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PROJECT REPORT

Flows of Polyester Textiles in Zwolle and Surrounding Areas

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INTRODUCTION

In September 2022 a group of 5 Global Project and Change Management students from Windesheim were assigned a research project by the foundation Natuur en Milieu Overijssel. This research project was coordinated through the client representative Ilse Postma, project employee of the foundation. Natuur en Milieu Overjissel helps coordinate the circular craft network WaardeRing, an organization committed to giving materials a new life in a high-quality manner. In alignment with WaardeRing's mission, the material in discussion and subject of this report is polyester textile.

With textiles, the majority of which being polyester textiles, becoming an increasingly large polluting waste stream worldwide, it is important to understand how this material can be re-used and processed in the most sustainable and circular way possible.

As such, the team was tasked with gaining insight into how polyester flows through the network of stakeholders in Zwolle, after a post-consumer textile enters the system. This is done to determine ways in which this system may be improved, to minimize or eliminate its potential negative environmental impacts in the Netherlands and abroad.

For the completion of this task, the flows of post-consumer textiles in Zwolle were mapped and the sorting and processing techniques these textiles undergo explored.

Likewise, to understand whether these processes were good practices or not, research was conducted into the current solutions being explored both in the Netherlands and globally.

After this understanding was achieved, recommendations on how Kringloops could improve their current practices were given and steps to achieve this were outlined.

Finally, the report offers a critical reflection and further outlook.

THE TEAM

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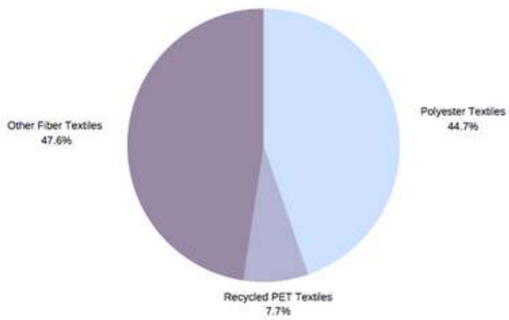
BACKGROUND OF THE ISSUE

This section gives an overview of what polyester textile is and the environmental issues it represents.

Polyester, also referred to as polyethylene terephthalate (PET) is a synthetic fiber primarily derived from crude oils, from which ethylene and terephthalic acid are extracted and refined. It is then put through a process of condensation to form ethylene terephthalate units, which are linked together to form polyethylene terephthalate, and compressed into pellets to sell. The pellets get melted and spun into filaments. These filaments are then combined into different types of yarn depending on the product. The yarn is then knitted or weaved into fabric that is then cut and sewn together to make garments (Palacios-Mateo, 2021).

In 2020, there were around 109 million tons of textiles produced worldwide, about 52.4% of which were made up of polyester (PET) textiles (Opperskalski et al., 2021). This equates to about 57.1 million tons of PET textiles. Of that 57.1 million, 8.4 million tons were recycled. Figure 1 depicts this data in the pie chart as 7.7%, whereas the 44.7% represents non-recycled textiles. Moreover most of these recycled PET textiles are produced from PET bottles, as opposed to post-consumer textiles.

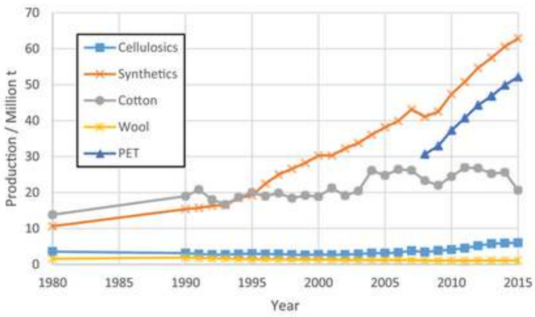
Figure 1
The Global Textile Production % 2020



In the innovative solutions developed to process polyester discussed in this report, it is stressed how difficult it is to recycle used polyester garments into new ones, to reach a truly closed loop value chain. According to Muthu and Gardetti (2020) the huge quantity of produced, and consequently disposed of, textiles are mainly a response to population growth, higher living standards, and the rapid rotation of trends in the fashion industry.

According to Janssen et al. (2020), in recent decades, the global production of polyester (PET) textile has increased. Between 1980 and 2007, when polyester overtook cotton as the dominant fiber in the world, the amount of polyester rose exponentially. The reason the use of polyester is so widespread is due to the material's economic viability and its physical properties. Polyester textile is easily washable, UV resistant, easily dyeable, and can be mixed with other types of fibers (e.g., cotton) to strengthen the fabric, and usually extend its lifespan.

Figure 2
Global Fiber Production from 1980 to 2015



The textile industry is not only one of the largest industries in the world in terms of production and employment, but also one of the most polluting. This industry pollutes through its use of water, chemicals, energy, and so forth (Bhatia et al., 2017). Polyester in particular, causes a vast number of environmental problems throughout its lifecycle.

The mixture used in the process of making polyester comes from a non-renewable fossil fuel resource, which is trapped within different rock layers deep underground, meaning that crude oil needs to be extracted through drilling and pumping. This consumes energy and heavily disrupts ecosystems in the surrounding areas. Additionally, throughout many different stages, harmful toxins that contribute to global warming and air pollution are produced and can be released if not controlled properly. Furthermore, thousands of different harmful chemicals are used in the dying, washing, and finishing processes of textiles. In addition, almost every mechanical force causes microfibers to detach from textiles. These in turn, are released into the air ending up in different ecosystems. For example, when polyester textile is laundered, these microfibers end up in the sewage from the laundry wastewater. Many countries use sewage sludge as crop fertilizer. This in turn causes polyester microfibers to be found all throughout the food chain, leading to health problems (Palacios-Mateo, 2021). The Netherlands incinerates its sewage sludge for energy recovery, which in this case partially combats the issue, however the toxins from these microfibers remain a risk factor to keep in mind.

As for the end of the life cycle of polyester textiles, which is more focused on in this report, several processes may occur. Polyester textiles can be recycled, reused, incinerated, or may end up in landfills.

In 2018, in the Netherlands 305,100 tons of textiles were discarded, of which only 44.6% were sorted. After sorting, out of the 44.6%, 53% were sold for reuse, 33% were recycled, and 14% was incinerated. This signifies that the majority of the textiles were unsorted, and thus treated as general waste and incinerated. Although these figures are not polyester specific, they serve as a good representation of how textiles tend to be handled.

Figure 3
Pie Chart of Sorted and Unsorted Textiles in the Netherlands

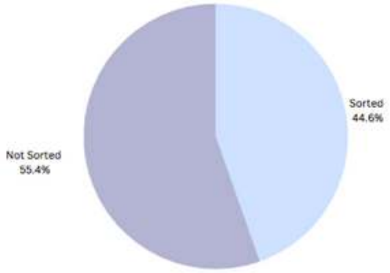
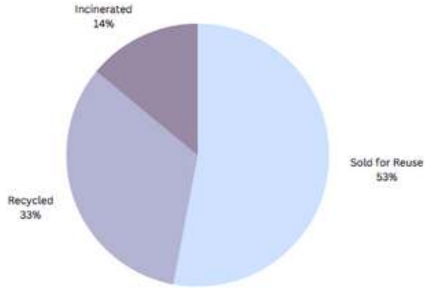


Figure 4
Pie Chart of Destinations of Sorted Textiles in the Netherlands



When incinerated, polyester produces toxins which are environmentally hazardous and threatening to human health. The damage of disposing of waste in landfills is also significant. Landfilling causes the release of many greenhouse gas emissions, as well as the contamination and pollution of soil and waterways. The Netherlands is one of the few countries which has already officially stopped disposing of waste in landfills. This waste is now incinerated or recycled instead (Palacios-Mateo, 2021).

COMMON METHODS OF RECYCLING

This section of the report aims to provide background knowledge on common recycling methods, in which a distinction between mechanical and chemical recycling is made.

The main challenge posed to textile recycling is the fact that the composition of most textiles is mixed, so they are made from a blend of both natural and synthetic fibers. The most common type of mixed textile is polycotton (a mix between polyester and cotton). Therefore, a variety of different steps are necessary to properly recycle these textiles.

Depending on the composition of the fabric blend, it can be recycled via chemical or mechanical recycling. The aim of both is to recover fibers, which can be spun into yarn, and in turn be used to create new textiles.

Mechanical and chemical methods of recycling are described in the following subsections.

Mechanical Recycling

Mechanical recycling can be used for textiles made from cotton or wool. These fabrics are shredded for further processing to separate the individual fibers.

The problem with this method is that it causes the shortening of the fibers, which significantly reduces their quality. To obtain a yarn of sufficiently good quality through mechanical recycling, an additional proportion of new cotton or wool fibers must be added. After this addition, virgin materials usually make up 60-80% of the composition of the new material. This means that the intended effect of saving raw materials in the recycling process is not entirely achieved. For this reason, wool and cotton are often only downcycled into insulation, heating materials, cleaning rags or fillers (Dissanayake & Weerasinghe, 2021).

Mechanical recycling is likewise used to produce new polyester textiles made from polyethylene terephthalate (PET).

In most cases, if the label on a piece of clothing says that it is made of recycled polyester, it means that it was made from high quality recycled PET, old car tires, and occasionally from plastic waste from the ocean. In other words, post-consumer polyester textiles are not involved in the recycling process. This is because polyester is oftentimes a blended fabric, which cannot be processed through mechanical recycling, as polyester cannot be extracted from the blend, and thus returned to its original state.

For PET to be recycled into polyester, the PET is shredded, cleaned, heated, and stretched into textile fibers. It is then spun into polyester yarn and can be reused for clothing (Malik et al., 2016).

Chemical Recycling

Chemical recycling is a process in which clothing made of synthetic materials, such as polyester, are shredded and broken down into their base monomers using chemicals, and then processed into new polyester fibers.

In order to present the process of chemical recycling, the following explanations refer to the article published in 2020, written by Suntinger for the ‘Innovation Origins’ journal, called “Recycling breakthrough for clothing made with polyamide”.

Polyamide (PA) is a synthetic, technically usable thermoplastic. PA has good chemical resistance to organic solvents, is easy to process, and has a high wear resistance. Polyamide’s properties come from the hydrogen bonds that are created by the amide groups. PA is mainly used in the textile industry for clothing, but also for fishing lines, ropes, parachutes, and sails (Domininghaus, 2012).

Polyamide is used in clothing to make textiles stretchier and more durable. Additionally, other fibers, such as cotton or wool, are added to increase the comfort of the article of clothing. These mixed fibers in clothing are difficult to recycle as they are usually spun together into the yarn, making separation difficult. Previous attempts of separation were unsuccessful, due to the severe damaging of fibers to the point where they are too short to be spun again.

In the approach the article describes, the polyamide is dissolved, and the wool/cotton can easily be broken down back into their original fibers. With this technique there is only a minimal reduction in fiber length. This approach introduces the opportunity to recover wool and cotton by dissolving the polyamide they are frequently mixed with.

Research is being conducted on a mixture where calcium ions can break the hydrogen bridges between the polymer chains, allowing the attractive forces between the polymer chains to be lowered. In this way, polyamide can be dissolved without the use of toxic organic solvents.

LOCAL FLOWS OF TEXTILES

This main chapter gives insight into the local textile flows in Zwolle and the surrounding area.

At the beginning of the project, the team was given a set of contacts of stakeholders that were relevant to the textile industry and could have helped in the exploration of the topic of polyester processing within the Overijssel context. As such, one of the first steps taken in the process of researching this topic was the contacting of each stakeholder in order to arrange interviews.

During the interviews with the stakeholders that the team was successful in getting in contact with, new stakeholders would come up in discussion, creating a snowball effect. This process led to the interaction with, or research of, the stakeholders introduced below.

Disclaimer

The initial task was to track the flows of polyester textile. However, a trend that can be observed in all the following information provided, is that there is little to no polyester specific information. This is because the majority of the stakeholders operating in Zwolle do not concern themselves with treating polyester as a separate textile stream, as there is no reason to do so. For the moment, approaches to processing polyester are not cost-effective at a large scale.

Likewise, it is important to mention that the textile flows can no longer be tracked after a certain point. In most cases, with the current ways of operating and levels of transparency that companies provide, the journey of a textile garment can only be tracked up until it is sold abroad, upon which information on its further journey is lost and unclear.

Introduction of the Stakeholders

KringCoop

KringCoop is a national recycling cooperative that supports its members in organizing the sorting processes, the sale of various textile sub-streams, and innovation in the field of textile recycling. In addition, the cooperative is developing a web-based registration system to register the various sub-streams and to report these transparently (KringCoop, n.d.). Kringloop Zwolle is a part of this cooperative. An interview was conducted with Jos Habets (head of KringCoop) on 21.10.2022.

Textile Sorting Center (Kringloop Nieuwe Deventerweg)

The Textile Sorting Center, also known as the Kringloop at Nieuwe Deventerweg, is part of the Stichting Kringloop foundation. This center has two main goals: to limit waste streams by reusing products and raw materials, and to provide those further away from the labor market with employment. (Kringloop Zwolle, n.d.) Being true to its name, the Textile Sorting Center is responsible for the sorting of all textiles that are then sold in local Kringloops in Zwolle. The project team's contact person was Lian Meesters (head of the Textile Sorting Center), through which a tour of the Textile Sorting Center was arranged on 5.10.2022.

NLD used garment recycling B.V.

LD is a clothing collection company that purchases, sorts, and packages wearable post consumer textiles, to ship them abroad (to European and African countries) to be sold at secondhand markets (NLD, n.d.). NLD was contacted upon finding out about their partnership with the Textile Sorting Center, but obtaining further information was not possible.

Sympany

Sympany is one of the largest textile collectors in the Netherlands, that collects and sorts textiles into various streams. They partner with a network of stakeholders to undertake reuse and recycling initiatives (Sympany, n.d.). Unfortunately, arranging an interview with Sympany was not possible, forcing the project team to rely on online sources for information.

ROVA

ROVA is one of the largest household waste collection companies in the Netherlands. They are working together with 23 municipalities to arrange the collection of waste, manage outdoor spaces, and provide them with information on waste, raw materials, sustainability, and circularity (ROVA, n.d.). In terms of the processing of textiles, ROVA engages in the collection and sorting of textiles, along with their main sorting partner (ReShare). The team held an interview with Marjolein Mann (a policy advisor for ROVA) on 16.11.2022.

ReShare

ReShare is a branch of Salvation Army (Leger des Heils), that collects, and sorts used textiles, in order to sell them in secondhand stores and process unwearable clothing in ways that promote sustainability and circularity. Similarly, to Stichting Kringloop, ReShare offers people with distance from the labor market employment opportunities (ReShare, n.d.).

Wieland Textiles

Wieland Textiles focuses on three core activities, which are the purchase and sorting of post consumer textiles, the sale of sorted textiles to buyers within the Netherlands and abroad, and the development of innovative initiatives to help the company achieve these activities (Wieland Textiles, n.d.). Although the team often circled back to Wieland throughout the research process, and contacted various members of the company, a reply was unfortunately not received in the time span available for the project.

Ducky Dons

Ducky Dons collects used feather and down pillows and duvets and uses them to make new products. The feathers and down are used as stuffing for new duvets and pillows, whilst the cover material of the used pillows and duvets are reused in various ways, for example as insulation material (Ducky Dons, n.d.). The team was successful in setting up an interview, which was held with Nick van Nieuwenhuizen on 17.10.2022.

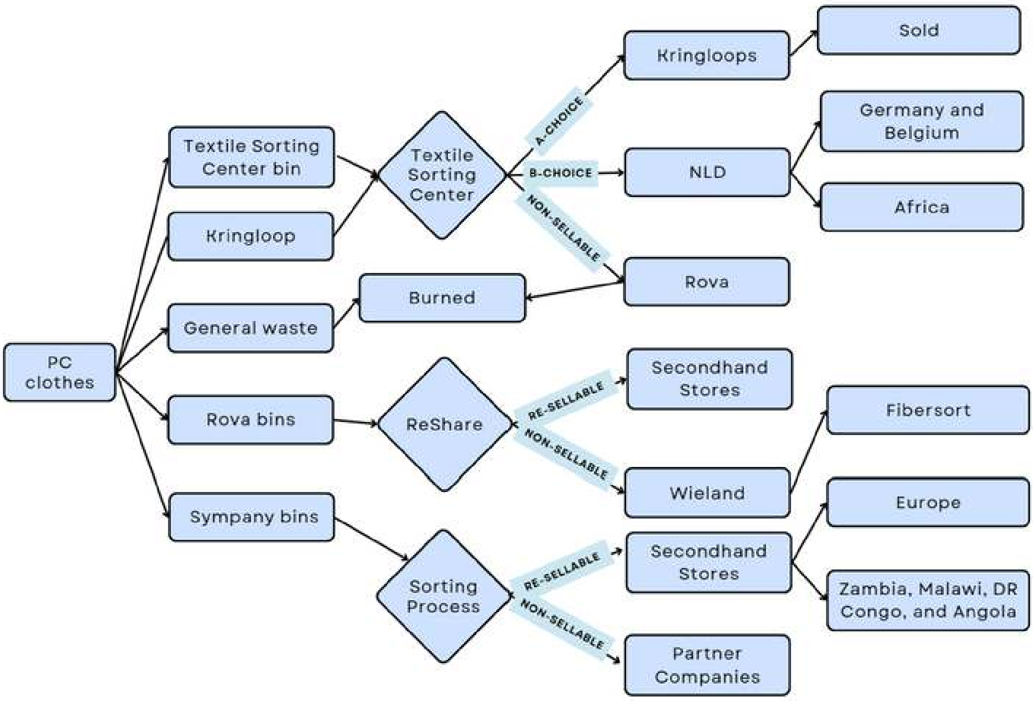
Frankenhuis

Frankenhuis is a textile recycling company that carries out several types of services. These services include: the conversion of PC textiles into fibers, the recycling of clothing and textiles received from businesses, confidential recycling of textiles, and the involvement in both regional and European initiatives in the field of textile recycling and circular thinking (Frankenhuis, n.d.). The team was unable to set up an interview with Frankenhuis, as they were busy moving facilities during the duration of the project.

IKEA Zwolle

IKEA is a global furniture company which was considered a stakeholder because of the company's usage of large amounts of polyester in its bedding and upholstery products. The team reached out to the local store in Zwolle, to understand if a focus on recycling polyester was currently present within the company. Although some information was obtained from the 12 Sustainability Leader of the local branch, an interview to further discuss things could not be arranged.

Map of Local Flows



Journey of a Textile Garment

This section aims to describe the journey that a textile garment makes when the consumer wants to get rid of it within the Zwolle context, depending on the choices the consumer makes.

When the time comes, a garment may be disposed of according to the following scenarios:

1. The garment may be taken to a local Kringloop (e.g., Nieuwe Veerallee)
2. It may be taken to the Textile Sorting Center (Kringloop Nieuwe Deventerweg)
3. Dropped in a ROVA textile container
4. Dropped in a Sympany textile container
5. The garment may be thrown away as general waste

In the first two cases, the textiles will first go through the sorting process at the Textile Sorting Center.

Textile Sorting Center

Clothing sorted in the Textile Sorting Center get sorted into three streams:

1. A-choice textiles: Clothing gets sold in Kringloops.
2. B-choice stream: Clothing is packed into bags and shipped in a container to European countries (such as Germany and Belgium), to be sold at secondhand markets. This occurs after the clothing is sold to NLD, a company that sorts and packages clothing that is suitable for reuse and shipment elsewhere. According to an agreement made between NLD and the Textile Sorting Center, the clothing purchased by NLD and shipped abroad stays within Europe.
3. Non-sellable: Clothing is thrown away via ROVA containers.

According to Lian Meesters (head of the Textile Sorting Center), the non-sellable stream makes up 4% of all processed textiles monthly. However, it is unclear whether this 4% is disposed of via a general waste ROVA container or a textile ROVA container.

Rova

If one were to drop their article of clothing into a ROVA textile container, it would take the route described below.

Once the textiles are collected from the containers, they are sorted at ReShare, a branch of Salvation Army (Leger des Heils) and ROVA's main sorting partner. The textiles are sorted into two categories: re-sellable and non-sellable.

Non-sellable clothing gets sent to Wieland facilities, in which it is sorted according to the material it is made from, and color, using their Fibersort technology (more in-depth information about this process can be found in the 'Dutch processing approaches' section).

Re-sellable clothing gets sold at secondhand stores or sent to alternative buyers (ROVA, n.d.- a). Unfortunately, this is the extent to which re-sellable clothing can be tracked with the information available, as which stores/buyers are sold to are not specified.

According to Marjolein Mann, currently, no information regarding the composition of the textiles that are collected is available. As such, polyester follows the same journey as the rest of the textiles and may only be separated from other textiles during the sorting process of non sellable textile, if deemed necessary by the sorters.

However, as stated by Marjolein Mann, ROVA collects between 4,5 to 5,5 million kg of textiles every year within the Netherlands through ROVA containers. Based on the statistics provided by Janssen et.al (2020) and Opperskalski et.al. (2021) that 52.4-60% of global textiles are polyester, the team estimates from the textiles that ROVA collects yearly, 2,3 to 3,3 million kg are polyester.

Sympany

Sympany collects textiles via containers and through door-to-door collections. The latter process is arranged through their partnership with Climpex.

Similarly to ROVA's process, the clothing is sorted according to whether it is re-sellable or non sellable. Re-sellable clothing is sold to secondhand stores/markets in Europe (Sympany, n.d.-a) and Zambia, Malawi, DR Congo, and Angola (Sympany, n.d.-b).

Non-sellable clothing is processed in various ways, according to which partner this task is undertaken by, as Sympany partners with a variety of companies that work in different ways (e.g., spinning fibers or making insulation and acoustic panels (Sympany, n.d.-c).

Alternative Pathways

Ducky Dons

Receives a few tons of synthetic duvets a month without having requested their donation, as the company has not found a way to process synthetic duvets in an appropriate and relatively non-expensive way. Within Zwolle, Ducky Dons receives duvets from The Textile Sorting Center and Sympany.

However, Ducky Dons is currently working on pilot projects in hopes of addressing the issue of processing these synthetic duvets, by looking into both chemical and mechanical methods of recycling and trying to determine what partner would be most suitable for the job.

IKEA Zwolle

Polyester is not treated as a separate waste stream, as separating it from the residual waste stream is not cost-positive. However, used upholstery covers (some of which are made of polyester) can be brought in by customers and disposed of at the container (Stoffenbak) at the entrance of the store. It is unclear, however, what percentage of these covers are polyester textile and what happens to the covers after they are disposed of at the container.

Frankenhuis

As those associated with Frankenhuis could not find the time to meet with the project team, the only input available to the team was the information that could be found online. According to this information, Frankenhuis recycles non-wearable post-consumer and industrial textiles by fiberizing these textiles (Twente, 2017). Clients can also request fibers of a specific composition to be made, either from Frankenhuis' collection of raw materials, or their own textiles. Several types of fibers are given as an example, which are: cotton, jean, acrylic, and polyester (Frankenhuis, n.d.-a).

Other than textiles being brought in by businesses, it is not entirely clear where these textiles are procured from. It would seem that the collection part of the process is executed by other members of the Boer group (which Frankenhuis is a part of), such as, Curitas and Fashion to Fibers, which then send non-wearable textiles to Frankenhuis after sorting (Boer Groep, n.d.). However, it is unclear whether their collection points are available for consumers living in Zwolle.

ALTERNATIVE APPROACHES

In this section, alternative options for the end-of-life cycle of polyester textiles are presented. These are wide-ranging and include recycling, sorting and downcycling approaches, along with possible substitute material options.

Dutch Processing Approaches

There are various companies and organizations located in the Netherlands that work on solutions regarding polyester sorting and/or recycling, and are the most well-known and advanced in their technologies. Nevertheless, these companies are still quite young and are still working on improving and upscaling their practices. For this reason, it is difficult to find a lot of detailed information about the companies mentioned below. Along with their practices, a new upcoming law will also be discussed.

UPV (Uitgebreide Producenten Verantwoordelijkheid)

The UPV law, is an upcoming Dutch legislation which is planned to be implemented by the 1st of January 2023. This law would obligate textile producers to become responsible for the collection, sorting, recycling, reuse, and waste processing of products they bring onto the Dutch market. In most cases, this obligation would take the form of monetary liability. Although 2023 is the official date by which the law will be enacted, the companies have until 2025 to start concretely reporting on the changes they want to implement and the results they plan to provide (Modint, 2022).

Wieland

Valvan Baling Systems and Wieland Textiles launched Fibersort on March 14th, 2018. Within the Fibersort project, Valvan Baling Systems lead the design, engineering, software development, and construction of the Fibersort machine. This optical sorting technology enables the quick and efficient scanning and sorting of numerous stacks of garments into uniform categories of fibers with specified compositions, colors and/or structures. Up to 45 textile categories can now be sorted, which consist of combinations of 15 color types and 15 types of fiber.

This is a cost-efficient recovery of highly valuable raw materials from discarded garments for the production of new clothes. As of 2022, Fibersort can upcycle 170,000 tons of discarded garments into valuable raw materials for new clothes. Fibersort can sort 900 kilos of post consumer textiles per hour. Likewise, Wieland Textiles invests in trim-clean technology, which makes it possible to remove buttons, zippers, and labels yourself.

Wieland Textiles and Valvan Baling Systems are joining forces with other frontrunners in the textile industry to develop a new manufacturing industry based on raw materials from discarded textiles. This network is developed as part of the Interreg North-West Europe project 'Fibersort: closing the loop in the textiles industry'. Their main product is PCC (Post Consumer Clippings). These discarded garments are used as feedstock for a circular textile industry (Innovatie: Fibersort, 2022).

CuRe chemical recycling

In Emmen a pilot polyester recycling factory wants to recycle any type of used polyester, including colored polyester or mixed polyester (which are more difficult to recycle compared to virgin polyester). The factory wants to convert these materials into clear pellets with the same properties as virgin grade polyester. Together with Morssinkhof, Cumapol, DuFor, and Niaga, in close collaboration with NHL Stenden University, they discovered a smarter and scalable solution to create a fully circular polyester chain. They recycle any type of used polyester by purifying it and converting it into high-grade, ready-to-use 100% rPET which can replace PET from fossil-derived sources. Following their successful lab scale experience, a pilot plant has been built in Emmen for rapid scale-up. The pilot plant has a capacity of 20 kg/h in a continuous process. As soon as the CuRe Technology is validated and tested, there will be the possibility for 25 kta (kilo tons per annum) of textiles to undergo being processed in Emmen. The project team had email contact with CuRe and the company stated that they are currently reviewing all the steps in their technology with many kinds of feedstock to validate the necessary processes (CuRe, 2022).

Rouwmaat Group

Rouwmaat is specialized in making an alternative fuel from non-recyclable films, synthetic clothing, and rugs. In most cases, these materials are not recyclable because they consist of a composite of different types of plastics. These plastics are considered undesirable by regular waste incineration plants because they raise the temperature in the ovens too much. However, Rouwmaat can produce fuel grains out of these waste streams for ovens in the cement and chalk industry, who require very high temperatures to begin with. The material here serves to replace lignite/brown coal and enables these ovens to achieve the desired temperatures (Rouwmaat, n.d.).

Sympact

Sympact founded by Sympany, Paul Burst and Michel Walstock, develops and implements new circular products and concepts, based on non-wearable textile waste. They use the fine characteristics of materials like cotton, polyester, or acrylic, and combine these with existing materials. This combination can be used in all kinds of applications, such as building materials, floors, wall material, fences, roadblocks, acoustic panels, and furniture. Every product they develop is made of recycled material and is ready for recycling again. The design and choice of material is geared to this (Sympact Solutions, 2022).

Fibritell (Kringcoop)

In an interview, Jos Habets mentioned Fabritell. These are scanners that can scan textiles and show the percentages of different materials of which they are composed. As of 2022, Kringcoop is conducting pilots with two scanners

Global Processing Approaches

After looking into different processing techniques and pilots existing in the Netherlands, the project team decided to investigate options present outside the Dutch scenario. These are all seen as possible contributors to more sustainable methods of processing polyester textiles and are presented in the following section.

Wiping Rags

In research from Piribauer and Bartl (2019), when the re-use of textiles is not economically feasible, or the clothing has damages that are not economically viable to be repaired, cutting the clothing down to cleaning and wiping rags is seen a possible recycling operation. This is not an ultimate solution and ranks very low in terms of the waste management value chain. However, in Germany, there is already a standard for the production of recycled wiping rags, where only cotton, half-linen, and viscose materials that are blended with a certain amount of synthetic fibers, are considered. Another downside to this process is that polyester only plays a minimum role in the final product. Although recycled wiping rags are in competition with newly produced ones, at times with a price of up to 2 €/kg, it can be more valuable to produce wiping rags opposed to exporting the used textile abroad for example. It is however often labor intensive and expensive to create wiping rags from used textile. Therefore, their production is limited, depending on the market price of wiping rags at a determined moment and the current labor costs in the country where they are produced.

PLA & Lyocell (PL) as a Substitute to PET & Cotton Blends (Polycotton)

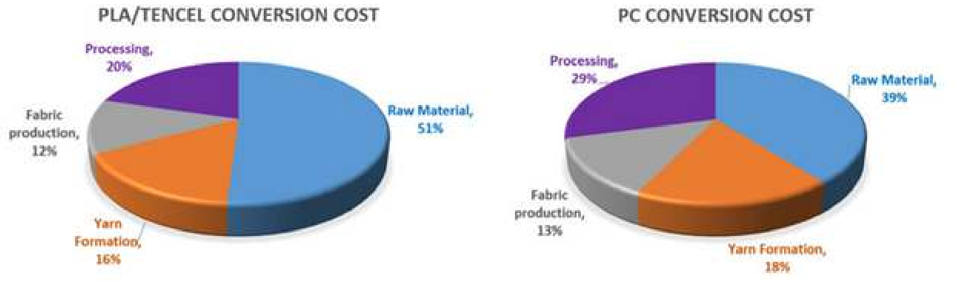
According to research conducted by Jabbar et al. (2019), the polylactic acid (PLA) and lyocell fibers blend can offer a good alternative to the commonly employed blend of polyethylene terephthalate (PET) and cotton fibers in textiles. As mentioned in the background of this report, PET fiber is non-biodegradable, depletes fossils fuels, and adds to landfill sites. In addition, conventional cotton requires large quantities of water and pesticides in its production. These facts potentially make substituting PLA & lyocell blends for polycotton blends an interesting alternative.

Lyocell is a solvent spun fiber from wood pulp and is considered to be a sustainable fiber because of replenished feedstock (sustainable managed forests), biodegradability and >99.5% organic solvent recycling efficiency during the fiber production. Furthermore, lyocell is comparable to cotton due to its absorbency power and high dry and wet tensile strength.

PLA on the other hand, is a thermoplastic aliphatic compostable polyester, derived from renewable resources. These recourses include corn starch in the United States, tapioca roots, chips or starch in Asia, or sugarcane in the rest of the world. The world PLA market, by revenue, in 2017 was valued at US $698 million, but is expected to attain US $2,091 million by 2023 with packaging and fibers being the key areas of application.

When comparing the two blends economically, despite PET and cotton blends still being cheaper in terms of raw materials and given their higher global market share, it is interesting to mention that in the yarn formation of cotton, fabric processing costs are higher, compared to PLA & lyocell blends, according to the actual cost calculations taken from a local textile mill in Pakistan and presented in Figure 6 below. Prices are likely to still vary over time and geographical location. In line with the principle of economies of scale, the price difference between PL and polycotton blended apparels could be reduced as the production demand increases for PL blended fabrics. For example, organic articles, which are more expensive than normal articles, are still preferred by certain consumers. Furthermore, there is a growing awareness amongst consumers to buy sustainable products, and as such, consumers may be willing to pay the price premium due to the environmental benefits, as well as the better/competitive performance properties.

Figure 9
Local Cost Comparison Chart of Fibers and Yarns



TEX2MAT

The TEX2MAT project is a FFG (Austrian Research Promotion Agency) promoted project, conducted by a consortium of 13 research institutions and private businesses that offers a solution for material recycling. The goal of TEX2MAT is to develop an innovative process for the material recycling of selected multi-material textile streams. Polyester and cotton blends were the focus of the TEX2MAT project, looking for a viable way to truly "close the loop" by creating new high-quality textiles.

To recycle blended fabrics, the fiber materials have to be separated and one of the two needs to be eliminated. There are chemical reactions that can remove certain fiber materials; however, there is always the potential for unwanted side reactions, and many of the needed chemicals are potentially harmful to the environment. A possible solution to this is the use of enzymes.

Using this approach, cotton can be converted into glucose and polyester into polymers and can thus be recycled relatively easily. The obtained glucose can be used as a raw material for different platform chemicals. Platform chemicals are defined as chemicals that can serve as substrates to produce various other higher value-added products. TEX2MAT successfully demonstrated the functionality of this entire processing chain by the complete removal of cotton from textiles and the weaving of new towels with recycled polyester.

Figure 11
TEX2MAT Chemical Recycling Machine

In terms of upscaling possibilities, within the project, the reaction volume per batch had the possibility to be increased from 1 l to 60 l, which is a significant improvement. However, to operate the process at an industrial scale, there is still optimization work to be done. For example, the chemicals used in the pre-treatment and hydrolysis would need to be re-used multiple times to create a truly environmentally friendly process. This is also where the main limitations to scale-up are found. For the hydrolysis process itself, only a slightly agitated low temperature vessel is needed, in which the textile hydrolysis would take approximately a day. The investment and operation cost for enzymatic hydrolysis is estimated to be quite low compared to membrane separation for removal and re-use of the enzyme. The same is true for the purification of the used pre-treatment solutions or the mechanical presses used in the pre-treatment steps. While the development of the industrial process is not finished yet, it can be said with confidence that the process finally opens the door for a significant change in textile waste management by providing an ecological solution for one of the most important textile waste fractions.

Scandinavian Recycling Companies

Research by Chan et al. (2020) explains how Sweden, Finland, and Norway (referred to in this case as Scandinavia) are on the frontline of textile recycling processes. The research they performed analyzed successful Downstream Mixed Textile Recycling (DMTR) processes concerning the recycling of PC (post-consumer) textiles that have blended fabrics. In the following section, 5 different companies from Chan et al.'s research, deemed to be the most valuable in terms of polyester textile recycling specifically, are presented.

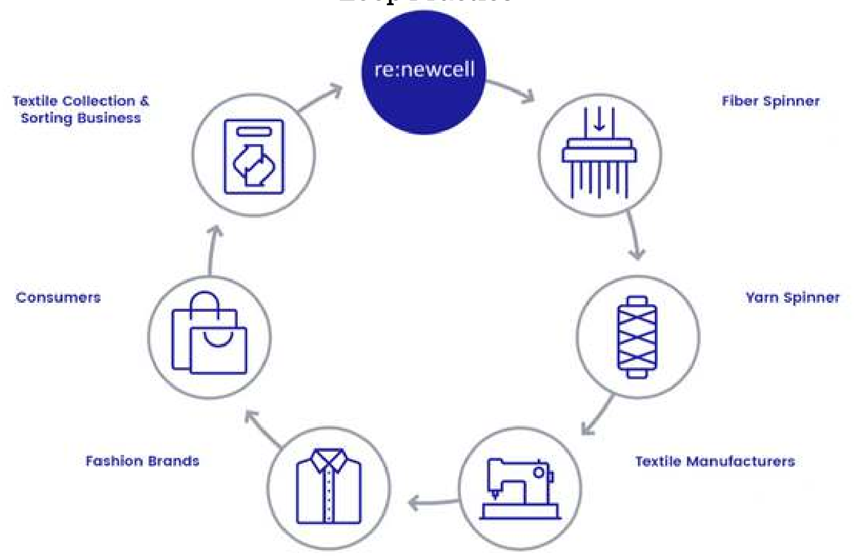
Re:newcell

Re:newcell is a Swedish company founded in Stockholm in 2012, based on the principle that decomposing cellulose is the key in recycling textiles. In 2017, they opened their first pulp production plant in Kristinehamn, which can produce up to 7000 tons annually. The production at this plant is a demo that can potentially be upscaled to 30.000 tons in the future. Re:newcell produces pulp that is called Circulose, which is made from PC cotton or high cellulosic garments. The production plant runs on 100% renewable energy, from wind and hydro energy. The PC garments that arrive in Kristinehamn are mechanically treated to separate the buttons and zippers. The textile remainders are then shredded, decolored, and degraded into a cellulose sludge, for which no virgin material is needed. The decoloring is done by dissolving the dyes with a reductive. Afterwards, bleaching is used to remove the remainders of color that are still present in the textiles. 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.

Cotton has a high cellulose content, which is needed to produce Circulose. Therefore, clothing with a high cellulose content is favored in the recycling process. The cellulose sludge is converted into Circulose pulp by drying the sludge. The produced Circulose material is sold as either pulp or fibers, from which brands can produce garments. Re:newcell does not collect or sort PC textiles, but they collaborate with collection and sorting companies like Sympany. From these collectors and sorters, they need a PC textile stream with a cellulose (cotton or viscose) content of over 98%. This is one of the downsides of the company in terms of the project teams' research, as Re:newcell is not an entirely polyester focused company.

In terms of quantity, Re:newcell prefers incoming textiles to be delivered twice per month in batches of 5 metric tons at minimum.

Figure 12
Re:Newcell's Position in the Textile Recycling Industry as a Closed Loop Practice



Pulp is pushed through a fiber spinner to form the fibers, that then form the base for the new textiles. The fibers are combined then to produce yarn, which are converted into textiles at the textile manufacturers.

The recycled fabrics are then bought by fashion brands that sew garments out of the Circulose fabric. Consumers buy the garments, discard them, and via collection and sorting companies they can end up at Re:newcell to be recycled again. After production of Circulose garments, it is possible to recycle them again, which closes the loop. So far, H&M has produced a garment in their Conscious collection made from Circulose material produced by Re:newcell.

With Re:newcell the energy consumption is 50%-100% less than the production of virgin cotton. In addition, the process is completely circular and does not add virgin input materials. This is all very positive, however, a significant limitation to this company is the fact that the input textile needs cellulose at 98%, such as cotton or viscose, making it a less interesting solution when focusing more prevalently on polyester. However, the company has stated that they plan to focus more heavily on polyester in the future. Furthermore, for Re:newcell's processes to be carried out, at the moment there is no economic benefit. Re:newcell has had a loss of 242.9 euros/ton. It must be considered that Re:newcell has said that they expect to become profitable in the coming years.

Södra

Södra is a Swedish company founded in 1938 in Skogsudden, and are the founders of a textile recycling project called OnceMore. Globally, OnceMore is the first recycling technique that can recycle mixed PC textile streams on a large scale. Mixed polycotton textile streams are used for this recycling technique. OnceMore can separate the cotton from the polyester present textiles. Different methods are applied in this process, depending on whether polyester or cotton is the desired end product from a polycotton blend. In the case of OnceMore, the cotton is needed for the recycling process, causing the polyester fibers to be depolymerized or dissolved. The cellulose pulp produced from trees in OnceMore's forests, is mixed with the retrieved pure cotton fibers from the polycotton separation. This cellulose pulp is called dissolving pulp and is produced from birch trees. From these trees, the cellulose fibers are separated from the other wood elements. The raw material produced using the OnceMore technique is of high quality and is used to produce textiles.

Figure 13
OnceMore – A Textile Raw Material Made to Close the Loop

The recycling process takes place at their pulp mill in Mörrum, where they processed 20 tons of PC textiles in the autumn of 2019. They are still working on a decoloring technique, which means at present they can only recycle white textiles. Furthermore, they are exploring opportunities to fulfil the aim of recovering a stream of polyester residual products. They are looking for companies that can provide Södra with sorted textile streams, either cotton, polycotton blends, viscose, or lyocell. 20 tons were processed in 2019, generating an output of 400 tons of pulp. The target for the future is recycling 25.000 tons of PC textiles annually and to be able to recycle all PC textile streams. Unlike Re:newcell, OnceMore has a profit of 2,557.31 euros/ton. However, for their processes to occur they use a lot of energy and to recover recycled textiles large quantities of virgin polyester are needed.

Telaketju

Telaketju is a Finnish project that is being organized on a national scale. It aims to gather the most efficient techniques and more advanced knowledge in the field of textile recycling by involving around twenty different stakeholders and covering the whole recycling chain. TouchPoint and Fibersort are two of the stakeholders from Telaketju that will be presented in more depth, as they seem to be the most promising. These two companies cover a variety of processes and can thus provide a broad overview of the different types of stakeholders within Telaketju.

TouchPoint

Touchpoint is a Finnish recycling company that oversees collection and sorting. Once sorted, it transforms disposed PET bottles and PC textiles into workwear pieces for the employees of different companies. The pieces produced are composed of polyester or mixed polyester fabrics. However, a requirement for the recycling technique is a composition of 98 to 100% of the same fabric. There is not extensive information on how exactly this supposedly low emission and carbon-neutral workwear is created.

RESTER

A sister company of Touchpoint is RESTER which was established in July 2019. Touchpoint collaborated with this company in 2021 on the project to build a textile recycling facility in Paimio, Finland. This was the first project where Touchpoint included PC textiles for recycling. They currently accept clean, dry, and sorted end-of-life textiles from companies and side flows of production. The received material consists of cotton, polyester, cotton-polyester, wool, polypropylene and mixed materials. As of 2020 this recycling plant was able to process up to 6,000 tons of textiles per year. Rester's facility is a modern mechanical recycling plant. During the process first buttons, zippers, etc. are removed from the textiles. After that textiles are cut into patches and textiles are mechanically opened to fibers. During the process, textile grades can also be mixed so that whichever the desirable outcome is can be achieved. From Rester recycled fiber yarn, different kinds of nonwoven materials like insulation, acoustics panel, filter fabric and composites can be manufactured. Unfortunately, for the moment being, no transparent information about the cost efficiency of Rester's processes is available.

NextChem

The DEMETO project was co-funded by the European Union under the Horizon 2020 program, with NextChem as coordinator of a consortium of 14 partners. NextChem completed construction of the first demonstration plant in Italy for the chemical recycling of PET and polyester from textiles. The plant is located in Chieti, in the Abruzzo Technology Park. The depolymerization technology adopted, based on the reaction of alkaline hydrolysis with the use of microwaves, allows the plant to chemically recycle PET and polyester textile fiber waste and obtain pure monomers to produce new polymers. NextChem is the developer and co-licensor of the depolymerization technology, owned by the Swiss start-up Gr3n, as well as the designer and constructor of the plant. Various types of materials, including polyester-based textile fibers, will be tested in the plant, which is capable of recycling almost 100 per cent of the incoming material, amounting to one million kilograms/year. This technology could contribute to the solution of some unresolved problems in textile waste recycling, such as mixed fibers. NextChem is convinced that this technology will contribute to improve a circular economy model on an industrial scale and claim this process is the first feasible and sustainable economically, environmentally and socially, industrial application of chemical treatment for reuse of PET/polyester waste streams.

The T-REX (Textile Recycling Excellence)

In October 2022, a consortium of 12 partners launched a new European Union (EU) funded three-year project to create a circular system for post-consumer textile waste. The project brings together 12 major players from across the entire value chain and research institutes, to create a harmonized EU blueprint for closed-loop sorting and recycling of household textile waste. Over a three-year period, the T-REX Project will collect and sort household textile waste and demonstrate the full recycling process of polyester, polyamide 6, and cellulosic materials from textile waste into new garments. Simultaneously, the project aims to demonstrate sustainable and economically feasible business models for each actor along the value chain, conduct lifecycle analysis of the circular process, integrate digital tools that streamline the process of closed-loop textile recycling, and produce circular design guidelines. Veolia will lead 24 the post-consumer textile waste collection, sorting and division to work with the feedstock needs of the respective textile recycling technologies of Infinited Fiber Company, BASF, and CuRe Technology. The recycled fibers will be converted to yarn by European manufacturers Linz Textil and TWD Fibres, from which Adidas for example will create demonstration products which have end of life recycling in mind (The T-REX, 2022).

CONCLUSION

Ideally, the issue that polyester presents should be addressed at the beginning of its lifecycle, when it is produced. As mentioned in the background, the reason why there is so much textile waste to begin with is due to the huge quantities of clothing fast fashion companies produce from cheap materials like polyester, and consequently the amounts consumers buy and dispose of. Therefore, ideally fast fashion companies would need to shift their approach. Beyond reducing the amount fast fashion companies produce, they should also be more conscious of producing multi-material textiles, as these are difficult and laborious to recycle. Therefore, in the ideal future, multi-material textiles should be reduced or avoided altogether. The textile and apparel industry should keep in mind a 'design for recycling' approach and consumers should be made aware of the consequences of purchasing multi-material textiles.

However, as presented in the 'Alternative approaches' section, the processing of polyester textiles at the end of their lifecycle can be approached in several ways. As these approaches are generally considered to be expensive on a large scale, information from Chan et al. (2020), proposes that to make these private companies profitable, the introduction of a bonus malus system based on extended producer responsibility (EPR) should be considered. A system like this could allow a profit-orientated operation of recycling processes and could therefore raise collection rates, and subsequently also recycling rates by making their implementation economically feasible. Such a system would also encourage the further development and application of novel recycling techniques. Furthermore, this would also facilitate the rise of innovative high-tech companies on the market like some of the ones mentioned in this report.

Based on the team's understanding of the local flows of polyester the following scenarios of changes that could be implemented are presented below.

SAMPLE OF A TEXTILE FLOW

In a Co-creation session held on 5.12.2022, the results of the previous sections were presented to the client and discussed. During the session, the client asked for a sample flow of a what an improved flow for polyester textile would look like, in the local scenario of Zwolle.

Scenario 1

The first ideal scenario would entail the Textile Sorting Center in Zwolle to sort the textiles they receive into only two streams: sellable and non-sellable. In other words, the B-choice stream would be eliminated and partnership with NLD terminated.

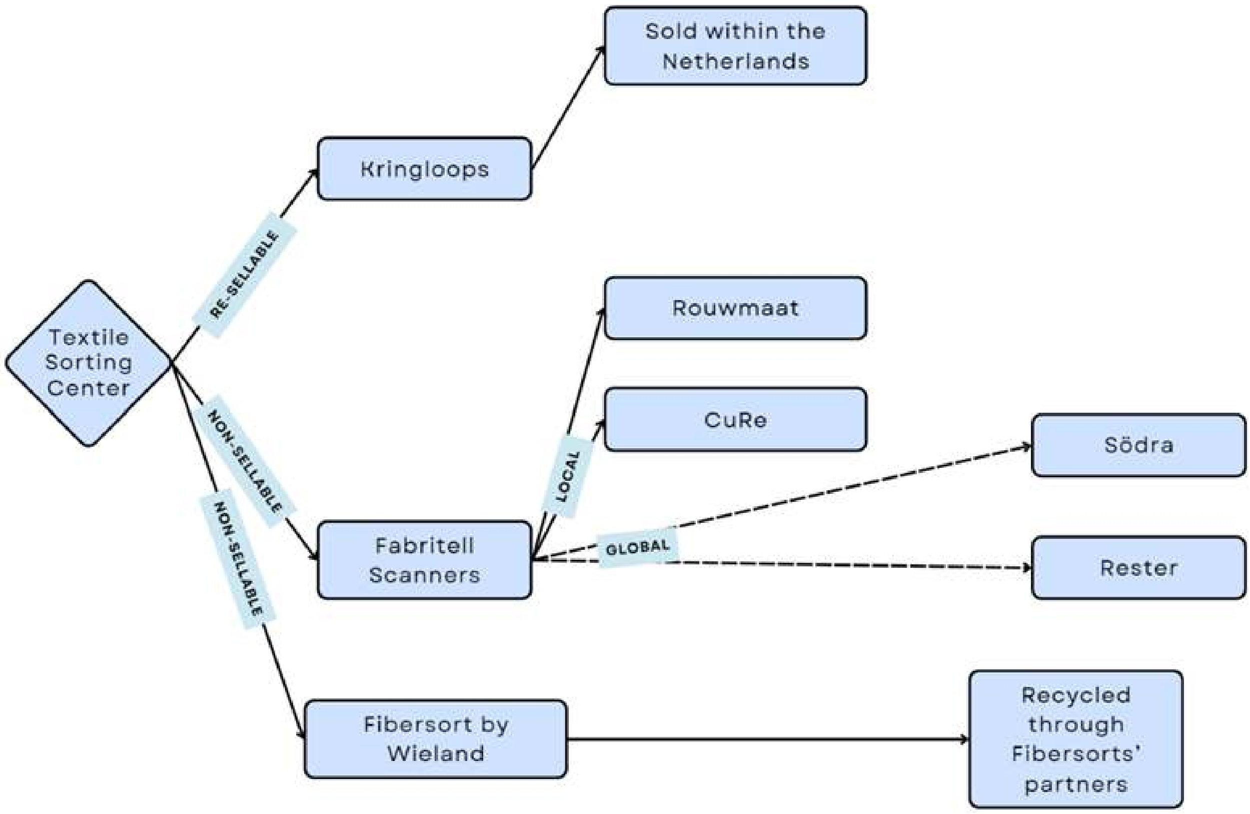
This choice would contribute to assuring that no textiles, even accidentally, end up in foreign countries or locations where they are not able to be sorted appropriately and as a result, contribute to the pollution of the environment. Although NLD assures that no textiles leave the borders of Europe, the project team still believes it would be wiser for textiles disposed of in the Netherlands to stay within the borders of the Netherlands and be processed by companies working on frontline technology.

This scenario would then see the non-sellable clothing be sorted by material either through the Fabritell scanners and then sent to a recycling company such as CuRe or Rouwmaat. Or through the more industrial sorting facility Fibersort, provided by Wieland, where it would then get recycled through Wieland's partners.

Alternatively, after being sorted, the textiles could be sent to one of the foreign companies mentioned in the report for processing, like Södra or Rester as they are well-established companies who have the capability for processing higher quantities of textiles. However, the project team would still recommend the collaboration with Dutch companies, when possible, to avoid transportation costs, further pollution, and need for more intense tracking of the flows.

To make up for the possible loss of income provided to the Textile Sorting Center by NLD, municipalities who are interested in the responsible processing of their textile waste should be made aware of the alternative options available and be given the choice to pay for them. The choice of this scenario is made off assumptions which the project team believes would increase transparency within the flows.

Figure 14
First scenario



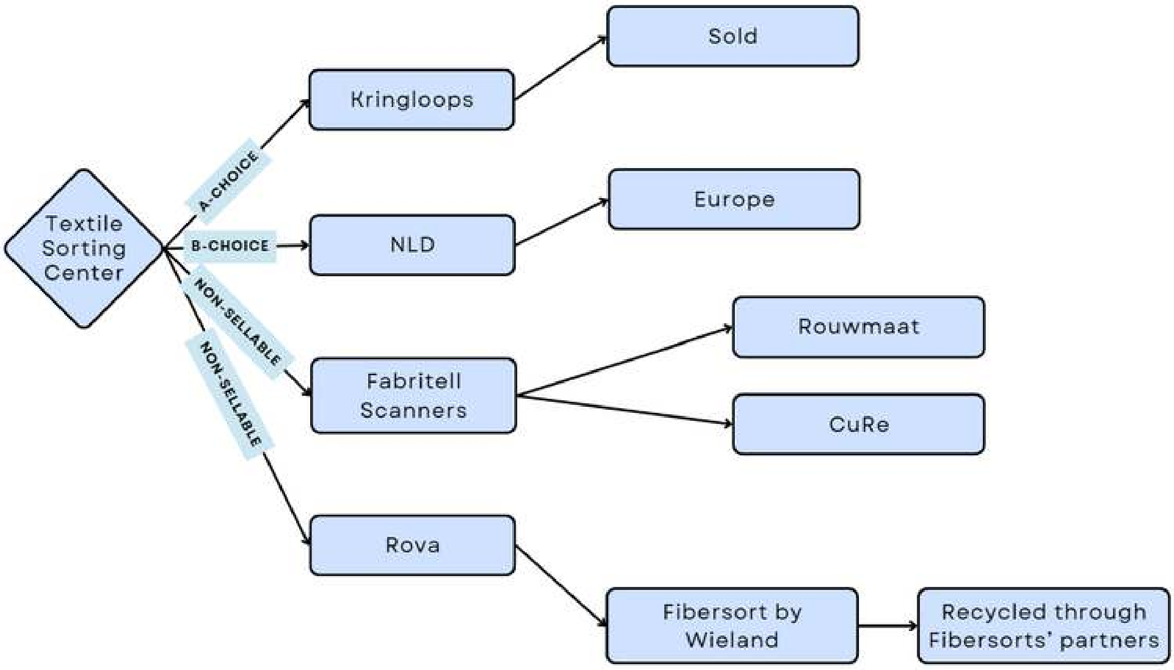
Scenario 2

The second scenario individuated by the project team involves a different approach to handling the 4% of discarded textiles by the Textile Sorting Center. This scenario assumes that the 4% of discarded textiles are treated as general waste by ROVA and thus incinerated.

Instead of handling this waste stream as such, sorting it using the Fabritell scanners and then sending it to a recycling organization, such as CuRe, would allow it the possibility of another life. Alternatively, it may be sorted and recycled via the more industrial sorting facility provided by Fibersort.

This would likely be the simplest change to make, as removing the B-choice flow and the Textile Sorting Center's agreement with NLD could limit the Textile Sorting Center economically, meaning that an alternative source of income would need introducing, or support offered, before any further changes can be made.

Figure 15
Second scenario



LIMITATIONS OF THE PROJECT

Considering the topic that this report is handling, the following limitations in producing this report are identified.

The Broadness of the Scope

The issue of processing polyester is being approached globally by an immense number of stakeholders. Those stakeholders are likewise highly interconnected and often make up complex networks, as they handle various steps of the process.

For instance, when one stakeholder was contacted, the project team would find out that said stakeholder also cooperated with several other parties. This would lead to the project team being continually redirected to new stakeholders, making it impossible for the entire network to be covered with confidence, within the scope of this assignment.

Moreover, this is a multidimensional issue that can be approached from several perspectives (e.g., economic or technological based), each of which can serve as the subject of in-depth research, given the extensive material needed to be covered.

This means that within the current timeframe of the project, we could only scratch the surface of the initiatives undertaken on a local and global level.

The current Status of Innovation

As much as one may wish for there to be an already existing economically viable and realistic solution to this issue, the majority of the initiatives of recycling/processing of polyester textiles are just beginning to be developed, which means that ways of adapting them to a larger scale and more contexts have not been entirely established.

Transparency of the Information

Given the large number of stakeholders, who are often in collaboration with one another when dealing with the topic of processing polyester, it is easy to lose track of the flows of polyester textile. In principle the involvement of many stakeholders is not a bad thing, but when dealing with waste streams, especially when they end up outside of the Dutch context or even outside of Europe, it becomes impossible to say with confidence where and in what quantity, in this case polyester textile waste, ends up.

Non-reachable/unresponsive Stakeholders

Some stakeholders were unfortunately unresponsive or were too busy, responding only after several weeks. Therefore, the process of gathering information was highly time-consuming and not entirely conclusive. As such, oftentimes the team was forced to rely on information solely found online.

CRITICAL REFLECTION AND OUTLOOK FOR FURTHER INVESTIGATIONS

Despite the limitations mentioned above, the team was able to gather most of the desired information in the limited timeframe provided. The initial task to gain insight into the flow of polyester textiles collected by the Kringloops in Zwolle was fulfilled. Connections between stakeholders were shown and maps of the flows created.

Furthermore, not only could solutions from the local context be found and those from other countries researched, but also insightful background facts were collected to get a more complete picture of the problem. To even begin to be able to think of possible recommendations on how to improve the lifecycle of polyester textiles within the local scenario of Zwolle, the project team had to overcome a challenging, albeit interesting, learning curve.

For future research it would be useful to have closer contact with the main frontrunners in the technology being developed to process polyester textile in environmentally friendly ways. Moreover, to have the time to dig even deeper into how some of the flows individuated, continue, and where their final destination resides. Likewise, for future research further exploring the economic costs behind all the possible solutions should also be a focus point.

Nevertheless, the project team hopes that this report will contribute to making the readers more aware of the various dimensions of the topic of handling and processing polyester textile and facilitate the creation of valuable connections, by introducing the readers to various companies and the technology they developed, to tackle the issues presented by polyester.

REFERENCES

About Cure| CuRe. (2022, 9 september). Retrieved November 21, 2022, from https://curetechnology.com/about-cure-technology/

Boer Group. (n.d.). Textile recycling with purpose and innovation by tradition. Retrieved December 7, 2022, from https://boergroup.eu

Chan, A., Charles, A., Croci, F., Engel, F., de Oliveira Marreiros, R., Zweers, E., & Harmsen, P. F. H. (2020). Improving Dutch post-consumer textile recycling. Wageningen University & Research. https://edepot.wur.nl/563577

De Duurzame Kringloopcoöperatie (2021) KringCoop. Available at: https://kringcoop.nl/ (Accessed: December 6, 2022).

De laatste ontwikkelingen rond Besluit UPV Textiel. (2022). Dossier UPV | Modint. https://modint.nl/thema/dossier-upv/nieuws/2353-de-laatste-ontwikkelingen-rondbesluit-upv-textiel

Dissanayake, D.G. and Weerasinghe, D.U. (2021). Fabric Waste Recycling: A systematic review of methods, applications, and challenges. Materials Circular Economy, 3(24), 1-20. https://doi.org/10.1007/s42824-021-00042-2

Domininghaus, H. (2012). Kunststoffe: Eigenschaften und Anwendungen. Springer. https://doi.org/10.1007/978-3-642-16173-5

Ducky Dons. (n.d.). Recyclingproces dons. Retrieved December 7, 2022, from https://duckydons.nl/dons-recycling/recyclingproces-dons/

Frankenhuis. (n.d.). Home. Frankenhuis. Retrieved December 7, 2022, from https://www.frankenhuisbv.nl

Frankenhuis. (n.d.-a). You would like to buy fibers from recycled textiles or want to have fibers made from your own textiles. Retrieved December 7, 2022, from https://www.frankenhuisbv.nl/en/diensten/vezels/

Hoogcalorisch afval|Rouwmaat recyclet hoogcalorisch afval. (n.d.) Retrieved November 21, 2022, from https://www.rouwmaat.nl/hoogcalorisch-afval

Innovatie: Fibersort. (2022, 4 Augustus). Wieland Textiles. Retrieved November 20, 2022, from https://www.wieland.nl/innovatie-fibersort/

Jabbar, A., Tausif, M., Tahir, H. R., Basit, A., Bhatti, M. R. A., & Abbas, G. (2019). Polylactic acid/lyocell fibre as an eco-friendly alternative to polyethylene terephthalate/cotton fibre blended yarns and knitted fabrics. The Journal of the Textile Institute, 111(1), 129–138. https://doi.org/10.1080/00405000.2019.1624070

Janssen, C., Van der Vaart, I., Bos, I., Bakker, A., (2020). Fast Fashion Onderzoek Vermindering van de Negatieve impact. KplusV. 1019169-020

KringCoop. (n.d.). De duurzame kringloopcoöperatie. Retrieved December 7, 2022, from https://kringcoop.nl

Kringloop Zwolle. (n.d.). Over Kringloop Zwolle. Retrieved December 7, 2022, from https://www.kringloopzwolle.nl/over-kringloop-zwolle/

Malik, N., Kumar, P., Shrivastava, S. & Ghosh, S. B. (2016). An overview on PET waste recycling for application in packaging. International Journal of Plastics Technology, 21(1), 1-24. https://doi.org/10.1007/s12588-016-9164-1

Muthu, S.S. (2017). Sustainability in the textile industry. Textile Science and Clothing Technology. https://doi.org/10.1007/978-981-10-2639-3

Muthu, S.S. (2020). Environmental footprints of recycled polyester. Textile Science and Clothing Technology. https://doi.org/10.1007/978-981-13-9578-9

Muthu, S.S. and Gardetti, M.A. (2020). Sustainability in the textile and Apparel Industries. Sustainable Textiles: Production, Processing, Manufacturing & Chemistry. https://doi.org/10.1007/978-3-030-38545-3

Nextchem. (2022). Nextchem Completes Italy's 1° Demonstration Chemical Recycling Plant for Pet and Polyester Textiles. https://nextchem.it/news/nextchem-completes-italys1deg-demonstration-plant-pet-and-textiles-polyester-chemical

NLD. (n.d.). About us. NLD Used Garment Recycling. Retrieved December 7, 2022, from http://nldusedgarment.com/about/

Opperskalski, S., Ridler, S. J., Siew, S., Tan, E., Barsley, L., Denes, H., Gillespie, A., Gosai, A., Heaton, A., Hyde, T., Lambert, N., Marquardt, S., Seisl, S., Truscott, L., Weldon, C. & Bettany, P. (2021). Preferred Fiber & Materials Market Report 2021. Textile Exchange. https://textileexchange.org/app/uploads/2021/08/Textile Exchange_Preferred-Fiber-and-Materials-Market-Report_2021.pdf

Palacios-Mateo, C., van der Meer, Y., & Seide, G. (2021). Analysis of the polyester clothing value chain to identify key intervention points for sustainability. Environmental Sciences Europe, 33(2), 1-25. https://doi.org/10.1186/s12302-020-00447-x

Piribauer, B., & Bartl, A. (2019). Textile recycling processes, state of the art and current developments: A mini review. Waste Management &Amp; Research: The Journal for a Sustainable Circular Economy, 37(2), 112–119. https://doi.org/10.1177/0734242x18819277

Piribauer, B., Jenull-Halver, U., Quartinello, F., Ipsmiller, W., Laminger, T., Koch, D., & Bartl, A. (2020). TEX2MAT – NEXT LEVEL TEXTILE RECYCLING WITH BIOCATALYSTS. Detritus, 13, 78–86. https://doi.org/10.31025/2611-4135/2020.14030

ReShare. (n.d.). Wat wij doen. Reshare. Retrieved December 7, 2022, from https://www.reshare.nl/wat-wij-doen

ROVA. (n.d.). https://www.rova.nl/over-ons/diensten

ROVA. (n.d.-a). Alles over textiel. Retrieved December 7, 2022, from https://www.rova.nl/inwoners/pagina/60/Alles-over-textiel

S.C., Bhatia. (2017). Industrial pollution and its control. Woodhead Publishing India Pvt. Ltd. https://doi.org/10.1201/9781315148588

Suntinger, H. (2020). Recycling breakthrough for clothing made with Polyamide. Innovation Origins. https://innovationorigins.com/en/recycling-breakthrough-for-clothing-made-with-polyamide/

Sympact. (2022). What we do. Retrieved November 24, 2022, from https://www.sympactsolutions.com

Sympany. (n.d.). Stot tot Grondstof. Retrieved December 7, 2022, from https://www.sympany.nl
Sympany. (n.d.-a). Kleding Inzameling. Sympany. Retrieved December 7, 2022, from https://www.sympany.nl/kledinginzameling/
Sympany. (n.d.-b). Herdraagbaar blijft herdraagbaar. Retrieved December 7, 2022, from https://www.sympany.nl/bestemming/herdraagbaar-blijft-herdraagbaar/
Sympany. (n.d.-c). Samen werkingen. Sympany. Retrieved December 7, 2022, from https://www.sympany.nl/samenwerkingen/
T-REX. (2022). Driving textile recycling excellence. T-REX Project. Retrieved November 2023, 2022, from https://trexproject.eu
Twente. (2017, March 15). Frankenhuis: Textile recycling in a new era. https://twente.com/en/global-goals/12-responsible-consumption-and-production/frankenhuis-textile-recycling-in-a-new-era
Wieland Textiles. (n.d.). Focusing on three core activities. Wieland. Retrieved December 7, 2022, from https://www.wieland.nl/en/core-activities/