile waste collection through to the production of new feedstock for chemicals and textiles. The scope of research includes both mechanical and chemical recycling processes for cotton, nylon, polyester and wool fibres. They use biochemical processing to transform natural and synthetic fibres into chemical intermediates such as glucose for bioethanol, purified terephthalic acid (TPA) and ethylene glycol (EG) for the production of PET resins, protein hydrolysate for resins and adhesives and polyamide oligomers for various chemicals.



Technology Readiness Level	TRL4
Current and future capacities	A pilot textile recycling plant with a capacity to recycle 500 tonnes of textiles a year.
Energy required	Heating requirements: 192 kW Cooling requirements: 157 kW
Number of employees required to run the facility	Not commercial yet
INPUT & OUTPUT SPECIFICATIONS	
Accepted material (inputs) that can be processed by this technology	Mixed post-consumer textile waste
Critical contaminants	NA

Output of this technology and its function	For 1 tonne of textile waste: • 0.33 tonne of glucose from 100 per cent cellulose • 0.27 tonne of glucose from blend of cellulose/PET • 0.07 tonne of TA from pure PET • 0.08 tonne of TA from blend of cellulose/PET • <0.013 tonne of protein solution
Environmental impacts	Freshwater consumption: 1.998 tonne/hour for 200 kg/h processed feedstock
MARKETS	
Quantity of material sold annually	Not commercial yet
Sales trend in 2020 (increase, decrease or stable) and why	Not commercial yet
BUSINESS DEVELOPMENT INFORMATION	
Technology patented	NA
Estimated acquisition cost	Pilot: 16.5 million euros Plant producing 80,000 tonnes/year: 207 million euros
REFERENCES	
(Chemistry Can, 2021; Nikolakopoulos, 2019; Resyntex, 2021a, 2021b; Sustainability Consult, 2021)	

Circ. (Hydrothermal Process)

Table 26: Circ (Hydrothermal process)

Circ – formerly Tyton BioSciences (United States)	
TECHNICAL PROCESS DESCRIPTION	
Technical aspects of their recycling processes	Circ developed a water-based hydrothermal solution to recycle cotton, polyester and polycotton blended fabrics. Their low impact process can separate polyester from cotton by breaking it down to its monomer building blocks so it can be rebuilt into virgin polyester while maintaining the integrity of the cellulose. A pre-treatment step, such as mechanical cutting, reduces the size of the waste textile material. This shrinking generates a particle size of about 60 mm or less. The method treats the waste textile material in a subcritical water reactor at a temperature of about 105° C. to 190° C., a pressure of about 40 to 300 psi, for about 0 to 90 minutes, wherein one or both of a cellulose and a TPA and ethylene glycol (EG) are produced. The cellulose is further recovered thanks to a dissolution process forming regenerated cellulose.
Technology Readiness Level	TRL8: Circ started commercial production of recycled fibre in 2020, with Marubeni planning to use the materials. Though they're still a start-up, Circ will be putting their textiles to the test, and introducing them to the market later in 2021.
Current and future capacities	NA
Energy required	NA
Number of employees required to run the facility	NA
INPUT & OUTPUT SPECIFICATIONS	

Accepted material (inputs) that can be processed by this technology	The company has a flexible technology platform that can accept a wide spectrum of starting materials, such as cotton, polyester, poly-cotton, and other non-wood fibres.
Critical contaminants	The waste textile material is sorted before or after treatment in the subcritical water reactor. The sorting is based on colour, composition, weight per cent cellulose, non-cellulose components, or combinations.
Output of this technology and their function	Dissolving pulp that can be processed into a continuous filament fibre with comparable characteristics to viscose. Polyester monomers have a chemical equivalence to virgin monomers.
Environmental impacts	• Chemicals and dyes are separated in aqueous solution. • 70 per cent of the water used in process is recycled • Wastewater is treated by traditional wastewater management process.
MARKETS	
Quantity of material sold annually	Not commercial yet
Sales trend in 2020 (increase, decrease or stable) and why	Not commercial yet
BUSINESS DEVELOPMENT INFORMATION	
Technology patented	Yes. Circ plans to commercialize its technology globally, in partnership with fashion industry manufacturers and retailers.
Estimated acquisition cost	Not commercial yet.
REFERENCES	
(Bomgardner, 2020; Circ, 2021; Crane, 2020; Kumar, 2019; Tyton Bio, 2020)	

HKRITA (Hydrothermal Process)

Table 27: HKRITA (Hydrothermal process)

HKRITA (China)

TECHNICAL PROCESS DESCRIPTION

Technical aspects of their recycling processes

The Green Machine technology selectively breaks down cotton into cellulose powder. The polyester fibres remain unchanged, thus allowing the separation of the polyester fibres and the cellulose, without having to depolymerize the polyester fibres.

The process steps are as follows:

- Remove solid components from clothing, such as zippers and buttons.
- Shred textiles.
- Insert the shredded textiles as well as the "green chemical" and water. The mixture is 95 per cent water and less than 5 per cent organic acids. The cotton is dissolved, and the polyester remains solid.
- Increase the temperature of the reactor (between 110 and 150° C).
- Carry out the reaction with constant stirring for 0.5 to 2 hours.
- Filter the product, to separate the cellulose powder and the polyester fibres.

Recovered polyester fibres

Technology Readiness Level:	TRL8
Current and future capacities	100 kg per hour
Energy required	NA
Number of employees required to run the facility	4-6
INPUT & OUTPUT SPECIFICATIONS	
Accepted material (inputs) that can be processed by this technology	All blended material
Critical contaminants	• Spandex: no more than 10 per cent • Solid components that can be found on clothing, such as buttons or zippers, must be removed before textiles are processed in the process.
Output of this technology and their function	Polyester fibres can be subjected to spinning, and then be reused directly to manufacture new textiles. Cotton powder can be used to regenerate new cellulose fibres. It can also be used in absorbent materials.
Environmental impacts	Significant but pending LCA reports. The hydrothermal process uses only heat, water and less than 5 per cent biodegradable green chemical, to self-separate cotton and polyester blends.
MARKETS	
Quantity of material sold annually	Too early to tell

Sales trend in 2020 (increase, decrease or stable) and why	Increase due to brand interest
BUSINESS DEVELOPMENT INFORMATION	
Technology patented	Yes. They would allow third-party licensees and envision an expansion to Canada for post-consumer apparel processing.
Estimated acquisition cost	$1.5 million USD
REFERENCES	
(Hallerby, 2021; HKRITA, 2018; H&M Group, 2021; Notman, 2021; Williams, 2021)	

Comparative Assessment

COMPARISON AND RANKING – SORTING TECHNOLOGIES

Manual sorting:

- Each sorting and grading facility has different categories for the items they process. East-West in Germany for example uses 450 sorting criteria. Certex, a major sorter-grader in Quebec, produces 150 grades of materials (Mercier, 2018) and Canadian Textile Recycling , a major sorter-grader from Ontario, lists 92 different items of bulk clothing available for sale on their website. However, this lists does not include other material grades that are destined to become rags or bulk fibres, as well as rejects for disposal (Canadian Textile Recycling, 2021). Storry and McKenzie concluded that a typical North American sorter-grader will generate over 400 different grades of materials (Storry & McKenzie, 2018).
- To meet precise market demands for used clothing, the sorting-grading step is very labour-intensive, and represents an important operating cost. A study estimated the operating costs of an entirely manual sorting operation at 200 £/tonne (CAD$350/tonne) (WRAP, 2014).

- At 8.75 tonnes/hr (18,000 tonnes/year), East-West is a very large sorting operation. It employs 170 people at its sorting-grading facility, for an average yield of approximately 100 tonnes/year/staff. Certex, located in the Montreal area, sorts 6,000 tonnes/year of clothing and employs 100 staff (Mercier, 2018) for an average yield of 60 tonnes/year/staff.
- Since manual sorting is focused on recovering items with a high resale value, and reuse locally or on international markets, a large volume of lower-quality grades and waste is generated. This can be as much as 10-30 per cent of incoming materials in a sorting-grading operation. In Quebec, this stream is evaluated at 15,000 tonnes/year (CTTÉI, 2018). In the Vancouver area, it is estimated at 3,200 tonnes/year (Storry & McKenzie, 2018).
- Some grades are created to become rags and wipers. They consist of items unsuitable for reuse but with absorbent properties (ex: cotton). It is the only instance of selection based on material properties in a manual sorting-grading operation.

Semi-automated sorting:

- Manual sorting-grading can be improved using mechanical equipment for critical steps of the operation, in order to increase the overall yield and quality. Examples include infrared scanners, or the use of RFID or barcodes.
- A detailed review of various technologies available to assist manual sorting is given in **Appendix I:** Semi-automatic Sorting Processes
- The advantage of combining human senses with some apparatus capable of accurately identifying certain materials opens the possibility of reconfiguring grades to optimize their value on both reuse markets and recycling markets.
- A study on textile grades of lesser value showed that it could potentially feed recycling markets if the items were sorted according to their material composition (Mercier, 2018). A typical material composition profile of low-value streams from a sorting-grading operation is summarized in **Appendix J:** Low-value Grades and Rejects from Manual Sorting.
- The financial impacts of using various sorting technologies in a 16,500 tonnes/year sorting-grading facility has been modelled by WRAP. The study showed that the use of RFID tags or barcodes by the industry could significantly lower sorting costs, down to £70/tonne (CAD$123/tonne), and help improve overall quality (WRAP, 2014). This would require, however, significant changes in clothes labelling across the value-chain and manufacturers/retailers would bear the extra cost of tagging. Moreover, this approach would not apply to manufacturing waste such as end-of-rolls, cuts and trims.

Fully-automated sorting:

- Fully-automated sorting is made possible by combining automated detection with an automated system of sorting and ultimately distributing the items to the appropriate stockpiles. Both SIPTex and Fibersort (distributed by Valvan Baling Systems) rely on infrared identification for scanning but they differ in the means employed for the automatic separation of items.
- SIPTex employs three successive optical sorters, which allows for fully-automated sortation into 6 distinct material streams. This kind of system allows for a particularly high throughput and remains effective with very high conveyor speeds. The yield is estimated at 8,000-12,000 tonnes/year/optical sorter.
- This system could also be used to separate textile shreds and manufacturing waste, and this application is currently undergoing testing by some leading manufacturers of optical sorters such as Pellenc.
- Fibersort uses a conveyor distribution system akin to the one developed by Textile Recycler (Automation System, 2021), but with the addition of automated infrared scanning. In theory, this system allows for the separation of a material flow into numerous grades (currently 45) and is only limited by the ability of the scanner to differentiate different material categories. It is, however, slower than an optical sorter with an estimated yield of 3,500-4,000 tonnes/year.
- Item singulation is particularly important with Fibersort, and since items are ejected from the conveyor belt sideways, this system cannot manage several items across the belt's width.
- Accuracy will vary depending on speed, programming, material type, ejection efficiency and other factors, but is in general very high. Fibersort data demonstrated good results when sorting cotton and cotton/polyester blends, but a lower accuracy for pure polyester, viscose and polyamides (Interreg, 2018). Pellenc reported that more work would be needed to efficiently remove blends containing spandex.
- Some black items cannot be detected by infrared.
- There is little economic data available at this time on fully-automated sorting operations. The cost was modelled at £47.5/tonne (CAD$83/tonne) by WRAP (WRAP, 2014).

Table 28: Summary table – Sorting Techniques

Criteria	Manual sorting	Semi-automated	Fully-automated
Feedstock	Waste apparel and clothes	Waste apparel and clothes	All textile waste, residential and ICI

Tolerance to contamination	High	High	Moderate. Lower accuracy with polyester, viscose, polyamides, black items and blends containing spandex.
Critical contaminants	None	None	Bulky or large items (risk of entanglement)
Suitable for reuse markets?	Yes, hundreds of grades generated.	Yes, hundreds of grades generated.	No, sorting based on materials only.
Suitable for recycling markets?	No, low accuracy and output.	Potentially higher accuracy, low output.	Yes, high output and high accuracy.
Estimated capacity at industrial scale	60-100 tonnes/year/staff	Varies depending on technology	3,500-10,000 tonnes/year/machine
Technological readiness	NA	Industrial	Pilot to Industrial
Capital investment	Low	Varies depending on technology	< 300K-500K CAD$ per optical sorter
Environmental impacts	Exports: social and environmental impacts overseas	Exports: social and environmental impacts overseas	Low
Potential for implementation in Canada (+ to ++++)	NA	++++	++++
Pros	Very high precision to meet reuse market demands.	Very high precision to meet reuse market demands, and potentially some recycling markets. Higher yield than manual sorting only.	Very high precision to meet recycling market demands. Low cost, very high yields.

Cons	Not adapted to supply feedstock to most industrial scale recycling operations.	Some manual work required. Not adapted to supply feedstock to large recycling operations.	Cannot be used for reuse markets. Research still required to efficiently manage critical contaminants such as spandex.
Availability of pilot equipment	NA	Unknown	Yes

Assumptions and Limitations

- The level of automatization in Canadian sorting-grading operations is not fully known but is assumed to be low. A transition from manual to semi-automated sorting-grading across the industry could be envisioned to maintain the current reuse model, while efficiently processing lower-grade feedstock for recycling based on their material properties.
- Fully-automated sorting could be deployed in a location where waste streams from sorter-graders could be combined in order to achieve a scale comparable to the output of an optical sorter.
- Further opportunities involving automated sorting could be explored if current reuse models that rely heavily on exports are to be revisited.

COMPARISON AND RANKING – MECHANICAL RECYCLING

Open-loop mechanical recycling:

- Open-loop recycling technologies, in general, boast a high level of maturity and have been used by businesses for many decades.
- Certain contaminants may be problematic and must be controlled or avoided at all costs in the feedstock, such as metals and plastics, which may damage the equipment or present a fire risk (CETI). Low-melt fibres, such as spandex and elastane, should also be avoided since they may wind around the blades of the shredding or fraying machinery, and melt into place due to friction heat.
- Overall, an open-loop approach offers more tolerance to contamination than closed-loop recycling, since the chemical and mechanical properties of individually recycled fibres

are not as critical. In applications such as padding or upholstery, it is the bulk properties that are important.

- Previous research done by the CTTÉI pointed towards a mechanical open-loop recycling application offering the best available opportunity for a large-scale fibre recycling operation in Quebec, in terms of value and volume: insulation panels (CTTÉI, 2020). The manufacture of insulation panels, such as Blue Jeanious (by Jasztex), could become an interesting outlet for pure cotton or cotton and polyester blends, although there is currently a preference for homogenous feedstocks of denim. The demand in Quebec for such products vary from 2,500 to 17,500 tonnes/year.

Closed-loop mechanical recycling:

- Closed-loop (fibre-to-fibre) mechanical recycling applies to cotton and cotton blends, aramid fibres and wool. Cotton and primarily cotton blends can be frayed, carded and spun into new yarn. The fibres are usually too short, and must therefore be blended with virgin carrier fibres, in a minimal recycled:virgin ratio of 70:30 (CETI). The resulting yarn can then be used in the manufacture of new textiles. Fibres with very good mechanical properties, such as aramid (Kevlar) and wool, can sustain the fraying process and retain sufficient length to be re-spun into yarn, in a proportion up to 100 per cent recycled.
- A closed-loop mechanical recycling pathway for post-consumer polyester is not as appealing as chemical due to the weakening of the fibre strength. As discussed in section 1.2, it is much easier to melt plastic PET bottles to spin fibres. Also, polyester fibres do not possess sufficient mechanical strength to resist the fraying process and retain a length that would make them suitable for spinning into new yarn. The exhaust dyeing process used to colour polyester fibres significantly alters its mechanical properties and may render the material unsuitable for mechanical recycling (Lindström, 2018).
- A study conducted by WRAP established a business model for a fibre-to-fibre mechanical recycling operation in the UK. Processing costs for a 30,000 tonnes/year denim and post-industrial cotton operation were estimated to be £216 per tonne (CAD$378), excluding sales costs and overheads (WRAP, 2019). Although the model generated positive returns, a sensitivity analysis demonstrated that small changes (±10 per cent) in feedstock prices or sales could render the operation not economically viable.
- There may be a better economic case to make for small operations with high-value fibres, such as wool and synthetic polyamide fibres (ex: aramid fibres, see Section 1 for fibre values). In this context, operations with smaller capacities may be viable. General Recycled processes 400kg/hr at its Val-des-Sources plant, or 800 tonnes/year/shift.
- Contamination control is more critical in closed-loop recycling since the yarn produced must meet specifications that are at least similar to virgin yarn. In high-end applications,

such as fireproof aramid textiles, any foreign material fibres should be avoided, on top of non-textile contaminants. A survey conducted among recyclers in the United States identified acrylic, elastane, nylon and metals as the most undesirable contaminants in their feedstock (Accelerating Circularity, 2020).

Table 29: Summary table – Mechanical Recycling

Criteria	Open-loop recycling	Closed-loop recycling
Feedstock	All materials, pre-sorted to varying degrees of precision. Preference for ICI waste.	Cotton, wool, aramid fibres. Recycled cotton must be blended with virgin material.
Tolerance to contamination	Moderate	Very low. All contamination must be removed prior to processing. Must be colour sorted.
Critical contaminants	Spandex, elastane, metals	Spandex, elastane, metals
Integrated fibre-to-fibre solution?	No, but several recyclers also manufacture and commercialize end products.	Yes
Estimated capacity at industrial scale	2,500 tonnes/year (Quebec market for insulation panels) to > 100,000 tonnes/year (U.S. Recyclers)	Smaller: 800 tonnes/year (General Recycled) for high-value fibres
Technological readiness	Industrial	Industrial
Capital investment	Estimated to be > CAD$10M	NA
Environmental impacts	Dust production	Dust production

Potential for implementation in Canada (+ to ++++)	+++	++
Pros	Well-established markets. Good potential for a recycler to integrate an existing supply chain. Possibility to use well-sorted post-consumer streams.	Operations that can function at smaller scales to match supply and demand. Lower capital investment.
Cons	The value of end-products is generally lower than recycled fibres.	Less applicable to contaminated or heterogenous material streams, such as post-consumer waste
Availability of pilot equipment	Yes	Yes

Assumptions and Limitations

- Due to the high number and diversity of mechanical open-loop recycling solutions for textiles, there is a wide range of values for the various criteria listed in the table above. Since these are often industrial and well-established operations, it is ironically harder to obtain information from stakeholders as it may be considered as sensitive.
- The economic study from WRAP recommended enacting a few measures to overcome barriers to the implementation of fibre-to-fibre technologies, such as an extended producer responsibility, a greater optimization of the collection, sorting and pre-processing steps, and optimizing transport costs (WRAP, 2019).
- For some textile materials such as denim, there is a competition between mechanical recycling operations in North America and graders selling these textiles to the global second market. This competition means recyclers must pay relatively high prices to access the materials. The high costs for material that requires recycling are an obstacle against building a business case for a large-scale mechanical recycling operation in North America.
- Automated-sorting technologies presented above may open new opportunities to sort materials with a low resale value that would be otherwise too expensive to sort by hand. The rejects from sorting-grading operations contain a lot of cotton and polyester

that can be recycled if the material is being sorted for its fibre value and not only for the product re-use value. Hence an upgrade in sorting technology provides the opportunity to generate low-cost, high-volume yield material. The market for these low costs materials exists. SIPTEX, for example, must source its raw materials from 3 sectors, including bulk post-consumer waste leftovers, to keep its production running.

- In Quebec, the law still prevents the use of post-consumer material in upholstery, albeit an exemption applies to the following six items: vehicle or airplane insulation, safety and rescue equipment, pet accessories, caskets and shoes. Upholstery may become a profitable opportunity once the law is changed, and a new version of the regulations on labelling and the use of recycled content is currently being evaluated.

COMPARISON AND RANKING – CHEMICAL RECYCLING

Dissolution

- Dissolution technologies reviewed in this study apply specifically to cotton. Solvents are used to break intermolecular bonds between cellulose strands, making them soluble. The pulp can then be used to manufacture threads of regenerated cellulose through various processes.
- Re:newcell is an industrial scale operation close to maturity, and is modelled on the cellulose industry where wood biomass is usually the main feedstock. The output is a cellulose pulp that can be converted to viscose or lyocell by other stakeholders.
- Infinited Fiber uses a similar process to Re:newcell. Although still in the pilot phase, it aims at providing a more integrated solution to textile recycling since their output is a cellulosic thread ready to be used in textile manufacturing. Furthermore, they use a patented cellulose carbamate pathway. This process carries significant environmental advantages compared to viscose production. They also claim that the resulting fibres show superior properties.
- Evrnu relies on various treatments to filter out of wash contaminants such as dyes, oils, and non-cellulosic fibres. Although they claim to be able to manage various contaminants, it is unclear how much effort is required in sorting the material first to avoid unwanted downstream impacts in their process.
- Stretchy fabrics, such as elastane and nylon, are critical contaminants. Other contamination can be filtered out after the dissolution of cellulose, contrary to mechanical recycling processes. For non-critical contaminants, such as polyester in cotton, it depends on the technology as, for example, the reported tolerance varies from less than 2 per cent with Re:newcell, to 20 per cent with Infinited Fiber.
- All processes rely on solvents such as sodium hydroxide, bleaching agents, organic solvents, raising concerns about their environmental impacts.

- The technologies closest to maturity, Re:newcell and Infinited Fiber, are very large-scale operations that require significant capital investment.

Dissolution-Depolymerization

- By combining two chemical processes, those technologies offer the possibility to tackle multi-material waste streams (natural and synthetic blends) and recycle more than one fraction.
- Depolymerization of polyester allows for the purification and refining of its two chemical building blocks: ethylene glycol and terephthalic acid (TPA). They can be recombined in a controlled polymerization reaction to form a PET resin, with highly customizable physio-chemical properties. This process is the only available closed-loop recycling solution for polyester fibres.
- All case studies presented are still in pilot phase, and there is some uncertainty on the economic viability of an industrial scale operation. At scale, the operations would have a capacity ranging from 10,000 tonnes/year to 80,000 tonnes/year.
- A preliminary economic-modelling study conducted by WRAP demonstrated that a dissolution-depolymerization operation for recycling polyester/cotton blends, with a capacity of 30,000 tonnes/year for the first 4 years, then scaling-up to 50,000 tonnes/year, could be profitable. The processing costs are comparatively low, at £90/tonne (CAD$160). The model assumptions are very similar to the Blocktexx and Worn Again models. A sensitivity analysis demonstrated that only a significant drop in either cellulose pulp prices, PET resin prices or feedstock costs would generate negative returns (WRAP, 2019).
- Resyntex goes another direction and repolymerizes polyester to create a resin that could be spun again, while cotton and wool are sold as chemical commodities. Although it offers a more comprehensive approach to tackle all kinds of textile streams, an internal assessment recently demonstrated that even for a future production capacity of 80,000 tonnes/year, the process is not profitable (Nikolakopoulos, 2019).
- Although polyester and material blends are not considered as contaminants, it was reported, however, that material ratios must be known to some degree, and controlled to ensure that the processes work properly.
- Stretchy fabrics, such as elastane and nylon, are critical contaminants. Moreover, nylon (buttons) can interfere with the depolymerization process and must therefore be removed prior to this step.

Hydrothermal processing

- Hydrothermal processing technologies could be associated to either dissolution (in the case of HKRITA) or dissolution-depolymerization (in the case of Circ) technologies. The main difference is that hydrothermal processing is a clean process that eliminates the need for solvents that are costly and could be harmful to health of the environment.
- HKRITA has developed a fully-integrated solution that first involves sanitizing, colour sorting, metal detection and automatic storage. Then, the material is processed in a reactor. This equipment is also known as the Green Machine and was developed with support from H&M. The output is a cellulose powder that could be spun again by stakeholders, and loose polyester fibres.
- While HKRITA focuses on solubilising cellulose and extracting polyester fibres by filtration, Circ proposes a more aggressive treatment to also depolymerize polyester. They claim that this approach yields a higher purity in cellulose, while generating chemicals that could be sold to a PET production facility for a complete regeneration of the polyester.
- Spandex can be managed in proportions varying from 5-10 per cent.
- Such an approach is not suitable to remove most dyes. The clothes must therefore be colour-sorted first.

Table 30: Summary table – Chemical Recycling

Criteria	Dissolution	Dissolution-Depolymerization	Hydrothermal Processing
Feedstock	Cellulosic fibres only.	Cellulosic fibres, polyester or blends of both.	Cellulosic fibres, polyester or blends of both. Must be colour-sorted.
Tolerance to contamination	Up to 20 per cent non-cellulosic materials.	Concentration and type of non-cellulosic material must be known.	Concentration and type of non-cellulosic fibres must be known. Up to 5-10 per cent spandex tolerated.

Critical contaminants	Metals, spandex, elastane.	Metals, spandex, elastane, nylon.	Metals.
Integrated fibre-to-fibre solution?	Yes (Infinited Fiber) Re:newcell and Evrnu rely on stakeholders for sorting and/or fibre production.	No, outputs sold to third-parties for fibre production.	No, outputs sold to third- parties for fibre production. In the case of HKRITA, possibility for spinning recovered polyester fibres.
Estimated capacity at industrial scale	30,000 tonnes/year	10,000 – 80,000 tonnes/year	NA (estimated at 1 tonne/day for a pilot)
Technological readiness	Industrial	Pilot	Pilot
Capital investment	> CAD$100M (lower for existing facility retrofits)	> CAD$100M	NA (estimated at CAD$2M for a pilot)
Environmental impacts	Heavy use of potentially harmful consumables	Heavy use of potentially harmful consumables	Low. Water is used as the main solvent (95 per cent)
Potential for implementation in Canada (+ to ++++)	++	+	++
Pros	Presence of a cellulose pulp industry and infrastructures that could be retrofitted, lowering capital investment.	Potential for treating a complex waste stream.	Availability of smaller pilot units. Low environmental impact. Recovery of polyester fibres can

			shorten the supply chain.
Cons	High volumes required. Technologies only suitable for cotton, which means competition from export reuse markets.	High capital investment and volumes required. Need to build a large network around the technology to complete the supply chain (ex: for polymerization and spinning yarn).	Additional information is required on the financial feasibility of an industrial-scale operation. High capital investment and volumes likely. High energy consumption.
Availability of pilot equipment	Yes	No	Yes

Assumptions and Limitations

- Dissolution processes can regenerate cellulose threads, but always starting from the same cellulose molecules as building blocks. Unlike polymerization processes, the length (or degree of polymerization) of cellulose cannot be controlled, although it is possible that repeated recycling may damage and shorten the cellulose. More research is needed to evaluate how many recycling cycles cotton could sustain using those technologies.
- Further investigation is required to establish the sensitivity of chemical recycling processes to varying material ratios in the feedstock, specifically for polycotton blend, and see if it is adequate given the precision that can be achieved with automated infrared sorting.
- Some dissolution processes could be implemented by retrofitting existing infrastructure, such as paper mills, to greatly reduce capital investment. Since processing costs are expected to be lower in chemical recycling compared to mechanical recycling at the same scale, this may help to build a more competitive model.
- The use of industrial symbiosis strategies may make very complex processing operations, such as Resyntex, profitable, notably by sourcing solvents and other consumables for a lower cost.

- Overall, chemical recycling technologies do not seem to offer an easy way around dealing with some contamination usually present in textile waste, including in all post-consumer streams. The same critical contaminants are reported by both chemical recyclers and mechanical recyclers, and material sorting is critical in all cases.
- A major added-value to chemical recycling is the ability the remove dyes from fabrics, which is essential in a closed-loop recycling perspective. There is still a preference by the industry, however, for white of same-colour material (such as denim) because not all dyes can be efficiently removed (WRAP, 2019; Nikolakopoulos, 2019).

Initial Feasibility Study

Based on the findings and assumptions outlined in the sections Textiles in the Residential and Non-Residential Waste Streams, there is enough textile waste available to feed a textile recycling industry in Canada. However, because the material first needs to be diverted, not all the material is available today, this feasibility study is based on the minimal capacities of available industrial machinery. The initial study was completed to estimate operating costs and revenues for a specific recycling process targeting post-consumer polyester.

After comparing the various recycling processes, the decision was made to conduct an initial feasibility study on mechanical textile recycling due to: technology readiness; low capital investment; and it allows for lower volumes of textile waste to operate. The simplest and least-energy intensive recycling technology for both natural and synthetic fibres is mechanical recycling under today’s conditions (Roos, et al, 2019).

OPEN-LOOP RECYCLING OF POLYESTER INTO ACOUSTIC INSULATING FELT

Polyester fibres represent the second biggest source of recoverable post-consumer textile waste, for which very little recycling options are currently available. Chemical recycling technologies may become viable solutions for polyester recycling but are still in development. Currently, mechanical recycling breaks polyester fibres and makes it very difficult to spin yarns from this waste source. For this reason, the scenario selected is open loop recycling to make acoustic insulation felt. **Figure 8** shows the various hypothetical stakeholders involved in the model as well as their location.

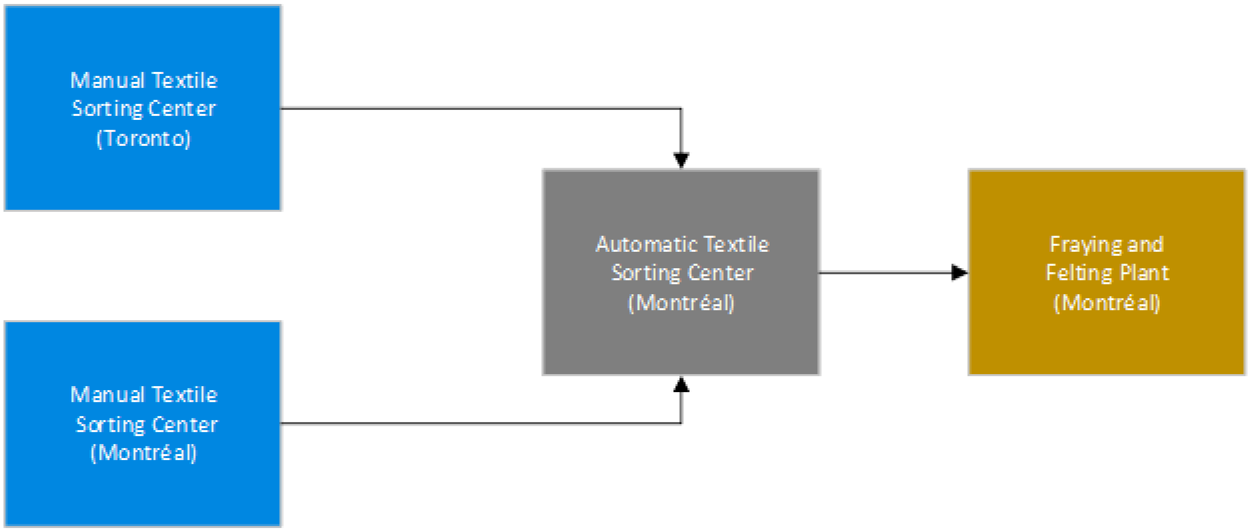


Figure 8: Open-loop recycling of polyester process diagram

EQUIPMENT REQUIRED

Manual Textile Sorting Centers

Manual textile sorting centers are currently equipped to process post-consumer clothing. This first sorting makes it possible to separate the clothes that can be reused from those that will be recycled.

Automatic Textile Sorting Center

Following manual sorting, it is necessary to perform automatic sorting to separate the fibres by material types. Recycling of single fibres results in products with greater added value. NIR spectroscopy technology was selected for this scenario, more specifically the Mistral + optical sorter by Pellenc (**Figure 9**). This equipment was presented in detail (see Sorting and Fibre Separation Case Studies). This automated sorting will generate a flow of polyester-only materials.

Figure 9: Tearing line post-consumer wastes by Laroche (Laroche, 2021b)

Defibering and Felting Plant

To make an acoustic insulation felt, it is necessary to acquire the following 3 units:

- A tearing line for fraying;
- An airlay line to carry, mix and spread loose fibres evenly;
- A needlepunch line to bind and densify the product.

The tearing line for post-consumer wastes by Laroche is a completely automated tearing line, can regenerate fibres for nonwoven and is ideal for a wide range of applications: bedding, furniture, insulation, automotive. It has a high production capacity and is fully controlled with touch screen operator interface (**Figure 10**).

Figure 10: Mistral+ by Pellenc ST (Pellenc ST, 2021)

The airlay line “Flexiloft” by Laroche is designed to produce fibre mats from all types of fibres: recycled fibres, natural fibres, artificial, synthetic, inorganic fibres but also mixtures with non-fibrous particles-based materials like plastic, wood, foam (**Figure 11**). The Flexiloft option allows more loft, resilience, homogeneity, and regularity of the web, all for a wider range of weights and thicknesses.

Figure 11: Needlepunch line by Andritz (Andritz, 2021)

The needlepunch line by Andritz allows one to customize the fabric's tensile strength and weight distribution. Needlepunching is a technique where mechanically carded fibres are bound by inserting barbed needles to facilitate the entanglement of the fibres (**Figure 12**).

Figure 12: Airlay line Flexiloft by Laroche (Laroche, 2021a)

PRELIMINARY ECONOMIC STUDY

A capital expenditure (CAPEX) is the cost for developing or providing non-consumable parts for the product or system. An operational expense (OPEX) is a variable cost tied to the system's operation. The model's initial feasibility is based on both.

Model Assumptions and Limitations for the Preliminary Economic Study

- The model is built on a 20,000 tonne/year feedstock consisting of rejects from sorting-grading operations in Toronto and Montreal. An assumption is made that this quantity is split evenly between Toronto and Montréal, and all recycling units would be located at the automated sorting center in Montreal.
- In the model, the sorting equipment would be installed within existing manual sorting facilities in Montréal. Only the extra costs associated with running the equipment are considered. The prices associated with the rental, construction or renovation of a building housing the fraying and felting plant have not been considered either.
- There is no landfilling costs for the 16,000 tonnes of non-polyester fibres. Realistically there is likely to be an elimination fee for some of the waste. Some of the sorted material

is recyclable however (for example, cotton that was not recovered at the sorting-grading step). Extra revenues from this stream could help offset disposal costs, but costs could not be estimated at this stage.

- Polyester fibres are often found in blended fabrics. Some of the fabric may be suitable to felting while others may not, depending on the ratio of polyester present. Optical sorting machines can be adjusted to detect and capture polyester blends of a specific ratio. The recoverable fraction of 20 per cent used in the model is a preliminary estimate only (yield of 4,000 tons of polyester/year).
- The production capacity is based on the maximum sorting capacity of the Mistral+ (Pellenc). Downstream equipment was chosen with a capacity to match the incoming sorted stream as closely as possible (1 ton/h). The actual capacities of each unit are presented in **Appendix G:** Pellenc ST Test Results.
- All equipment is in operation for 16 hours a day, 5 days a week throughout the year except for 2 weeks of maintenance. The supervisor works 8 hours a day. Two (2) operators are needed for the tearing and airlay line, and an additional operator for the needle punch equipment.
- Preferential rates could be negotiated with Hydro-Quebec for the cost of electricity (power).
- Taxes and inflation were not considered in this preliminary study, as the profits and losses are presented for the first year only.
- The cost of raw materials is considered null. Actual pricing will vary depending on the waste stream.
- Technical specifications such as density are based on the Wall-Mounted SoundSorb Acoustic Panels of Versare Made from high-density 100 per cent polyester fibres from PET bottles (Versare, 2021). According to the Mutrec study on textile circularity, this type of material retails for Can$ 4,400 per tonne (lower estimate). The bulk selling price was estimated at CAD$1732/tonne (Can$ 0.55 / ft^2).
- Ongoing work is required to ensure that market specifications are met and optimise potential product value.
- Specifications for CAPEX-OPEX calculations (Seider et al., 2017)
    - Commissioning
        - Installation = 45 per cent of Equipment
        - Instrumentation and Controls = 9 per cent of Equipment
        - Piping = 16 per cent of Equipment
        - Electrical = 10 per cent of Equipment
    - Operating Costs (OP)
        - Maintenance Cost = 3 per cent Capital Costs (CAP)
        - Plant Overhead = 2 per cent CAP + 50 per cent Maintenance Cost
    - Depreciation Expense (DEP): 10-year time horizon

Equipment Technical Parameters

Table 31: Equipment technical parameters

	Automatic Textile Sorting Center	Fraying and Felting Plant		
	Optical Sorter and Peripherals (Pellenc)	Tearing Line for Post-Consumer Waste (Laroche)	Airlay Line Flexiloft (Laroche)	Needlepunch Line (Andritz)
Operation time (h/year)	4,000			
Daytime working hours (h/year)	2,000			
Hydro-Quebec industrial rate ($/kWh)	0,1			
Operator salary ($/h)	35			
Supervisor salary ($/h)	60			
Current capacity (t/h)	5	1		
Annual capacity (t/year)	20,000	4,000		
Number of employees required	1	3		
Number of managers required	1			
Energy required (kW)	76.4	580	300	150

* All prices in CAD$

Transport Fees

Table 32: Transport fees

	3 and 4 Axles Vehicles Tonne-kilometer rates for bulk materials ($ / t-km) (*Bulk Trucking Tariff Compendium*, 2020)					
Regions	Loading to 0.9 km	1.0 to 9.9 km	10.0 to 29.9 km	30.0 to 64.9 km	65.0 to 159.9 km	160.0 km and over
Montreal	1.737	0.45	0.4	0.145		
Magdalen islands	1.84	0.647	0.647	0.226	0.168	N/A
Other regions	1.639	0.27	0.297	0.182	0.123	0.097

* All prices in CAD$

Table 33

	From the manual textile sorting center in Toronto	From the manual textile sorting center in Montréal
Annual feedstock (t/year)	10,000	10,000
Distance to the Automatic Textile Sorting Center (km)	540	10
Tonne-kilometer rates for bulk materials (except asphalt and stone) ($ / t-km)	0.097	0.4
Transport fee ($/year)	523,800	40,000
Total transport fee ($/year)	563,800	

* All prices in CAD$

Table 34

	Automatic Textile Sorting Center	Fraying and Felting Plant			
	Optical Sorter and Peripherals (Pellenc)	Tearing Line for Post-Consumer Wastes (Laroche)	Airlay Line Flexiloft (Laroche)	Needlepunch Line (Andritz)	TOTAL
CAP (Capital Costs, $)	951,718	4,504,205	3,711,206	2,061,787	11,228,915
Equipment ($)	446 ,816	2,114,650	1,742,350	967,975	5,271,791
Commissioning ($)	357,453	1,691,720	1,393,880	774,380	4,217,433
Project Management ($)	147,449	697,835	574,976	319,432	1,739,691
OP (Operating Costs, $)	262,422	694,773	531,228	364 016	1,852,439
OP ($/tonne of polyester felt)	65.61	173.69	132.81	91.00	463.11
Raw Materials ($)	0	0	0	0	0
Power ($)	30,560	232,000	120,000	60,000	442,560
Maintenance Cost ($)	28,552	135,126	111,336	61,854	336,867
Operating Labor Cost ($)	170,000	170,000	170,000	170,000	680,000

Plant Overhead ($)	33,310	157,647	129,892	72,163	393,012
R (Revenue, $)					6,928,806
R ($/ton of polyester felt)					1,732
DEP (Depreciation Expense, $)	95,172	450,420	371,121	206,179	1,122,891
NE (Net Earnings, $)					3,953,475
PO (Payout Period, year)					2.8

* All prices are in CAD$

In summary, the preliminary techno-economic evaluation for an open-loop recycling facility of polyester into acoustic insulating felt showed an estimated CAPEX of CAD$11.2M, an OPEX of CAD$1.8M and revenues of CAD$6.9M, for a potential payback period of about 2.8 years. The data seems promising at first hand, even though it is based on several substantial assumptions. On the other hand, the possibility of obtaining government funding for the implementation of this new recycling facility had not been considered at this point. Such funding for clean tech and environmental projects is currently available and could help reduce the CAPEX by a significant amount.

Conclusion of the Feasibility Study

A technology review was done to provide an up-to-date assessment of various textile recycling technologies, grouped into three categories: sorting, mechanical recycling and chemical recycling. Data collected from public sources as well as interviews with various representatives helped provided insight into the technological readiness for various solutions, the capabilities of technologies in terms of feedstock and products characteristics, as well as information on real-life case studies. A significant number of organizations confirmed their interest for an expansion in Canada, or for a collaboration with national partners. Although not all recycling initiatives were covered in the review, the cross-section includes 14 organizations spread over 3 continents, and a representative sample of technologies available or under development for textile recycling.

The comparative assessment highlighted the differences between technologies and the importance of having an appropriate match between feedstock characteristics, sortation, process, and market type. The availability of pilot-scale equipment should be considered when selecting a solution for Canada, as a small-scale project will be a necessary next step. Many of the technologies reviewed are streamlined for specific material types, and as such would not be easily adaptable to process heavily contaminated or variable waste streams, such as most post-consumer textiles. Automated sortation will be a critical step to consider in implementing an apparel recycling industry in Canada, as it can generate cleaner feedstock at high throughput and relatively low price (compared to manual sorting). Other strategies can be used to help tackle post-consumer streams, such as using cleaner post-industrial waste as a main feedstock to lower total contaminants in the process and generate higher quality products. Many of the case studies detailed in the review take place in countries where regulations, such as extended producer responsibility on textiles in France, provide economic incentives for recycling operations. Also, the vicinity of large retailers, brands or manufacturers (Sweden, Asian countries) can create market incentives that are amenable to a local recycling industry.

An initial feasibility study was done based on a mechanical polyester recycling scenario, which includes automated NIR sortation and the making of nonwoven felt for acoustic insulation. The capacity used in the model is not representative of the potentially available polyester waste in Canada but is rather based on the lower-range throughput from one production line of commercially available machinery. A preliminary CAPEX-OPEX was completed, in part using manufacturer data for machine costs, maintenance and power requirements. The results showed an estimated CAPEX of CAD$11.2M, an OPEX of CAD$1.8M and revenues of CAD$6.9M, for a potential payback period of about 2.8 years.

The model needs to be tested at pilot scale before considering a full-scale operation to validate the assumptions used and because some potential costs and revenues were not available at the time this study was conducted. Despite this, the initial outlook is overall positive and warrants further investigation for this specific scenario (open-loop polyester recycling). The proposed approach to initial feasibility may also serve to evaluate other opportunities to be included in a Canadian textile recycling roadmap.

Part Five: Recommendations to Support a Textile Recycling Industry in Canada

There are many ways to foster a recycling industry in Canada and to reduce the environmental impact of plastic waste resulting from textiles. We organized our recommendations into three broad clusters: process-focused, product-focused, and system-focused. Some of these recommendations can be relatively easy to implement, while others are more challenging; some are short-term while others may take longer.

Process Focus – Improved Efficiencies and Better Control Process

1. **Textiles as designated waste material:** If we don't measure it, we can't manage it or improve it. Usually, textiles are part of the waste category 'other' and not a separate source of waste. Therefore, it is nearly impossible to find data about textile waste in Canada. To address textile waste, both the federal government and Canada's provinces must monitor textiles as their own waste type. To this end, Environment and Climate Change Canada recently released the National Waste Characterization Report. This report is one of the few publications that show textiles as their own waste category designation, and will ideally be used to guide waste composition studies in years to come. However, it only looks at textiles as a degradable material; textiles that are non-degradable were included in the plastic resins (Tuzi, Fraser, & Pietka, 2020).
2. **Communicating the Value of Textile Waste:** There are a significant number of valuable textiles in the Residential waste stream that could be reused. Furthermore, based on our research, we see proof that an increase in diversion of used textiles would match an increase in demand of equal magnitude through the re-use sector. At this time, we do not propose a ban on textiles at the provincial or territorial level because there would be too much material that we currently cannot recycle in Canada. Still, each province should establish textile diversion programs (similar to NS and BC), and it should be mandatory that municipalities report textile waste data to the province. The federal government could communicate this message about the high volume of textiles in the waste stream to the provinces and territories and introduce textiles as the next waste source that needs to be addressed.
3. **Encouraging Textile Waste Diversion Programs:** Not every municipality is prepared to implement a textile diversion program. In this case, we recommend an intermediate collection program that only collects specific textile product categories.

Our Dumpster Dive study has shown that the product conditions and the fibre material that requires recycling depends on the different textile product categories in the waste stream. Knowing the differences between the product categories allows municipalities to set appropriate diversion rate targets, either for material suited for reuse, or that requires synthetic or natural recycling. For example, to collect material that is good enough for reuse, a municipality could set up a diversion program for used clothing. If the materials are used as a feedstock for synthetic recycling, a diversion program for bedding would be best. Hence, we propose specific textile diversion programs for municipalities that are not yet prepared to divert all textiles, and that both the federal and provincial governments help to share information and propagate resources to all municipalities.

4. **Funding Textile Diversion Programs:** Currently, we have almost no textiles from the Residential waste stream that require recycling; therefore, it is challenging to build up a new recycling industry without a demand for recycling facilities or the feedstock that needs to be recycled. We would like to see not only an increase in textile diversion programs, but also in landfill bans at the municipal level, similar to the city of Markham, ON. A phased approach to textile diversion programs could provide textile collectors the opportunity to build up the infrastructure. On the other hand, we know in Ontario that roughly nine per cent of residents do not donate any of their unwanted textiles, and have never considered doing so. There needs to be some action from municipalities to access this material, such as a waste disposal fee by the amount of waste produced, or more effectively, a ban, with accompanying educational outreach. The city of Markham is often mentioned as a leader with its textile diversion program, but it is seldom reported that Markham was only able to develop this program due to funding from the Federation of Canadian Municipalities (FCM). We recommend helping municipalities finance the establishment of textile diversion programs.
5. **Fostering a Textile Recycling Industry in Canada:** Used textiles are a commodity, and the markets for this commodity can change. We experienced this during the pandemic when charity collectors were not able to collect, and the bins were flooded with donations. As there is uncertainty around the used clothing market, it is wise to create recycling opportunities for textiles in Canada. However, the feedstock to build this recycling industry will most likely come from the IC&I sector, where material usually is not being donated for reuse but instead goes into landfill. During our interviews with reverse logistics service providers for brands and retailers, we recognized that many Canadian companies work within the U.S. A large amount of textile waste material is being transported across the border for shredding because of a lack of recycling facilities in Canada. It is interesting that reverse logistics providers pay for the shredding to protect the brand image of their customers, to ensure the material is properly managed and that their labels are not ending up in a landfill. This

willingness of brand owners to pay for recycling provides a window of opportunity for textile recycling in Canada, which could lead to an increase in clothing retailers who offer in-store take back programs as a form of extended producer responsibility (EPR). Hence, we recommend fostering a textile recycling industry in Canada that will reduce the shipment of textile materials to the U.S., mitigate the risk associated with the used clothing markets, and make Canada less dependent on selling used material overseas.

6. **Financing a Mechanical Textile Recycling Pilot:** Assuming that we can access either textiles from the Residential waste stream or from the IC&I sector that are not suited for reuse, then there would be enough feedstock and need for a textile recycling industry in Canada. This need goes beyond the few existing companies that already work in some capacity on textile recycling. It would require many facilities across the country to recycle textiles. Based on our research and the costs required to establish chemical textile recycling systems, we recommend supporting and investing in mechanical recycling processes. Non-woven felts can be used in many ways, and the application possibilities are not fully utilized. What is problematic is that felts are often seen as products of low value, and therefore, the development of technology must match with the feedstock and follow the development of the product through to its end markets. As indicated in our survey results, and through our stakeholder interviews we know there is an appetite for new sustainable business practices and an interest to work on multi-stakeholder pilots; the question is how to get it started. We recommend financing the research of such a pilot that starts with recycling post-consumer textile waste, and ends with a product sold in a store from one of the participating stakeholders.
7. **Tracking Specific Import Data on Textiles and Clothing:** Our survey results point to an industry-wide gap in knowledge around the volume and composition of textile waste produced by yarn and fibre mills, textile and clothing manufacturers, brands, and retailers. Therefore, assumptions regarding total volumes of textiles waste in Canada cannot be made. To better understand Canadian textile waste, we need to know what textiles (including clothing and non-clothing textiles) are imported into Canada. Today, we see the value of textiles only in dollars through what we import and export, but these numbers only indicate whether there is a trade surplus or deficit. There must be an opportunity to obtain better data through Statistics Canada on how many pieces, or meters, are imported into Canada, as well as the price, the weight and the composition of these products. A shipment document should include this information; thus, this data should be readily available. Understanding this data will help to track the material flows and set a benchmark for comparisons, for example, to recognize shifts in customer behaviour. We don't really know if customers buy more clothes every year or if the price for those clothes has increased; hence, we cannot make any prediction as to the waste.

8. **Funding a National Textile Diversion Working Group:** The idea of diverting textiles from landfills is still a new field in waste management in Canada. As a result, there are not many studies or organizations working on textile waste when compared to food or plastic waste. Based on our interviews, we recognize the need to bring the different stakeholders together. Yet, there is a lack of a national platform that connects the different stakeholders in Canada. At the same time, we need to be better connected with the research and development that is occurring in other countries, and build a national knowledge base around textile diversion. We recommend helping to establish a national textile diversion working group that fosters a circular textile economy, with multiple stakeholders across the value chain. A series of labs and workshops are required to bring these perspectives together and create a vision and a strategic plan to make fashion circular in Canada.
9. **A Legislative Reform on the Duty Drawback:** We recommend that the federal duty drawback be amended to create reuse and recycling incentives. The current framework incentivizes environmentally destructive practices. The most direct means to change the perverse incentive in the law is through legislative reform. We are aware that this requires Parliament to amend or repeal the Customs Tariff, which is a lengthy process, but just because something is lengthy, it doesn't mean we should ignore it. However, to not lose valuable time, we make the following recommendations that do not require legislative reform. A number of these recommendations may be implemented simultaneously:
    a) **Modify Memorandum D7-2-3:** modify Memorandum D7-2-3 to remove the examples provided for obsolete and surplus goods, as well as to highlight the legislative requirement that the goods must become obsolete or surplus as a result of processing in Canada. A field should also be added to K32 - Drawback Claim form to require that a CBSA officer has satisfied themselves that the goods became obsolete as a result of such processing. This has the potential to create a means for data on such practices to be collected. This may be a low-effort reform which would limit the applicability of the provisions and curb the incentive to destroy goods in order to qualify for the drawback, however, at best it is an interim solution because although it will potentially limit waste, it does not shift the paradigm away from destruction, but rather limits its application.
    b) **Incentives for Reuse & Recycling:** refund some or all duties related to unwanted goods. There are provisions in the Customs Tariff and the Financial Administration Act for this. In the 2018 fiscal year, for example, remissions of taxes, fees, penalties and other debts worth CAD$183,473,623 were granted by the Ministry pursuant to section 115 of the Customs Tariff. The purpose of this recommendation is to detract from the incentive to destroy goods for the purpose of the obsolete or surplus goods program, and instead have better

management such as reuse or recycling. The recommendation would be to award a refund only to owners of clothing inventory who dispose of their unwanted goods in a manner that is more socially and environmentally conscious. This has been done in the context of the Customs Tariff related to many items, including ballet shoes and some charitable goods.

10. **Review the Textile Labeling Act:** 'New materials only' regulation must be adjusted so that all provinces may include recycled content. In Ontario, this regulation was recently amended so that 'new material' means, (a) material manufactured for use as stuffing that has not been previously used, and (b) material not manufactured for use as stuffing that has not been previously used, and (b) material not manufactured for use as stuffing that is subsequently shredded, cut or reduced to a fibrous state through any other process for use as stuffing, and includes recycled material but only if it has undergone a remanufacturing process. In the provinces of Quebec and Manitoba, new material does not include (b) and therefore retailers such as Canada Goose, who is now using recycled down, is unable to sell their products in these provinces.
11. **Conduct Further Research on Repair, Refurbish, and Upcycling:** The focus of this study was to examine the feasibility of mechanical and chemical recycling opportunities in Canada. However, the options for repair, refurbishing, and upcycling also offer the opportunity to extend the life cycle of a garment. We recommend investing in further research about the potential for these methods to reduce textile waste to landfill.
12. **Action Plan on Zero Textile Waste:** While textiles are a small portion of plastic waste, this waste type is not a homogeneous group and easy to tackle. Still, it consists of many different categories requiring various recycling processes. While this study focused on polyester recycling because globally it is the most used fibre, there are many other synthetic fibres and products made out of synthetic fibres that are extremely challenging for recycling, such as elastane fibres or polyvinylchloride (PVC). Problematic is also the recycling of certain specific product categories such as shoes or umbrellas. We propose a Canada-wide Action Plan on Zero Textile Waste, which requires more research to determine the barriers and challenges and conduct pilots to develop possible solutions.
13. **Conduct Further Interviews and Landfill Audits:** The lack of data on textile waste is evident, particularly from the IC&I sector. However, during this study, we learned that a survey would not help gain data simply because most companies do not track their textile waste. Therefore, we do not think it makes sense to conduct further surveys with other industry sectors, for example, hospitals or hotels, about the amount of textile waste they produce. Until textiles are a specified waste type that is being tracked, this kind of research makes little sense. In contrast to the lack of data available, we learned that many companies agreed to an interview. There is interest

from the industry to address this topic, and we could obtain valuable information from the participants, and therefore, we recommend additional semi-structured interviews for other industry sectors to understand how they manage their textiles. Furthermore, waste audits are required to better understand the volume and composition of textile waste generated from the IC&I sector. During our research, we also learned that there is some transhipment of unwanted textiles to the United States. It would be valuable to track these transports to determine the scope, reasons, and material that is being shipped.

14. **Research Possibilities of Retrofitting Dormant Paper Mills:** There are several paper and pulp mills in Canada that are either struggling to stay in business, or that have closed and remain dormant. We recommend research to determine if these facilities can be retrofitted for chemical textile recycling.

Product Focus – Designing Fabrics/Garments with Less Impact

A critical aspect in waste management is how to make the waste better, or in other words, how can we reduce the number of synthetics in our landfills by making the products better.

15. **Encourage the Use of Reclaimed Fibres:** The Canadian textile industry is highly specialized in technical and home textiles, but not in clothing. Thus, there is no textile industry in Canada that produces recycled fabrics for fashionable clothes – at least not on a large scale. However, there is no reason why Canadian textile recyclers could not produce chips or pellets out of synthetic materials to use as a feedstock for reclaimed fibres. Similarly, recycled fabrics can be made from imported recycled yarn, or highly specialized home or technical textiles can be made from a recycled feedstock. Hence there is an opportunity for the government to support this industry by encouraging the use of reclaimed fibres through procurement, import duties, or by encouraging research projects with these fibre and fabric mills.
    a) **Procurement:** The public sector could take the lead to support change. One example is an updated guide for procurement that includes circular criteria and purchasing of garments tailored for different products based on resource consumption, quality and cost. Given the volume of government uniforms procured across several departments (Forestry, Fire, National Parks etc.), current 'green' procurement practices should be embedded, and local recycling companies should be given seniority at least for a specific time. Furthermore, to foster the procurement of products made from reclaimed fibres, it would be beneficial to have a database of companies producing

these products and to make this information accessible. Mechanical recycling of nylon, flame resistant (FR) or aramid material currently exists in Canada (QC and BC) and is the only facility of its kind in the world producing a recycled FR garment.

b) **Taxes & Duties by Fibre Content**: It is estimated that reclaimed fibres cost about 30 per cent more than virgin fibres. Depending on the product and other associated costs, there is a significant price difference that may be difficult to embrace with goodwill alone. It would therefore be beneficial to offer an incentive for products and textiles made from recycled fibres that could be imported with lower duties or taxes than conventional products. We are aware that the Canadian tax system is complex and that it depends on the kind of product and its country of origin, but it should also include the fibre material. Such a system is, for example, in place in Switzerland where the import duty depends on the fibre material. On the other hand, brand owners who use hard to recycle materials such as elastane should pay a heavier tax and have greater regulatory constraints on these products.

16. **Fund Specific Projects with Canadian Mills:** It would be beneficial to set up research projects with innovative start-ups and textile mills in Canada. A potential project could be to develop a process on how to recycle ocean fishing nets. Since these nets are mainly made of nylon and there is some expertise in Canada on how to recycle these materials, a collaborative project could lead to some interesting and innovative solutions.
17. **Support Post-Secondary Education for Design for Circularity:** A central role in creating better clothing products involves the designer and their approach to circularity. Many of the barriers to recycling can be overcome if we make changes to the design process, as this is where a product's ability to be part of the circular system is determined. Circular decisions that can be made in the design phase include the choice of fibres, what materials and components to add, where the item is produced, how patterns are designed, which production processes are included, and the lifespan of the product. A first step is to make it mandatory for all postsecondary institutions with fashion design programs in Canada to adopt a more circular approach to teaching design. Second, is that materials be made widely available to match either the biological or technical product cycle. Ideally, all components are made from the same fibre. For example, if a garment is made from both nylon and polyester, while they are both synthetic, they each require different recycling processes. Finally, we need to be able to identify those materials when they are being disposed, for example, it could be clearly labeled.
18. **Support Wool Spinning and Encourage the Cultivation of Flax and Hemp:** Polyester leads the global fibre demand, so it's not surprising that textiles in the waste stream are primarily polyester. It is one thing to divert polyester textiles from

the landfill, but another to foster polyester recycling. Still, one possibility is not to produce as much virgin polyester and instead encourage the production of alternative fibres. Canada is best suited for hemp and flax, and also offers the opportunity to generate wool. In Canada, wool is mainly a by-product of meat production; hence most farmers throw the wool fleece into waste because the price they can achieve is low and there are not enough opportunities for spinning the material. There is a new global awareness about the need for fibre diversity, which offers an excellent opportunity for these substitutes. We recommend supporting wool spinning, encouraging the agricultural sector to adopt more production of flax and hemp, and conducting further research into alternative fibre production in Canada.

19. **Fund Research on Mycoremediation to Reduce Textile Waste and Create Vegan Leather and Other Products:** For most, mushrooms are just food. However, mycoremediation offers a green chemistry approach to the solid-state bioremediation of textiles, as an additional means to divert textiles from landfills. Fungi are suitable for the aerobically driven catabolic process of waste decomposition, as many produce potent cellulases that rapidly and effectively decompose natural and synthetic fibres into their constituent parts. Furthermore, they offer the opportunity to create vegan leather, which could replace artificial vegan leather, also known as polyvinylchloride (PVC) and polyurethane (PU). Bioremediation of textiles and the production of natural vegan leather is new and combines research on textiles, technology and microbiology. We recommend funding research with mycoremediation as a means to reduce plastic waste.

System Focus – Influencing Habits and Values

It is in our hands to adopt a more proactive and systems-based approach that will truly “close the loop”. In order to ensure fully recyclable textiles, potential barriers need to be detected and new solutions designed.

If every residence in Canada would only own a few garments, textile waste would not be a problem. The massive amount of textile waste results from the overconsumption of cheap clothes, which are increasingly made out of polyester because this is the most affordable fibre available. Garments that are in need of repair are often thrown away because consumers have lost the skill to do even minor repairs, and professional repair services are seen as too expensive compared to the purchasing price of new garments (Goworek, Hiller, Fisher, Cooper, & Woodward, 2013). Other consumers dispose of their clothes because they are bored of them after only several times wearing them (Maybelle, 2015). Textile waste is a symptom of overconsumption, and in order to truly resolve this issue, it is necessary to reduce consumption and foster a society of reuse.

20. **Start a National Debate on Volunteer T-shirts:** During our waste audits we recognized that some product groups have a high potential to end up in the waste stream. The first group are volunteer t-shirts, of which there are a significant amount in the waste stream, with minor signs of use. It seems that people do not see value in these items. We recommend starting a national debate to discuss the need for volunteer t-shirts and fostering alternatives that might be available.
21. **Conduct Research on Reusable Shopping Bags:** Another product group of concern are reusable shopping bags. Ironically these bags were introduced to reduce plastic waste, but the number of bags in perfect condition in the waste stream is shocking. Further research is required if this practice of free multiple-use shopping bags makes environmental sense. Since their production has a higher environmental impact than conventional plastic bags, they only make sense if they are used multiple times. We recommend a consumer survey to gain more insights about the use of these bags.
22. **Retailers Inform Their Customers:** A particular source of waste is unused undergarments. Often these are sold in multi-packs, and customers do not try them on in the store. The customer may recognize that they do not fit at home, and this results in the entire package going to waste. While customers might not have the right to return these garments, they might also not realize that they can be donated, or they may feel uncomfortable doing so. It is not widely known that second-hand retailers in Canada sell used undergarments in their stores. Therefore, the product offering of three undergarments for one price, without a return option, is an incredible source of waste. Fashion retailers should be encouraged to inform their customers on what they can do with the merchandise if it does not fit. In addition, they should be responsible for educating their customers on how to care for garments so they are kept in use for longer, and what to do with them at end of life (i.e., donate for reuse or recycling).

Understanding the need and potential for textile waste diversion, ECCC hired Fashion Takes Action to conduct this broad-scope assessment of pre-feasibility for textile recycling in Canada. With the project sequence of background, waste auditing, technology assessment, semi-structured interviews and literature research, we were able to map out the known data on flows of textile waste in Canada, with an eye to both pre- and post-consumer waste. Taking into account the fairly high degree of assumptions required to formulate pre-feasibility assessment, the study still reached twenty-two strong recommendations that the ECCC can take forward when considering initiatives to reduce, prevent and divert textile waste.

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Appendices

Appendix A: Semi-Structured Interviews with Key Stakeholders

Abate, J (2021). Sustainability Officer at Keilhauer, Toronto ON

Bethell, S (2021). Co-Founder Bank & Vogue, Ottawa ON

Eleiter, A (2021). Co-Founder Debrand, Vancouver BC

Habash, H (2021). Vice President Operations at Goodwill Industries Ontario Great Lakes.

Iida, J (2021). Sustainability Operations Program Manager, lululemon, Vancouver BC

Kasper, D (2021). Vice President, Sales & Product Development, General Recycled, Vancouver BC

Kenney, B (2021). Recycling Development Officer, Nova Scotia Environment, Halifax NS

Krampelj, S (2021). Managing Director, Canadian Kidney Clothes, Kitchener ON

Layfield, D (2021). Senior Manager, Material Solutions at TerraCycle, Philadelphia PA

McLean, M (2021). Manager Sustainability, Innovation & Corporate Waste Management at Canadian Tire Corporation, Toronto ON

Roy, C (2021). Product Development Manager, Duvaltex, Saint-Marie QC

Sahsi, N (2021). Director at Canam International Textile Recycling, Vancouver BC

Shumpert, T (2021). Vice President Reuse & Recycling at Savers/Value Village, Seattle WA

Storry, K (2021). Senior Engineer, Metro Vancouver, Vancouver BC

Thompson, G (2021). VP Corporate Citizenship, Canada Goose, Toronto ON

Zukowski, C (2021). Director of Marketing, Unifi Manufacturing, Greensboro NC

Appendix B: Markham Textile Recycling Program Case Study

In 2016, the City of Markham launched Ontario's first municipally administered textile recycling program. In April of 2017, a curbside ban on textile material was implemented, made possible by the City's clear bag requirement for curbside garbage. A vital element of the textile recycling program is that residents can donate all of their unwanted textile materials – not just material good enough for reuse. This message is significantly different from many other textile diversion programs. Markham has focused intensely on educating its residents about the types of material that be donated for both reuse and recycling.

Before the program launch, the City conducted focus groups with residents to understand their attitudes towards the donation bin industry. Residents expressed several concerns, identifying the poorly constructed plywood boxes dropped behind commercial plazas as eyesores, and complained about a lack of customer service and education as to what could be donated. There was substantial confusion about who the operators of these bins were, and questions about where donated textiles were going. This feedback helped shape the core components of Markham's program, including the use of municipal branding on containers, partnerships with registered charities, the strategic deployment of safe, steel donation bins in high-traffic, well-lit areas and a City-led promotion and education campaign. Markham also invested in developing nine "SMART" bins – shed-style containers outfitted with sensors and solar lighting designed to erase the stigma left behind by the traditional dilapidated plywood donation box. These flagship containers are now located at community centres and fire stations, guaranteeing 24 hours availability at safe locations.

Since the program's launch, Markham has placed more than 160 municipally-branded donation containers at a variety of public and private locations across the City. These containers have helped divert more than 20 million pounds of textile material away from landfill and into the hands of charities, who use the proceeds to support their community programs. In 2020 alone, the City's charitable partners collected 3.5 million pounds of textiles, which is equal to approximately 10 lbs of textiles per capita – all despite the impacts of COVID-19. While the program has performed exceptionally well and has received three major municipal awards, the City is most proud of the awareness it has generated regarding the environmental impacts of 'fast fashion' and the human rights issues that plague the textile industry.

We contacted Claudia Marsales, the Senior Manager of Waste & Environmental Management at the City of Markham, to ask her what was most surprising about the accomplishments of their textile recycling program. Mrs. Marsales responded with a few things that stood out: "Initially, we were overwhelmed with all the donations in the first few weeks following the launch. We never anticipated that there was so much textile material stowed away in our residents' closets. Thankfully, our program partners adapted quickly to the required service levels and provided excellent service now for many years. What I find most encouraging is how much our resident's care about what happens to their old clothing – the way they support this program is incredible, and all of its successes are because of their commitment to a better, greener Markham" (Marsales 2021).

Appendix C: Access to Information Act Annex

This request is in response to your *Access to Information Act* request.

The Canada Border Services Agency is committed to providing the highest level of client service and we would be pleased to assist you with any questions or concerns you may have regarding the handling of your request. You may contact Traci Pantalone at 343-291-6126 or by e-mail at traci.pantalone@cbsa-asfc.gc.ca, using our file number as a reference.

Please refer to the annex for information of the processing of your request.

Yours truly,

Anick Cantin

Team Leader

Enclosures: (2)

Annex

Our File Number	A-2019-10560 / TPANT
Your File Number	
Request Text	I am looking for the most up-to-date and available data from CBSA regarding duties refunded pursuant to the Customs Tariff, sections 109-111 related to Obsolete or Surplus Goods. The same has been summarized in CBSA Memorandum D7-2-3. I would like to know how much refund has been paid out by Canada (in the most recent reporting year available) to individuals or companies for obsolete or surplus goods. I would also like to know the total amount of duties collected by CBSA for imported goods for the same time period, as a means of comparison.
Request Disposition	Disclosed in part
The following line indicates which section of the *Act* was invoked by the Agency if the information was not all disclosed to you.	
Summary of Exemptions	26 The material in the record or part thereof will be published by a government institution
Link to the Access to Information Act	http://laws-lois.justice.gc.ca/eng/acts/A-1/
Comments	The CBSA refunded $8,019,662 by means of the Drawback Program between April 1, 2018 to March 31, 2019 for obsolete or surplus good that met the legislative conditions established in section 109-111 of the Customs Tariff. In addition, for the period noted in the above paragraph, the total amount of duties collected by the CBSA for imported goods is being withheld pursuant to section 26 of the Act as the information is set to be published within 90 days.

Address	Information Sharing, Access to Information and Chief Privacy Office Place Vanier Tower A 333 North River Road, 14th floor Ottawa, ON K1A 0L8

Should you be dissatisfied with the processing of this request, you may file a complaint within sixty days of receipt of this notice to the Information Commissioner of Canada by submitting a complaint in writing or online to:

Office of the Information Commissioner of Canada

30 Victoria Street

Gatineau, Québec K1A 1H3

https://www.oic-ci.gc.ca/en/submitting-complaint

Office of the Information Commissioner of Canada

30 Victoria Street

Gatineau, Québec K1A 1H3

https://www.oic-ci.gc.ca/en/submitting-complaint

Appendix D: Survey Questions

Pre-Consumer Textile Waste Survey for Fibre and Yarn Mills, Clothing Manufacturers and Retailers

The survey was designed for three industry sectors. Below is a summary of the survey questions, but in some instances where the same question was asked of each sector, these have been combined.

Company Profile Questions:

- Are you a Canadian owned company? In which Province/Territory is your headquarters located?
- Is your textile waste kept in Canada?
- About how many full-time employees work at your organization?
- What is your company's approximate annual revenue?

Product Volume & Composition Questions:

- Please indicate the estimated per centage of materials you use (chosen from list)
- What is the highest volume of fibres in your apparel and textile products?
- What fibre blends do you work with most often?
- What products do you manufacture? Type of manufacturing?
- What finishes/treatments do you apply to your products? Check all that apply
- What are the core fabrics you use? check all that apply
- Does your organization currently use recycled fibres or yarn?
    - What % of your product includes recycled content?
    - What is your end product(s) that use recycled fibres or yarn? (check all that apply)
    - How much does recycled fibres/yarn account for your total production (estimated per centage)?
- For each item that you import or purchase locally, indicate the total number of pieces/annual basis.

Textile Waste & Recycling Questions:

- Do you know how much fibre, yarn or fabric/textile waste/excess inventory, damaged and returned products your company generates annually?
    - What do you do with this waste?
- If you are not measuring or monitoring your waste, what are the reasons?
- Do you currently recycle some or all of your textile waste materials?
- Do you sort your waste for recycling? If so how?

    - Where do you send the majority of your textile waste for recycling?
- Do you pay for your textile waste materials to be collected?
    - What is the average price per lb that you pay for collection?
- Have you identified recycling technologies that work for your waste streams and manufacturing processes? Please explain.
- What are the main issues preventing the adoption of zero waste or recycling strategies in your organization? check all that apply
- Do you work with any industry partners/reverse logistics to take back fabric scraps, yarn or garments etc.?
- How significant of a problem is excess inventory for your company due to the COVID-19 pandemic?
- How interested would you be in participating in a textile recycling pilot program?

Broader Circularity Questions:

- Do you develop product using any of the following circular strategies? Check all that apply
- What issues make it difficult to engage in fibre recycling or other circular strategies?
- Does your company have or engage with a zero waste or circularity program (for example, reuse, repurpose, recycle)?
- Do you offer an apparel/textile product take-back program to customers?
    - Who manages your take-back program?
- Does your company have commitments or goals related to apparel and textile circularity strategies?

Follow up Survey: Canadian Retailer Inventory Questions:

- About how many full-time employees work at your organization?
- What is your company's approximate annual revenue?
- What does your company do with broken or damaged products?
- What does your company do with unsold merchandise?
- Would you be interested in partnering with facilities that repair or refurbish broken or damaged products?
- Would you be interested in participating in a textile recycling pilot?
- If you answered yes to either of the above, please provide contact information so that we may follow up with you.

Appendix E: Canadian Textile Mills & Manufacturers Surveyed

A & B Fibreworks

A.R.S. Sport INC.

Adidem

Agent Reclaim

Aimant la vie

Akka (GANTERIE B.C.L. LTÉE (LA))

Alain Piché Collection

Alberta Apparel

ALDO Group

Aleur

Alex S. Yu

Alfred Sung

Allison Wonderland

Amanda Moss

Amaranth Designs

Amazon Sewing

Ametx Yarns

Amplify Apparel

Barcelona Collective

Bare Beach

Bastien Industries

Batik Boutik

Beau Fab Inc

Beauce Jeans

Beaufille

Belinda Visag

BELLANTONI

Bertrand Marois Designer

Birds Of North America

BoiHér

Bonnetier Inc.

Boulay Auvents Camping Inc.

Boutique Mariclod

Brave Leather

Brave Soles

Bridesmaid

Collection Arianne

Collection POINT VIRGULE

Comrags

Conception Citadin 2005 Inc.

Confection Katvin Inc.

Confection NF Denim

Confections C. Cliche INC.

Confections Lamartine Inc. (Les)

Confections Pagar Inc.

Cottonhouse Inc.

Cougar

Création Confort Inc.

Créations Cindy-Ann Inc.

Créations Manon Lortie

Créations Robo Inc.

Créations Stella Mary

Créations Valzère Inc.

CRW Design

Anavi Designs	Briggs and Little	Curve Appeal
Anian MFG	Broderie Aile d'art	Custom Wollen Mills Ltd
Anomal Couture	Broderies Spectra 2003 Inc.	Dagg and Stacey
Anupaya	Brunette The Label	Daub + Design
Apparel Solutions	Bula Canada	Design and Pattern
Arc’teryx	Bully Boy Lingerie	Di Carlo Couture
Ardene	Buttercream	Distribution Emblème Inc.
Arez Couture Inc., My Lbd	C&O Apparel	Distributions Chibou 2010 (Les)
Aritzia	Caffrey Van Horne	Distributions Yvette Laroche Inc.
Arkel Inc.	Caitlin Power	Dorian Who
Arturo Denim	Camille Côtē	Duffield Design
Atelier B	Canada Goose	Duvaltex (CANADA) INC.
Atelier D'Ilathan Inc.	Canada Sportswear	Dynamite
Atelier New Regime	Canadian Service Apparel	e3 Koncept
Attraction Inc.	Canadian Tire Corporation	Eclipse Enterprise D'Insertion
Au Costumes 911	Candace Daniela	Eco Couture
Autoliv Canada Inc	Cansew Inc.	Ecologyst
Auvents St-Laurent	Carmina De Young	Ecolove
Avid Apparel	Casa Como And Design	Eleventh Floor Apparel

Ayam Creation

Azure Lazuli

Bajoue

Ballin INC.

Bano Eemee

Barcelona Collective

Enfin Sports Mode Inc.

Entoilages & Biais Block Ltée

Entoilages Interforme Inc. (Les)

Entreprises Rym Inc.

Envers Design Inc.

Erietta Boutique

Eve Gravel

Excess Design Services Inc.

Fabrication Lori-Michaels Inc.

Faire Child Makewear Limited

Femme de Carrière Inc.

Fibres Jasztex Inc.

Filature Lemieux Inc.

Caulfeild Apparel Group

Cedar & Vine

Centre Industriel De Confection

Chemise Empire

Chemise L.L. Lessard

Christopher Paunil

Harricana By Mariouche

Harry Rosen

Hatley LBH

Hayley Elsaesser

Heirloom Hats

Herschel Supply Co.

High Output Apparel

Highline Apparel

Hilary Macmillan

Hip And Bone

Hoi Bo

Holt Renfrew

Honubelle

Elisa C-Rossow

Eliza Faulkner

Ellegro

Ellie Mae

Empire Clothing Manufacturing

Encircled

Kdon

Kim Nguyen

Kinnear Upholstery (Rembourrage)

Kit and Ace

Kloth Clothing Designs Inc.

Knix

Kollontaï

Kombi Sports Inc.

KOTN

Krane

Kwesiya

L. Davis Textiles (1991) Inc.

L.O.V.E. Bélier

Filspec Inc.

Fine Cotton Factory

Frank & Oak

Frank Lyman Design Inc.

Fred & Bean

Free Label

Frett Design

Friday Sock Co.

Fumile

Funky Buddah Collection

Gaia & Dubos

Gap Canada

Gary Majdell Sport Inc.

Gemine Design

Genevieve Dostaler

Giant Tiger

Gildan Activewear

Giraldof S.E.N.C.

Glatfelter Gatineau Ltee

Gogo Sweaters

House Of Hayla

House of Knot

Hoyden

Hudson's Bay Company

Hugo Sports

Illyria Design

Industries Arctic North Inc. (Les)

Industries Beco Ltée (Les)

Industries Longchamps Ltée (Les)

Industries Majestic (Canada) Ltée

Industries Tek-Knit

Industries Wipeco Inc. (Les)

International Knitting Mills

Intracan Sportswear Mfg. Co. Ltd.

J&J Contracting Cutting

Jax + Lennon

Jennifer Glasgow Design Inc.

Jessica Redditt Design

Joe Fresh

John + Jenn

L'Atelier Marie-Cuir

L'Uomo Strano

La Monarch

La Vie en Rose

Lacets Arizona Inc.

Lamarque

Laura Siegel

Lavoie & Pleau Inc.

Lawrence Scott Inc

Layette Minimome

Le Chevrier du Nord

Le Lin Quotidien

Le Lou Ula

Les Agrès de Pêche ACPG Inc.

Les Ateliers Manutex

Les Ateliers Plein Soleil

Lesley Hampton

Libel Confection et Déco

Lieberman - Tranchemontagne Inc.

Lights Of All

Golden Lion Garment Factory Ltd

Golriz-Design

Granted

Great Canadian Hemp

Gregg Homme

Greta Constantine

Gruven Inc.

Gulf Island Spinning Mill Co-Op

H&M Canada

Joseph Ribkoff Inc.

Jouvence

Joyce Seppala Designs

Judith & Charles

Jules Francisco

Kaela Kay

Karma Collective Apparel Canada

Kate Austin Designs

Katrin Leblond Design Inc.

Linda Morisset

Lingerie Najerika Inc.

Lingerie Patricia

Lionheart Custom Apparel

Little & Lively

Lizzy Wear

Leave Nothing But Footprints

Lois Laine

Lola & August

Lole Women

Londre Bodywear

Louve Montreal

Love & Nudes

Lucie Grégoire Modiste

Lucie St-Georges

Luigi Petrella Tailleur

Lululemon

Lumber Jill Apparel

Lux And Dae

MICHAEL TYLER COLLECTIONS

MICHEL DESJARDINS DESIGN

MICHEL SIPLING

Miik Inc.

Mike Paul Atelier

Mikhael Kale

Mini Mioche

MINI PARALLÈLES (LES)

Mini Street

Minnow

Obakki

Odrea

ODYSSEE 2001 INC.

Oggi

Oh Seven Days

Okay Sport

Olivia Rubens

Ooobaby

ORATEX INC.

Panaashe Organics

Luxton	MIP INC.	Papaya & Co
MacAusland’s Woollen Mills Ltd.	Mirabelli	Parade Organics
MAILLAGOGO INC.	MODE AVALANCHE INC.	Paul Hardy Design
MAISON DE JEAN CRISAN (LA)	MODE ÉZÉ PLUS	Pcp Clothing Inc.
Maison Marie Saint Pierre	Modern Baby	Peace and Cotton
Malika Rajani	Modes A.S.M Inc. (Les)	Peace Collective
MALIS-HENDERSON INC.	Modes Corwik Inc.	Peak Apparel
Malvados	Modes Crystal Inc.	Peerless Garments
Mani Jassal	MODES MUSE INC. (LES)	Perfect Patternmaking
Manufacture de Chapeaux Magill	MODES SOFTWORKS INC. (LES)	Perfection Inc.
Manufacture de Vetements Empire	MOHAIRBEC INC.	Peros Garment Factory
MANUFACTURE FINNIE LTÉE (LA)	MONDOR LTÉE	Petit Velours Confections
Mariclaro	Moulinage des Textiles Industriels 3A	Philippe Dubuc
MARIE SAINT PIERRE DESIGN INC.	Mountain Equipment Co-op (MEC)	Pine Falls Clothing
Marimac Group	MW Canada	Pink Tartan
MAROTEX	My Inner Fire	Piper & Skye
MASTER KID INC.	Myco Anna	Plastifil Inc.

MATERNITÉ DU-DATE INC.

Matt & Nat

Mayer Official

MAYO JO

MÉDI-TOILE INC.

Meemoza

Melanie Jacqueline

MeMi Collective

Mercy House

MÈRE HÉLÈNE INC.

Message Factory

Mettamade

Naked and Famous Denim

Narces

Natalia Baquero

NATURE 3M INC.

Neya Couture

Niko Apparel Systems

Niminimi

Noemiah

Nooks Design

Nudnik

Nygard

Oak + Fort

Power of My People

Prairie Sweater Co.

Preloved

Pretty Denim

Obakki

Odrea

ODYSSEE 2001 INC.

Oggi

OhSevenDays

Okay Sport

Olivia Rubens

Ooobaby

Pro Elvis Jumpsuits

Pro Stitch Garment Services

Productions Extrême

Produits Industriels Pyrotek Inc.

Progoti

Pur Inc.

Purple Moose Sock Company

Shefford Textiles Ltée

Shelli Oh

Shilango

Shirt Fit

Sid Neigum

Silk Laundry

Simons

TOGES ERIKA ERIKSSON INC.

Tony Chestnut Design

Top Marks D.B.A.

Triarchy

Tribal Fashion

Tricot Bains Inc

TRICOTS BAINS ENR.

Pya Importer

Qimmik Canada Inc.

Quartz Co.

Racine Carrée 4

Radley Prep

Raffinalla TMA

Rainbow Jeans

Rayonese Textile Inc.

Redwood Classics

Regitex

Reitmans Canada Ltd.

Rentex Mills Inc.

RespecTerre

Rock n' Karma

Roopa Knitting Mills

Roots Canada

Rudsak

Ryu Apparel

S. Cohen Inc.

S.H. Custom Tailor Inc.

Simplifi Fabric

Simply Merino

Smash & Tess

Snug As A Bug Inc

Soia & Kyo

Sokoloff Lingerie

Source My Garment

Sous-Vêtements U.M. Inc. (Les)

Sous-Vêtements Yves Martin Inc.

Sport Cartise Inc.

Sportchief

Sporting Life

Sprout Collection Ltd.

Standard Trade Denim

Starkers

Start Concept Apparel Ltd.

StedFast

Stormtech

Strong And Free

Sugoi

TRICOTS DUVAL & RAYMOND LTÉE

TRICOTS LELA INC. (LES)

TRICOTS NADER

TRICOTS PARISIENS LTÉE

TRICOTS TERRYTEX INC.

Trimark Sportswear

TYR SPORT

Uguu Apparel

Unbelts

Uncle Studios

Uncuffed

Uniform Handmade

UNIFORMES LOFT INC. (LES)

Unika

UNIQUELY GALIANO

Unttld

Uptick Apparel

Utility Garments

VALÉRIE DUMAINE INC.

Vancouver Yarn

S.P. Badu

Saint Lyon

Saltwater Collective

Sanibel Vétements et Accessoires

Sans Soucie Textile + Design

Sanskar

Sarah Sue Design

Sarah Sue Maclachlan Design

Sarina Fashion

Saxx Underwear Co.

Seaway Yarns Limited

Second Denim

Secrets du Style (Les)

Seine River Shepherds

Selfish Swimwear

Sérigraphie Nationale Inc.

Sessa Wearables

SGS Sports Inc.

Sweet Hollows Designs

Sympli - White House Design

TAMGA Designs

Tanya Batanau Design

Taproot Fibre

Tatum & Olivia

TAVAN & MITTO

Tentree

TÊTU-TÊTU

Textiles Monterey

The Good Tee

The Saltwater Collective

The Sleep Shirt

Thief & Bandit

TISSUS GEO. SHEARD LTÉE (LES)

TJX Canada

Tmr Collection

Todoruk Designs

VÉRONIQUE MILJKOVITCH

VERSATILE PAR AJAMIAN INC.

Vertical Suits

VÊTEMENTS DE CUIR ANGORA INC.

VÊTEMENTS OÖM MODE ÉTHIQUE

VÊTEMENTS PEERLESS INC.

Vintex

Wallace Playford

Watson Gloves

Wee Woollies

Whitney Linen

Wool 4 Ewe Fiber Mill

WS and Company

Wuxley Movement

Yoga Jeans

Zvelle

Appendix F: Technology Readiness Level Chart

Technology Readiness Level	Phase	Details
TRL0	Idea	Idea: Concept not proven, and no experiment has been conducted
TRL1		Basic research: The needs are described, for the moment without proof of feasibility
TRL2		Technology formulation: Concepts and applications are formulated and described
TRL3		Need for validation: An objective has been formulated and the stakeholders are following
TRL4	Prototype	Prototype on a reduced scale: Prototype in the laboratory.
TRL5		Almost full-size prototype: Prototype in use environment
TRL6	Validation	Prototyping of the system: Testing in a real environment, performance close to target
TRL7		Demonstrator: The technology works in a real environment and is in the pre-commercial stage
TRL8	Production	Complete and qualified system: The technical and commercial processes are qualified and tested.
TRL9		Marketed system: Technology available to customers

Appendix G: Pellenc ST Test Results

Test # 1: Separation between 100% Polyester vs 100% Cotton

Negative fraction: Polyester

Positive fraction: Cotton

Test # 2: Separation between 100% Polyester + PU Logo vs 100% Polyester

Negative fraction: Polyester

Positive fraction: PU Logo vs 100% Polyester

Test # 3: Separation between Cotton <60% vs Cotton> 60%

Negative fraction: Cotton <60%

Positive fraction: Cotton> 60%

Test # 4: Separation between Cotton <40% vs Cotton> 40%

Negative fraction: Cotton <40%

Positive fraction: Cotton> 40%

Test # 5: Separation between Black Polyester vs Black Cotton

Negative fraction: Black Polyester

Positive fraction: Black Cotton

Appendix H: Overview of Current & Potential End Market for Fibersorted materials - Textile to Textile Recycling

Organization	Location	Output	Uses
A.S.T.R.I	Prato, Italy	Yarn, Fabric	Clothing (Weaving, Knitting)
Advance Non-Woven	Roende, Denmark	Non-woven	Insulation; Construction
AKSA	Taşköprü, Turkey	Fiber	Clothing; Household Textiles; Outdoor; Industrial Uses.
Altex Textil Recycling	Gronau, Germany	Fibre	Insulation; Automotive; Geotextile; Drainage
Ambercycle	Los Angeles, US	Pellets	Yarn; Fabrics; Clothing
Antex (EcoAntex)	Angles, Spain	Yarn	Clothing; Automotive; Decoration
Aquafil (Econyl)	Arco (Trento), Italy	Yarn	Fabrics; Clothing
Artistic Milliners	Karachi, Pakistan	Fabric	Clothing (Denim)
Asahi Kasei (Bemberg)	Nobeoka City, Japan	Yarn	Continuous filament non-woven; Yarn
Belda Lloréns (EcoLife)	Alicante, Spain	Yarn	Clothing
Birla Cellulose	Madhya Pradesh, India	Viscose Yarn	Clothing
BlockTexx	Manly, Australia	Pellets, Fibre, Cellulose Powder	Yarns; Fabrics; Cosmetics; Pharmaceutical; Food
Bonded Logic	Arizona, US	Non-woven	Insulation, Acoustical Products

Brightloops	Amsterdam, Netherlands	Garment	Knitting (sweaters)
Cardato	Prato, Italy	Yarn; Fabric	Clothing (Weaving, Knitting)
Chain Yarn	Taichung City, Taiwan	Chip; Yarn	Clothing (Sportwear; Ski; Fashion)
Circ	Virginia, US	Pulp; PES	Yarn for Clothing
COM.I.STRA	Montemurlo (Prato), Italy	Yarn; Fabric	Clothing (Weaving)
Culp Contract	North Carolina, US	Fabric	Clothing; Upholstery
Dunya Tekstil	Catalca-Istanbul, Turkey	Fibre	Open-End Yarn Manufacturing; Paper Pulp; Medical Bleached Cotton, Various Medical Products; Felt; Furnishing; Automotive
ETS H. Moncorgé	Cours la Ville, France	Fibre	Automotive, Clothing, Construction, Furnishing, Geotextile
European Spinning Grp	Rekkem, Belgium	Yarn	Denim; Knitwear; Workwear; Towels; Tents
EVRNU	Seattle, US	Fiber	Yarn; Fabrics; Clothing
Far Eastern (FEFC eco)	Taiwan	Yarn	Clothing
Fast Feet Grinded	Susteren, Netherlands	Rubber; Foam; Fibre	Playground or other sports flooring, Footwear, Geotextiles
FENC (TopGreen rTex)	China	Fabric; Garment	Clothing
Filatures du Parc	Brassac, France	Yarn	Knitting; Hosiery; Weaving; Upholstery; Carpeting; Handknitting yarns.

Flyleather - Nike	Hilversum, Netherlands	Fabric	Shoes
Formosa (Sunylon)	Taiwan	Chip; Yarn	Carpets
Frankenhuis	Haaksbergen, Netherlands	Fibre	Automotive; white goods; drainage; felt; insulation; acoustic panels; office partitions
Fulgar (Q-NOVA)	Mantua, Italy	Fibre	
Geetanjali Woollens	Mumbai, India	Fibre; Yarn; Fabric	Clothing; Woven Fabrics
Giotex	New York, US	Yarn	Clothing (Weaving, Knitting)
Hilaturas Arnau	Barcelona, Spain	Yarn; Fabric	Clothing (Weaving; Knitting)
Hilaturas Ferré (RECOVER)	Banyeres de Mariola, Spain	Yarn	Clothing (Weaving, Circular and Flat Knitting); Home textiles
Hilaturas Jesús Rubio	Barberà del Vallès, Spain	Yarn	Clothing; Accessories; Home textiles; Automotive upholstery
Hivesa Textil SL	Alicante, Spain	Fibre, Yarn, Non-wovens	Geotextiles, Insulation, Blankets, Filling, Non-woven fabrics.
HKRITA (Garment2Garment)	Tsuen Wan, Hong Kong	Garment	Clothing
HKRITA (Novetex)	Tai Po, Hong Kong	Fibre	Yarn; Fabrics; Clothing
Hyosung (Regen™)	Seoul, South Korea	Chip; Yarn	Yarn; Fabrics; Clothing
Infinited Fiber	Espoo ,Finland	Yarn	Fabrics; Clothing
Ioncell	Helsinki, Finland	Yarn	Yarn for Clothing
Ioniqa	Geleen, Netherlands	Pellets; Chip	Packaging; Bottles; Clothing

Iris Textiles	Guatemala City, Guatemala	Yarn; Fabric	Weaving
ISKO (R-TWOtm)	Bursa, Turkey	Yarn; Fabric	Weaving; Clothing (Denim)
Jeplan	Tokyo, Japan	Flake, Resin, Yarn, Fabric	Fabrics; Clothing
Kishco	Mumbai, India	Fibre	Open-end yarns & shoddy fibres; Non-wovens
Leigh Fibers	South California, US	Fibre	Acoustic Insulation; Automotive
Lenzing (Refibra)	Lenzing, Austria	Yarn	Fabrics; Clothing
Loop Industries	Quebec, Canada	Resin; Fibre	Packaging; Bottles; Clothing
Marchi & Fildi (Ecotec Trademark)	Biella, Italy	Yarn	woven textiles for clothing, upholstery, jersey knits, flat-knitted products, hosiery, carpeting
MartexFibe	Charlotte, US	Fibre	Non-woven; Filling; Yarn manufacturing
MPO Recycling	Berghem, The Netherlands	Fibre	Insulation; Automotive; Geotextile; Drainage; Plastic Sector
Navarpluma (NEOKDUN)	Arazuri, Spain	Down	Bedding/ Clothing
Nilit (EcoCare)	Migdal Haemek, Israel	Yarn	Fabrics; Clothing (Outdoor; intimate apparel, legwear, active, ready-to-wear)
North American Wool Stock	Montreal, Canada	Fibre	Automotive; Insulation; Floor, furniture, mattress Padding; Home Insulation; Stuffing for Sports Equipment; Sound Deadening
Nurel (RecoNylon)	Zaragoza, Spain	Fibre; Yarn	Clothing (Sportwear; Swimwear; Underwear)

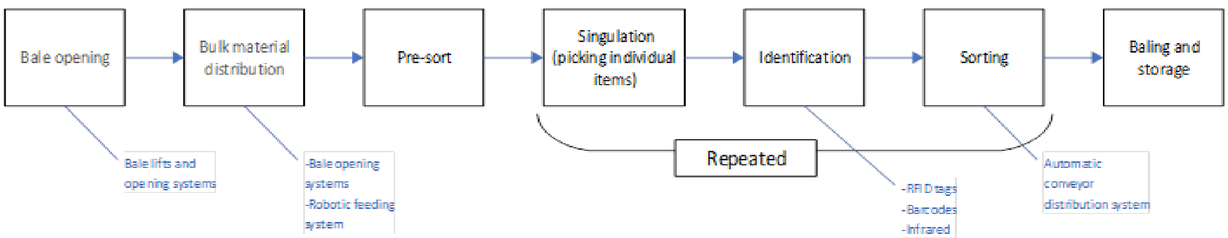
Osomtex	Oregon, US	Yarn, Fabric, Garment	Knitting (socks); weaving; felt. Reformation partnership
Premiere Fibers	Virginia, US	Yarn	Apparel; Hosiery; Seamless; Flags & Banners
Procotex	Dottignies, Belgium	Fibre	Automotive, matress, geotextile, insulation, drainage, composite.
PureLoop	Ansfelden, Austria	Pellets	Yarn; Fabrics; Packaging; Pipes
Purewaste	Helsinki, Finland	Fabric, garment	Clothing (Weaving, Knitting)
PurFi	US JV with Concordia Textiles in Waregem, Belgium (2020)	Non-woven; Yarn; Filament; Other products	Non-wovens (Personal care; Baby Wipes; Medical; Household; Industrial); Yarns & Filaments; Performance Wear; Industrial Wear; Tiles & Composites; Paper & Packaging
PWO Industries	Johor, Malaysia	Fibre; Yarn	Automotive, Wiper Cloths, T-Shirts, Gloves
Re:Down	Lyon, France (Also service USA and Asia)	Down	Filling (Garment, Homeware); Insulation; Fertilizers
Re:Mix	Gothenburg, Sweden	Pellets; Fibre	-
Re:Wind (Mistra Future Fashion)	Stockholm, Sweden	Viscose filaments; PES monomers	Clothing
Re.Verso	Prato, Pistoia, Macerata, Italy	Yarn, Fabric, Garment	Knitting
Really	Copenhagen, Denmark	Non-woven	Acoustical products; Solid textile boards

RECYCLEATHER	Kowloon, Hong Kong	Leather Fabric	Clothing; Upholstery; Architecture
Renewcell	Stockholm, Sweden	Pulp	Yarn; Fabrics; Clothing
RISE (The Regenerator)	Gothenburg, Sweden	Pulp and pellets	Yarn for Clothing
Robert Levy	Fresse sur Moselle, France	Fibre	Spinning, Filing and Non-Wovens
Rohdex	Unterschleissheim, Germany	Down	Clothing; Apparel
Saxion (SaXcell)	Enschede, Netherlands	Fibre	Yarn; Fabrics; Clothing
Södra	Mörrum, Sweden	Pulp	Yarn; Fabrics; Clothing; Bedding
SOEX Recycling Germany	Ahrensburg, Germany	Fibre	Products for other industries
SOGE International	Plaine Magnien, Mauritius	Fibre	Yarn manufacturing, Automotive, Mattress
Soprana - Filati e Tessuti Tecnici	Biella, Italy	Yarn; Fabric	Clothing (PROTECTIVE and SPORTS); FILTRATION fabrics; TECHNICAL END USES.
Spanflex®	Yilan County, Taiwan	Yarn	Clothing
Tesma Cashmere	Montemurlo (Prato), Italy	Fibre; Garment	Clothing (knitting)
Texcar	Italy	Fabric	Carpet; Upholstery; Canvas paintings; Bags
Texloop-Circular Systems	California, US	Yarn; Fabric	Clothing + other by-products.
Textil Santanderina	Cabezón de la Sal, Spain	Yarn; Fabric	Clothing (Weaving)

The Brickle Group	Rhode Island, US	Fibre	-
Toray (CYCLEAD TM)	Tokyo, Japan	Fibre	-
Unifi (Repreve)	North Carolina, US	Yarn	Apparel; Outdoor Gear; Accessories; Hosiery; Flocking; Footwear; Automotive; Medical Accessories; Industrial Gear
Usha Yarns	Punjab, India	Yarn	Knitting (Clothing; Hosiery) ; Weaving (bed sheets, blankets, denim, shirts and suiting) ; Specialty Yarns
Velener Textil GmbH	Velen, Germany	Yarn	Clothing; Workwear
Vicente Barber Belda	Valencia, Spain	Fibre	Open-End Yarn Manufacturing; Geotextiles; Mattress; Shoe filling
Volcat (IBM)	San Francisco, US	Polyester powder	Clothing; Packaging; Others
Wageningen University	Wageningen, Netherlands	Elastane monomers	-
Wolkat	Tilburg, Netherlands & Tanger, Maroc	Fabric, Non-wovens, Products	Products; Mattresses; Others (Woven fabric and Non-woven Collections)
Woolagain	Rhode Island, US (1 facility US, 1 facility India). Division of The Brickle Group	Yarn, Fabric	Weaving, Knitting (Hand knitting; Sweaters; Hats; Gloves; Scarves; Socks; Outerwear; Blankets; Shoes; Handbags; Belts; Rugs; Pillows; Window treatments)
Worn Again	London, UK	Pulp and pellets	Yarn; Fabrics; Clothing

Appendix I: Semi-automatic Sorting Processes

Manual sorting-grading can be assisted using mechanical equipment for critical steps of the operation in order to increase the overall yield and quality. A general process flow diagram for a manual sorting-grading operation is shown below, as well as automated technologies that may be involved at the various steps. Brief descriptions for each step and the associated technologies are given below:



Adapted from (WRAP, 2014)

Some materials' shipments will arrive in bales. This requires removing straps, loosening the compacted material and feeding the sorting line. An automatic bale opener can perform most of these steps, which are otherwise labour-intensive. The material can be further distributed to manual pre-sort or sorting stations automatically by a robotic suspended rail (Valvan Baling Systems, n.d.). Each manual station is equipped with a bulk reserve placed on a scale. The robot will stash incoming material and distribute it to the stations that register a low reserve. Overall, this system allows staff to remain at their post and focus solely on sorting without having to refill their reserve.

A pre-sort step is essential in larger sorting-grading operations, to prevent undesirable items from contaminating or blocking the sorting line. Then, singulation is performed to allow for the proper identification of individual items. This step is particularly important when a scanner is involved downstream, and should prevent items from overlapping each other on the conveyor belt. This can be achieved manually or mechanically, for example though the use of a metering drum.

There are many sorting criteria for which human senses are the only option, but some decisions may be accelerated, with increased accuracy, through the use of infrared scanners that can detect colour and material type. It may be used to provide high quality feedstock to markets that rely on fibre characteristics, such as wipers and rags (WRAP, 2014). RFID and Barcodes can be embedded with all information available upstream from the sorter-grader, such as manufacturers, retailers and thrift stores. Relevant information could include brand, material type, date of manufacture, retail value, origin, etc.

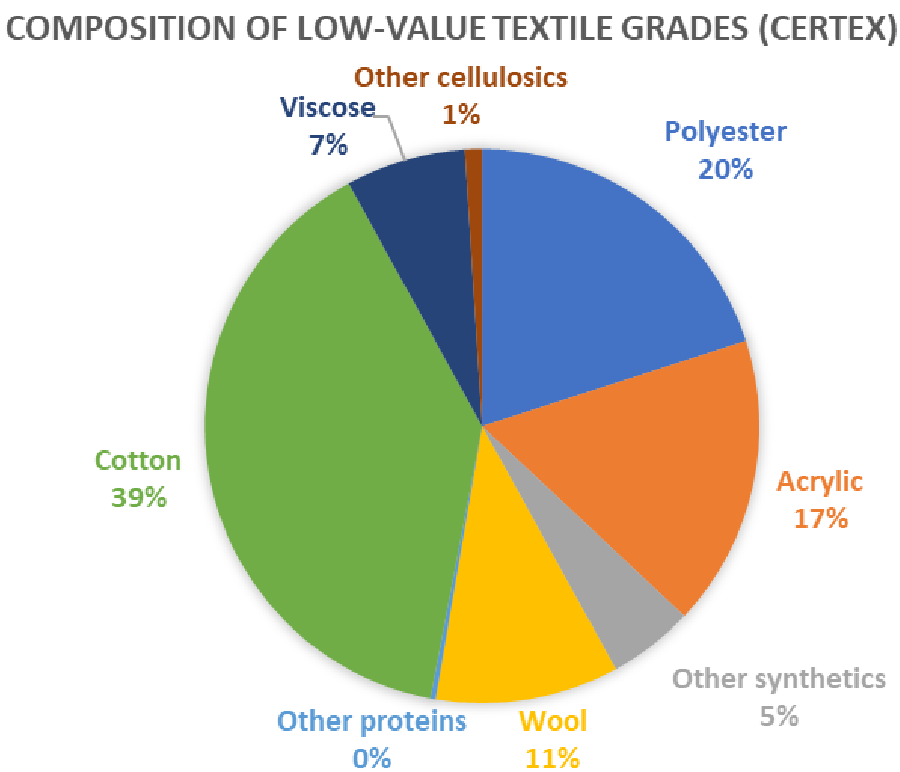
Sorting and stockpiling material into hundreds of grades requires a lot of space and material handling when done manually. Automatic conveyor distribution can be used to optimize this step. Each item is first identified at manual sorting stations, then the operator types in a code corresponding to the item category on a keypad, drops the item on a conveyor belt, directing the item to the proper pile (Automation System, 2021) . This system is used in large warehouses in combination to a barcode or RFID scanner system. This approach could theoretically be used for textile recycling, provided that each item is fitted with a tag that would allow for an automatic categorization of the item.

Appendix J: Low-value Grades and Rejects from Manual Sorting

Post-consumer apparel grading is done with a relatively high precision level and attention to criteria such as:

- Garment type (men's shirt, blouse, etc.)
- Size and gender
- Fabric type (cotton, blend, synthetic)
- Colour
- Brand
- Style (vintage value)
- Age (how old is the item)
- Quality (presence of stains, wear or rips)
- Fibre strength or absorbency (for rags and wipers)
- An overall appreciation for the value of each item (depending on market demands)

A manual sorting-grading operation is aimed primarily at selling materials to export markets for reuse. Rejects from such operations, as well as lower-value grades that may not always be in demand, constitute a mixed material stream that could be suitable for further processing and recycling. Work done at Certex demonstrated that certain material grades could be created specifically for the purpose of feedstock to recycling markets (Mercier, 2018). In this typical North American operation, up to 20 per cent of sales (in weight) could undergo sorting based on fibre types, in proportions that are summarized in the figure below. Of this total, 51 per cent of items are single material, while 49 per cent are made of a blend of fibres. 47 per cent of all items were also contaminated with buttons, zippers and other non-textiles and require pre-processing before being recycled.



Adapted from Mercier, 2018

Appendix K: Communication with Jason Johnson from Allertex

Jason Johnson, Technical Sales & Business Development Director

ALLERTEX OF AMERICA, LTD

336-906-6581

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Tearing Line for Post Consumer Wastes – Laroche

Includes cutting, tearing on 6 cylinders EXEL 15000, cleaning of metals, plastics, bale press and air filtration

Price: 1 420 000 EUR FCA Cours la Ville, including supervision of installation and start up

Installed power: 580 KW

Operators: 2

Capacity: 1200 kg/hr

Airlay Line Flexiloft 2400 – Laroche

Includes blending line with 3 feeders, blending feeder, double EXEL 2000 opener, metal detector Airlay Flexiloft 2400, air filtration

Price: 1 170 000 EUR FCA Cours la Ville, including supervision of installation and start up

Installed power: 300 kW

Operators: 2

Capacity: Up to 1400 kg/hr (depends on product gsm)

Needlepunch Line - Andritz

Price: 65 000 EUR

4.5 meters 60mm stroke with 1200rpm speed with suction and blowing

Installed power: 105 kW

