FINAL REPORT

An investigation of European waste textiles sorting facilities and opportunities for South Australia

Green Industries SA Women in Circular Economy (WICE) Leadership Scholarship

Penelope Morrison

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I thank Green Industries SA for selecting me as the recipient of the 2022 Women in Circular Economy (WICE) Leadership Scholarship and my workplace, the Northern Adelaide Waste Management Authority (NAWMA), for co-funding my research trip.

This support enabled me to learn more about waste textile sorting facilities in Europe and the wider opportunities for establishing an innovative waste textiles recycling industry in South Australia.

I also thank my mentor for this project, Dr Marcia Kreinhold for her unwavering enthusiasm and well-informed advice.

The azulejo tile design on the front cover was inspired by my trip to Spain and Portugal and is underlain by a textile weave symbolic of the purpose of the trip.

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Acknowledgement of country
We acknowledge and respect the Traditional Custodians whose ancestral lands we live and work upon and we pay our respects to their Elders past, present and emerging. We acknowledge and respect their deep spiritual connection and the relationship that Aboriginal and Torres Strait Islanders people have to Country. We extend our respect to all Aboriginal and Torres Strait Islander people and their nations in South Australia and across Australia.

Preface

Through my experience working in the environmental and waste sectors during the last 28 years, I have seen many instances of misplaced reusable resources termed 'waste'. Whilst there have long been systems to recover items that are easily returned to secondary raw materials at the end of their useful lives (such as glass from glass jars), additional thought is required for substances that are more complex to recover such as blended fibres from waste textiles. More complicated situations, however, can provide opportunity for creative solutions. This, and the enormous potential for reducing negative environmental impacts, generated my interest in circular processes within the fashion and textiles industry.

Being aware that better sorted secondary raw materials will lead to better recycling outcomes, I undertook a study tour of waste textile sorting facilities in Spain and Portugal to learn about circular opportunities for waste textiles.

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Executive summary

Post-consumer textile waste is one of the fastest growing waste streams in the world and its disposal is frequently associated with significant environmental damage. Closed-loop recycling of waste textiles can interrupt this negative impact. Across all recycling operations, better sorting of waste products results in the recovery of higher quality secondary raw material streams, which leads to better recycling outcomes. The focus of my project was to research European waste textiles sorting facilities to learn about sorting methods used to obtain high quality outputs.

During a two week study trip to Spain and Portugal in April and May 2023, I visited different facilities with sorting capabilities ranging from 3 to 35 tonnes per day. I also interviewed the Communication Team Lead from Sysav in Sweden to learn about the Siptex facility, which is the world's largest fully-automated textile sorting facility and has the capacity to sort more than 90 tonnes of material per day.

Waste textile sorting methods include manual, semi-automated and fully-automated. In Europe, it is becoming more common for waste textile clothing garments to undergo both manual and automated sorting. This ensures good quality items are captured for reuse and contaminated material is removed, before the remaining items are classified for mechanical and chemical recycling.

Automated waste textile sorting technologies use both NIR and VIS spectroscopy and have been developed from equipment used for sorting waste packaging. Some manufacturers of automated textile sorting equipment already have a presence in Australia.

A major driver of the rapid growth of the textiles recycling industry in Europe is the EU Waste Framework Directive which mandates separate waste textile collections by January 2025. The speed at which the closed loop textiles recycling industry is advancing in Europe indicates that this emerging industry will become a global norm in the future. Australia's first National Clothing Product Stewardship Scheme was released in June 2023. It identifies closed loop recycling as one of four key priority areas and has the potential to be a mechanism for raising up to $36 million/year of funding for initiatives that reduce textile waste.

South Australia, with its track record of early adoption of resource recovery and recycling systems is recognised nationally and internationally for its achievements and is well positioned to host a textiles sorting, recovery and recycling hub.

Introduction

Impacts of textiles on the environment

Post-consumer textile waste is one of the fastest growing waste streams in the world. The Ellen Macarthur Foundation reports that every second, the equivalent of a rubbish truck load of clothes is burnt or buried in landfill (Ellen Macarthur Foundation, 2017).

Discarded textile waste is responsible for many negative environmental impacts such as leaching chemicals into soil and waterways and releasing toxins to the atmosphere when incinerated. Further to this, valuable raw materials are lost when items are not recycled which leads to the extraction of more raw materials from nature, to make new products. Much of the environmental impact occurs in developing nations as clothes from western countries are sent overseas as part of the global second-hand clothes trade. For example, as much as 40% of the 15 million garments that arrive for sale in the Accra clothing markets in Ghana each day are deemed worthless on arrival and are dumped in landfill (Besser, 2021).

The production of textiles also has significant environmental impacts, using large amounts of natural resources such as clean water. Annual global greenhouse gas emissions from textiles production amounts to 1.2 billion tonnes (Ellen MacArthur Foundation, 2017). Many items used routinely to produce textiles are reliant on crude oil extraction. These include inorganic fertiliser for growing fibre-producing crops such as cotton, chemical pesticides, dyes and finishes. Crude oil is also a raw material used to produce synthetic fibres such as polyester. Even the consumer use stage of the textile life cycle has impacts such as laundering of synthetic clothing accounting for 35% of primary microplastics released into the environment (European Parliament, 2020).

In Australia more than 200,000 tonnes of clothing are discarded to landfill each year (Allan et al., 2023). Overall, 860,000 tonnes of textile, leather and rubber waste was generated in Australia in 2020-21 (Blue Environment, 2022). The discarded textile material is termed 'waste' because it is no longer used for its intended purpose. From a circular economy perspective however, much of this material has the potential to be used as secondary raw material to replace virgin natural resources in the production of new textiles. This process is referred to as 'closed loop textile recycling'.

One of the most important levers that the fashion industry can use to reduce its environmental impact is closed-loop recycling (McKinsey & Company (2022a). However, currently less than 1% of waste textiles worldwide undergo closed loop fibre-to-fibre recycling to produce new textiles. Other 'recycling' is usually downcycling into lesser quality items such as cleaning cloths or insulation. Unlike being respun into new yarn and turned back into textiles to 'close the loop', these 'downcycling' outcomes are usually the final step in the material's life cycle before being discarded.

Demand for clothing that contains recycled fibre is increasing. As consumers become more aware of the negative impacts arising from the disposal of waste textiles, some are seeking out more sustainable options. In response, many companies are taking steps to improve their value chain operations (and enhance their reputation) by introducing targets to incorporate recycled fibre into garment production. In 2022, Inditex, one of the largest fast fashion groups in the world, increased its use of recycled materials by 90% compared to 2021 levels making 78,675 tonnes of such material available to customers. (Inditex Group, 2023).

Europe's response to waste textiles management

The EU Waste Framework Directive defines the basic principles related to waste management for Member States of the European Union. In 2018 amendments to the Directive included legislation for Member States to promote re-use activity and repair networks, facilitate proper waste management and, by 1 January 2025, to set up separate collections for waste textiles (EUR-Lex, 2018).

As a result, each Member State of the EU will need a system to facilitate the separate collections and subsequent recycling of waste textiles. Currently such systems are at varying degrees of development.

For example, in 2007, France was the first EU country to declare a legal framework for managing textile waste through an extended producer responsibility (EPR) policy with the goal of holding textile producers responsible for the collection and recycling of end-of-use clothing, linen, and shoes (Knowledge Hub, 2021). However, some other EU countries are yet to make progress towards developing the required new systems.

Waste textiles management in Australia

Clothing textiles were listed on the Australian Government's *Minister's Priority* List for 2021-22 (DCCEEW, 2021), thus identifying this waste stream as one that required urgent stewardship action. Acknowledging the waste clothing problem in Australia, a National Clothing Product Stewardship Scheme (NCPSS) was prepared by a consortium led by the Australian Fashion Council. The scheme, called Seamless, was launched with a *Roadmap to Clothing Circularity* in June 2023. *Seamless* aims to improve the design, recovery, reuse and recycling of clothing to drive circularity in the fashion industry by 2030. The Roadmap proposes that the following actions are needed to achieve these aims (Australian Fashion Council, 2023a):

- Incentivising clothing design that is more durable, repairable, sustainable and recyclable.
- Fostering new circular business models for clothing based on reuse, repair, remanufacturing and rental.
- Expanding clothing collection and sorting for effective re-use and to ensure non-wearable clothes are recycled.
- Encouraging citizen behaviour change for clothing acquisition, use, care and disposal.

Whilst participation is currently voluntary, the scheme is being implemented under the Australian Government's Product Stewardship Act 2011 and may become regulated if not enough industry members voluntarily adopt and participate in the scheme to achieve the desired outcomes. If industry members do sign up, their actions and the associated actions of stakeholders and citizens are projected to divert 60% of end-of-life clothing from landfill by 2027 (Allan et al. 2023). One of the *Roadmap to Circularity's* four priorities is 'Closing the Loop'. The focus is on "... significantly expanding existing clothing collection and sorting practices for effective reuse, and enabling clothing to be recycled into new high-value products and materials" (Allan et al. 2023, p. 7).

Current local practices to deal with waste textiles

In 2020-21, South Australia recovered 1,600 tonnes of textiles and leather waste from municipal waste streams for recycling (GISA, 2022). This is a small amount given the likely volume of textile waste being generated and furthermore, does not include waste textiles from the commercial and industrial sector.

Metropolitan Adelaide has well-established three-bin kerbside collection systems for household waste. General advice from local councils to people discarding of used household textiles, is to follow the waste management hierarchy and reuse any good quality items through avenues such as clothes swap events or donation to charitable reuse stores. For non-usable items, advice includes downcycling into rags and cushion fill or creative upcycling into things like shopping bags and rugs. For disposal through the kerbside waste collection service, residents are directed to dispose of waste textiles into the general waste bin resulting in the loss of this resource to landfill as well as municipalities incurring waste disposal costs including Solid Waste Levy charges.

Another problem with disposal at the kerbside is the incorrect use of the yellow-lid recycling bin for unwanted textiles. When such items arrive at Material Recovery Facilities (MRFs), they are not recoverable and are disposed of as waste. At MRFs these materials can also cause operational issues such as getting caught in machinery and potentially contaminating other recoverable resource streams.

In November 2021, a Northern Adelaide Waste Management Authority (NAWMA) region kerbside bin audit showed up to 4.4% of the general waste stream and up to 6.4% of the household recycling stream, was comprised of discarded waste textile material. Annually, this equates to approximately 2,000 tonnes of waste textile material generated by residents within NAWMA's three constituent councils: The City of Salisbury, City of Playford and Town of Gawler (around 120,000 households). These waste textiles are unsuitable for reuse due to the high incidence of contamination resulting from their inappropriate disposal.

Figure 1: A sample of waste textiles founds in a NAWMA kerbside bin audit in 2021

End of life options for waste textiles

The Waste Management Hierarchy is an internationally recognised framework used to guide desirable behaviour for the sustainable management of waste.

Figure 2: Waste Management Hierarchy (NAWMA, 2023)

Reuse and repair

Reuse and repair/repurposing of discarded textiles are better options compared to recycling, disposal to landfill or incineration with energy recovery according to circular economy principles of keeping resources at their highest value for the longest period of time. Whilst the focus of this report is on sorting and recovery of waste textiles for recycling, this should only be considered after all higher order opportunities have been exhausted.

In the fashion industry, fast fashion encourages a high consumption of new clothing garments and the disposal of used items after a short period of time. These low-cost items are increasingly made from cheaper, non-durable materials which limits their potential for reuse. With the diminished opportunity for reuse, some of these items may be suitable for use as a source of fibre for recycling back into new textile products.

Recycling

Reinjecting post-consumer waste textile fibres back into the textile manufacturing industry as a replacement for virgin materials from nature, is a positive and truly circular activity. The textile recycling industry includes both mechanical and chemical processes. Closed loop mechanical recycling of cotton and wool fibres is well-established in countries like Portugal, Spain and Italy. Chemical recycling suitable for synthetic and blended fibre textiles is growing in sophistication with much research and development being undertaken overseas as well as in Australia. Queensland based company, BlockTexx (2023) uses a chemical recycling process called S.O.F.T ^{R} (Separation of Fibre Technology) to recover separated polyester and cellulose from blended fibre textiles.

Through Australia's Roadmap to *Clothing Circularity*, it is proposed that multiple recycling facilities for cellulosic (i.e., fibres made from cellulose), and synthetic fibres should be operational in Australia by 2030. However, before recycling can occur, collection and sorting of material is required, and better sorting will result in better recycling opportunities.

Collection and sorting of waste textiles

Collection and sorting are fundamental precursors to recycling waste textiles and both are identified by the NCPSS as areas towards which funding raised through the scheme, will be directed. A general summary of collection and sorting methods is provided below, followed by detailed case studies for each sorting facility I investigated.

Collection of waste textile materials

Existing methods for collecting unwanted post-consumer textiles in Europe include a variety of schemes such as charity bins in public places. Most neighbourhoods in Spain have these with some systems, such as that run by Caritas España (see Case Study: Formació i Treball) having downstream arrangements with textile recyclers for the non-reusable fractions that are collected. Donations to second-hand stores and retailer take back schemes also exist. Additionally, community members can take items to municipal Resource Recovery Centres in some places. Pre-consumer materials such as unsold off-cuts from garment manufacturers are also often sent to sorting and recovery facilities (where these exist), as this is generally less expensive than sending to landfill or incineration.

Manual sorting of waste textiles

Historically, sorting of post-consumer clothing has been a manual process and worldwide this is still the most common method used. Manual sorting operations generally focus on the recovery of quality articles that can be reused as clothing garments. The unusable fraction (i.e., unwearable) is divided into items suitable for downcycling into rags and non-reusable waste material to be disposed of.

More sophisticated textile recycling methods make it increasingly necessary to sort waste textiles into categories based on specific fibre types and blends. The diversity of textile fibres is outlined in Figure 3.

Whilst sorting blended fibre materials can be done to some extent by a person reading the composition label of a waste garment, there are two main drawbacks. Firstly, garment labels do not always reflect the exact composition of the textile material or are worn out and cannot be read. Secondly, manual identification slows the sorting process. Automated sorting can overcome both of these issues. However, while automated sorting yields better results, all the organisations I spoke with reinforced the importance of an initial manual pre-sort by trained and experienced sorters. This is because any reusable fraction should be kept recirculating to extend the life of such resources and also because it enables the removal of any unsuitable fraction (i.e., unclean or wet garments) before material arrives at the automated sorting facility.

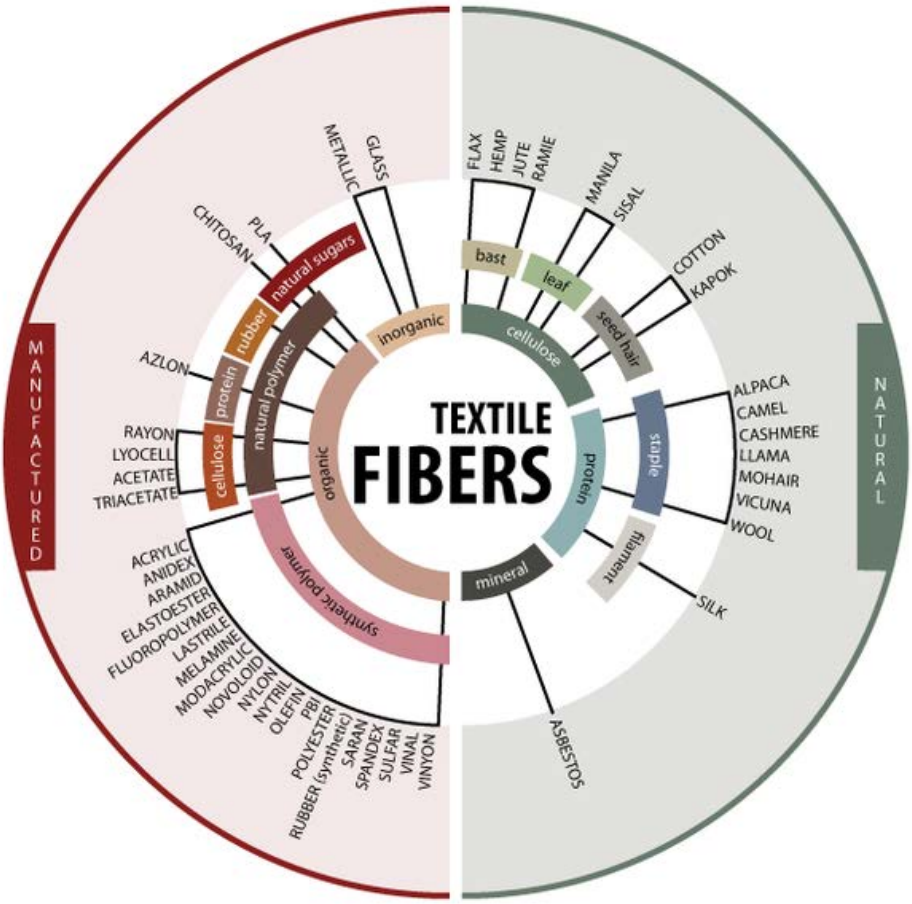
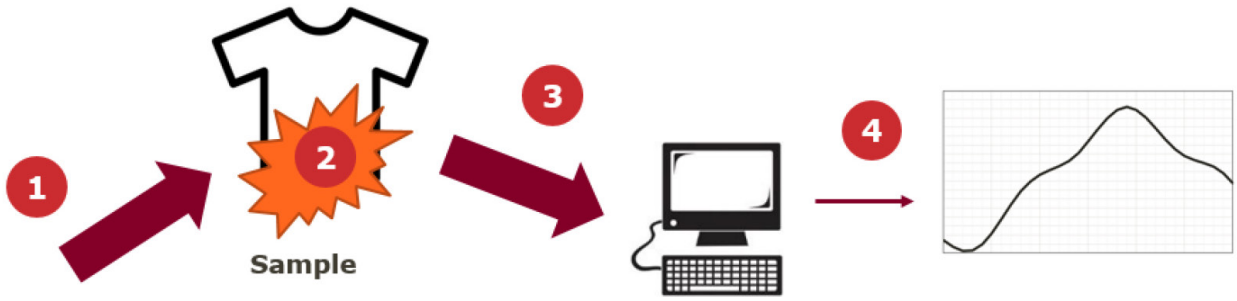


Figure 3: Manufactured and natural fibres used in textile production (Textile and Fibre Science, 2023)

Fibre identification using automated textile sorting technology

Textile recycling requires feedstock of known composition and recyclers will restrict the types of material they accept. For example, a cellulose recovery facility may restrict its input material to only very high percentage cotton textiles. To enable recycling, mechanisms are required which can determine textile composition quickly and accurately. To achieve this, advances are being made by manufacturers of industrial-scale automated textile classification and sorting equipment. Automated textile sorting equipment using NIR (Near Infrared) spectroscopy has been found to be most suited for the differentiation of textile chemical compositions (see Figure 4).



1. An electromagnetic wave is sent to the sample for analysis.
2. The wave and the sample's chemical structure interact (molecule, atom, bonds etc.).
3. The wave is measured after having interacted with the sample.
4. A spectrum is produced. The spectrum represents the sample's chemical signature.

Therefore, the spectrum's comparison of an item's unknown composition with a reference spectra database of pre-recorded samples enables the composition of the item analysed to be determined.

Figure 4: How spectroscopy works (Terra, 2020)

Automated textile sorting technology has been developed from sorting equipment originally designed to separate packaging, commonly used at MRFs. As with MRF equipment that can be programmed to identify PET bottles and cardboard, the textiles sorting equipment can be programmed to identify a range of pure and mixed composition textiles such as 100% cotton, ≥ 60% cotton, ≥ 90% polyester. The technologies that I investigated also used artificial vision to sort by colour.

Micro NIR scanners

Whilst I did not see any during my trip, through online research I identified handheld micro NIR scanners that are portable and can be used for small-scale textile identification operations.

Limitations of automated sorting technologies

Research and development are ongoing at each of the facilities I visited, with staff emphasising the importance of good relations with technicians who were often called upon to trouble shoot. Detection of pure fibre materials is more reliable than of blended fibres. In some cases, coatings and finishing can give a misreading depending on which side of the fabric faces the NIR analyser.

Research has shown that very thin fabrics can allow NIR spectra to penetrate through the fabric and result in non-matching recognition. Cura et al. (2021) found that ageing caused chemical changes, especially in the cotton spectra, that hampered its recognition.

There is increasing demand for this automated sorting equipment, particularly in Europe which is heading towards separate waste textile collections by municipalities in 2025 (EUR-Lex, 2018). Work is underway to improve the functions of the technology with a range of suppliers now manufacturing their own versions. Some of these are referred to in the case studies discussed in the next section of this report.

Case studies

During my research trip to Spain and Portugal, I visited facilities of varying scale that sorted waste textiles using manual, partially-automated and fully-automated systems. The following is an overview of the operations at each facility.

Coleo, A Coruña and Mataró, Spain

Established in Barcelona in 2018 as a garment design and production company, Coleo has since expanded its operations to include the recovery and recycling of waste textiles and the use of recycled fibre textiles in its garments. The EU legislation mandating the separate collection of waste textiles was the driver behind setting up the company's 1,000m^2 automated sorting facility in A Coruña in 2020, which currently sorts around 3.3 tonnes of material/day. About 75 people are employed across the two sites. A third 3,500m^2 pre-sort facility is in development at A Coruña.

Figure 5: Coleo's automated sorting operation at A Coruña

Figure 6: Garments passing along a conveyor belt are identified by composition and color with a mixed system of Artificial Vision and NIR Spectra

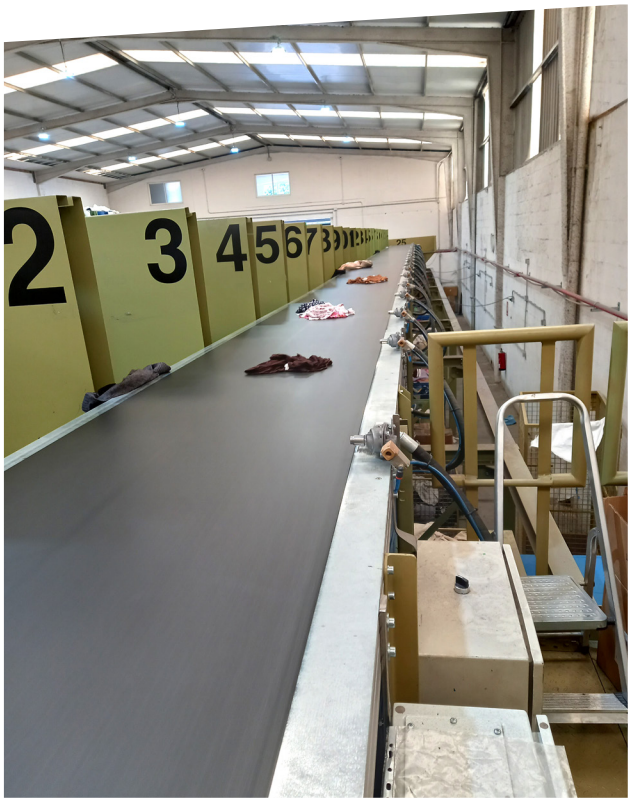


Figure 7: Air jets direct items of different fibre composition into numbered sorting bays. The PICVISA system can sort up to one garment/second

Coleo's sorting facility deals with both pre- and post-consumer waste textiles. The fully automated sorting equipment used is the Spanish PICVISA ECOSORT TEXTIL optical sorter. PICVISA specialises in the design, manufacture and supply of optical sorting equipment for the classification of materials, recovery and valorisation of waste (PICVISA, 2020). At Coleo, the ECOSORT TEXTIL sorter is currently programmed to recognise and sort into 24 different fibre composition categories with new ones constantly being developed (potentially, up to 70 categories can be sorted). Air jets sort materials of different composition, after these pass by the camera and NIR scanner. Although fully-automated sorting occurs, it was still necessary to have a person feeding stock into the machine in an ordered manner to ensure that items moved separately along the conveyor belt and thus could be individually scanned.

Yarn is made from the recovered materials (with no dyeing) and incorporated into new textiles in conjunction with spinning and weaving partners in Catalonia. Garments manufactured from the recovered fibre textiles are predominantly sold to Inditex (also based in A Coruña) for sale through its retail outlets such as Zara as part of its sustainability-focused *Join Life* program [1]. To date, Coleo has manufactured 4.2 million garments with more than 20% post-consumer recycled textile fibre. The company has plans to expand into other European countries.

I learned that capital investment to set up a 5,000 tonne/year automated textile sorting facility using the same equipment as Coleo's A Coruña plant in Spain, would be around EUR 1 million (AUD 1.6 million). This would cover the cost of machinery, investment in auxiliary equipment, a bale press, sorting crates, and tables. Such a facility would require a floor space of around 3,000 m^2 to 5,000 m^2. For a larger operation sorting between 10,000 to 20,000 tonne/year, the cost would increase to around a EUR 2 million (AUD 3.2 million) and require a facility size of between 7,000 m^2 -15,000 m^2.

1. See https://www.zara.com/au/en/z-join-life-mkt1399.html

Figure 8: Waste textile items manually sorted for reuse before being sorted by composition at Formació i Treball

Formació i Treball, Catalonia, Spain

Formació i Treball is an NGO (Non-Government Organisation) which focuses on waste textile reuse and increasingly recycling, together with more than 20 other business units belonging to Caritas España [2]. About 700 people who are at risk of social exclusion are employed through the Catalonian facility carrying out tasks including collection, sorting and distribution of textiles. Whilst employed at the facility, workers participate in a variety of informal and formal skills development training programs with the majority going on to find employment in the wider community after, on average, about one year.

Each day approximately 35 tonnes of predominantly post-consumer waste clothing material is sorted into different streams at the facility. Some material is onsold in Caritas' second-hand stores, other quality wearable material is sent to Africa, Asia and South America for onsale and a small portion (approximately 4%) is considered unusable and is disposed of as waste. The remaining fraction (35%) is considered non-reusable as clothing and is sent to different European companies as raw material for recycling. Most of this is mechanical but Formació i Treball is also actively involved with partners conducting research into chemical recycling. The organisation plans to double its sorting capacity by 2024, when it constructs a second factory near Barcelona.

[2] Established in 1947 Caritas España is the official confederation of the social and charitable action organisations of the Catholic Church in Spain. https://www.caritas.eu/caritas-spain

The Valvan Fibersort™ unit I viewed at Formació i Treball was a semi-automated system. Rather than needing garments to be spread out on a conveyor belt as they pass under a NIR scanner, the technology relies on garments being pressed against a NIR scanner by a person who then sorts the item based on the information displayed on the digital screen. This operation therefore provides employment for a local person. Valvan's headquarters is in Belgium and the company supplies sorting and baling systems to the textiles and recycling industries globally.

Figure 9: VALVAN's Fibersort™ semi-automatic unit in use at the Formació i Treball facility

Siptex (Swedish Innovation Platform for Textile Sorting), Malmö, Sweden

Sysav is a waste management company owned by 14 municipalities (approximately 710,000 households), for whom it manages all household waste. Siptex is a research project owned by Sysav and is the world's first industrial-scale, fully automated textile sorting facility. While I was unable to visit the facility, I undertook an online interview with Anna Vilén, Sysav's Communication Team Lead.

The Siptex facility focuses on sorting pre- and post-consumer textiles for fibre-to-fibre recycling. Post-consumer material is collected at community recycling centres (i.e., Resource Recovery Centres), second-hand stores and NGOs in Sweden. It is then sent to Germany where there is a tradition of textile sorting, and Baltic countries, where labour costs are cheaper, to be pre-sorted by hand. Material not identified for reuse or as waste (i.e., wet or contaminated material) is trucked back to the Siptex facility in Sweden.

The facility was designed and built by Stadler. It uses four NIR and VIS spectroscopy TOMRA AUTOSORT® units to sort by fibre type. It also has the capacity to sort by colour. The facility sorts between 4.5 – 5 tonnes of material per hour equating to around 16,000 t (2 shifts) /24,000 t (three shifts) per year. Set up costs for establishing the sorting plant were approximately EUR 5.1m (AUD 8.4m) with total capital expenditure approximately EUR 7m (AUD 11.5m).

Initially Siptex encountered some difficulties finding markets for sorted material. It was also reported that keeping up volumes of sorted materials to ensure a consistent supply to meet demands of downstream markets that have been established, can also be challenging at times given the varying composition of material received.

Figure 10: The Siptex facility in Malmö (photo courtesy Sysav)

Valérius 360, Porto, Portugal

Valérius 360 is the recycling arm of Valérius Textêis - one of the biggest textile manufacturers in Portugal. The company works with predominantly pre-sorted pre-consumer waste from manufacturing – i.e., clothing offcuts from other Valérius companies and customers. All the waste material feedstock is sourced from Portugal and is sorted by colour and composition before it arrives at the Valérius 360 facility in Malta (north of Porto).

The yarn produced on-site can contain up to 50% recycled content (c.f. typically 30%). Valérius staff attribute this high level of recycled content in part to the productive working relationship with technicians who often need to be called upon to adjust machinery so as to accommodate the use of recycled fibres. Up to six tonnes of yarn can be produced daily at the facility. No sorting equipment is used on site. It was interesting to note that because the company only accepts material already sorted by composition and colour, it does not need to dye the yarns it produces. It can also create a range of different coloured yarns through blending feedstock material.

Figure 11: At Valérius 360 waste textiles are colour sorted enabling yarns to be produced without the use of dyes

Figure 12: The author with yarn spinning equipment producing yarn with mechanically recovered fibre

Modacc Clúster, Barcelona, Spain

I also visited Modacc Clúster in Barcelona, a private business association that supports and advocates on behalf of fashion companies from within the Catalan fashion and textiles sector. Its function is to promote the competitiveness of the Catalan fashion sector both within Spain and abroad. Receiving local, regional and European government funding, the organisation has approximately 150 members and 12 staff.

Staff keep abreast of the evolving textiles landscape to advise members on how to respond to EU strategies and objectives that affect local production as well as sale of goods in other EU member states. They also research the latest industry innovation and developments to then provide training to member companies. Such an organisation can provide invaluable assistance to an industry, especially an emerging one such as fibre-to-fibre textiles recycling.

Key findings

Demand for recovered product

To establish a viable textile recycling industry for South Australia, demand and markets for post-consumer recycled fibre products should ideally be in place before developing sorting and recycling infrastructure. This concept is not new to the recycling industry, where it is understood that there must be a commitment to buying recycled content product otherwise resource recovery businesses will fail. A recent example is the collapse of Australia's largest soft plastics recycling program, REDcycle, attributed to a combination of an oversupply of waste material and limited end markets.

Policy drivers

Encouragingly, the facilities that I visited in Spain and Portugal were actively expanding their operations. This included building a manual pre-sort operation at Coleo and a factory to double annual sorting capacity at Formació i Treball. The driving force behind this expansion of operations was the assuredness provided by the EU Waste Framework Directive (EU WFD 2018/851). As the EU looks to make the local textiles industry more circular, those in the textile recycling industry feel the next likely step is a ban on the export of textile waste meaning existing textile sorting and recycling operators will be able to offer immediate disposal solutions when such an announcement is made. EU WFD 2018/851 is also a factor behind member states creating (EPR) schemes for textile waste.

Volumes

Through my conversations with facility operators, I learned that it is preferable for waste textile sorting to be undertaken at a large scale. This enables the operator to supply the required volumes of sorted material that partners further down the textiles recycling chain require in an ongoing capacity. However, with ingenuity, smaller operations were still able to be successful. Examples included where the company was working on consignment with the supplier of waste material, as with the case of Valérius 360, or where the company had both sorting and garment making operations so that it could create its own demand for textiles with post-consumer fibre content, as was the case with Coleo.

Textiles recycling chain

The textiles manufacturing and remanufacturing chains consist of multiple stakeholders. When the focus is on remanufacturing using post-consumer waste, stakeholders including yarn, fabric and garment manufacturers

need to be willing and suitably resourced to work with recycled fibre that has different characteristics to that sourced from virgin natural resources.

Both Spain and Portugal have long-established textile industries. This means they have large and small companies which work together to undertake all aspects of textile manufacturing (and increasingly re-manufacturing). Even so, local mills are closing as manufacturing is moving off-shore to places such as Asia. Good relations were necessary to foster productive and ongoing collaboration especially when recycled materials were likely to create new challenges, an example being the length of recovered fibres being different from the length of virgin fibres that machinery in yarn spinning operations, is traditionally designed to deal with.

Waste textiles stream selection

During my research trip, I was told that the hardest fraction of waste textiles to work with is post-consumer clothing garments. This is due to the inherent variability of this stream including presentation quality. For example, some items may be soiled, worn out or wet; some may have been washed many times and are clean of textile finishing chemicals, whereas others may have not been washed and still contain chemical residues. 'Disruptors' such as buttons and zippers also need to be manually removed. The enormous range in the potential composition and colour of materials means that when sorting, space is required for several separate categories to be collected (each of which may result in viable quantities at variable times resulting in intermediate stocks). Sorting operations will vary in size as dictated by the number of separate streams the sorter decides to recover.

Opportunities for South Australia

Growing interest in waste textiles recycling

Textile recycling technologies are increasing in Australia signalling that there is interest and potential for growth in this area.

At its Queensland facility, the company BlockTexx is already successfully using a chemical recycling method, on par with those designed internationally, to recover separated polyester and cellulose from blended fibre fabrics. The company is on track to scale up its current operation from recycling 4,000 tonnes to 10,000 tonnes of textiles per year. Plans are also in place to develop a second facility in NSW to divert a further 30 – 40,000 tonnes of waste textiles from landfill each year (Doogue, 2023). Research is also being undertaken at the Institute for Frontier Materials (IFM) at Deakin University, which has a circular economy focus on adding value to textile waste including blend separation technologies (IFM, 2023).

Whilst Australia currently lags Europe in terms of waste textile sorting and recycling infrastructure, this is not necessarily a bad thing. The benefit is that we can learn from the trial and error of others and 'cherry pick' solutions most applicable to local requirements. Multiple companies are developing automated textile sorting equipment as outlined in this report's case studies. Some companies already have a presence in Australia such as TOMRA, well known for developing the reverse vending machines in NSW.

Funding sources and the national clothing product stewardship scheme

The Australian Government (DCCEEW, 2023) is investing $250 million in new and upgraded recycling infrastructure through the Recycling Modernisation Fund with allocation of funding decided by state and territory governments, based on the gaps identified in recycling capacity. That Australia is on track to have an NCPSS for waste clothing operational by July 2024 is a significant and positive step towards developing onshore textiles recovery and recycling operations.

The NCPSS includes a levy for raising funds. At 4 cents/garment, it is expected the scheme could raise $36 million per year for initiatives that reduce textile waste if 60% of the market (by volume) sign up to the scheme. Specifically, as previously stated, part of the funding will be allocated towards "expanding clothing collection and sorting for effective re-use and to ensure non-wearable clothes are recycled into new high value products and material" (WRAP, 2023).

South Australia's Waste Strategy 2020-25 (GISA, 2020) categorises textiles as a problematic waste and identifies priority actions that include supporting investment in textile recovery technology and researching opportunities that may reduce the generation of textile waste and increase the recovery of textiles (GISA, 2020). It may be possible for GISA to partner with the NCPSS or the Australian Government to support the development of a local waste textiles recovery and recycling hub. State government incentives could also be considered to encourage textile recycling stakeholders to set up in South Australia.

Development of end markets

It would be prudent to have some assurance that end markets are in place for recovered materials before facilities are built around waste textile sorting and recovery. Research into, and the development of, end markets could support the future waste textiles recovery and recycling industry in South Australia.

Demand for products containing post-consumer recycled fibre is essential and individual brands and retailers can take the initiative to create more circular systems. Country Road's Recycled Cotton collection is "...made using 30% recycled cotton sourced from our off-cuts and faulty garments which are shredded, re-spun and blended with virgin cotton" (Country Road, 2023). Whilst this is not post-consumer fibre, it is a step in the right direction as it is normalising the use of blends of recovered and virgin fibres. State and local governments can both play a role by stipulating the inclusion of (preferably locally-recovered) post-consumer recycled fibre in uniform and other procurement specifications. GISA's current research into quantifying uniforms streams across state government will provide useful baseline data. As with any business venture, medium to long term contracts would provide certainty of demand for producers.

Potential for small-scale projects and multi-stakeholder collaboration

Small volumes of textile waste should not be seen as a deterrent to the development of a textiles sorting and recovery facility (providing end markets are in place for recovered material). Activities that commence on a small scale can be trialled and refined then scaled-up if necessary, once business operations are optimised.

Adelaide may not have as large a volume of waste textile material compared to other Australian cities; however, volumes from any one sector can be increased, and risk can be spread, by sharing resources between private industry, recycling charities, NGOs and government organisations. This may include shared capital and operational expenditure, use of infrastructure, sites and waste textile collection systems.

Whilst it is important to work towards development of an onshore textiles recovery and recycling industry in South Australia, in the short to medium term, partnerships could also be formed with interstate and overseas collaborators. In line with the NCPSS proposing a national approach to making the fashion industry more circular, initially supply chain stakeholders could be nationally based, rather than local. It may even be necessary to partner with international stakeholders, that could provide the services not yet established in Australia such as yarn and textile mills that have expertise working with recycled fibres. With increasing demand over time, local small-scale operations could be scaled up. Alternatively, well managed small-scale operations such as Coleo can be successful providing they are part of a stable value chain and they can produce consistent outputs.

Recycling facilities could also be established that focus on particular waste textile streams such as uniforms or other specific garments collected through retailer take back schemes, pre-consumer off-cuts, or a specific type of post-consumer waste, eg clean hotel linens such as sheets, towels and pillow cases.

Next steps

Sources of locally and nationally-generated waste textiles should be identified and the different streams quantified. Determining availability of the range of feedstocks would assist to identify which type of fibre-to-fibre recycling operation(s) would be best suited to SA. As noted by Greenaround (2022), there are opportunities to intercept household textile waste disposed of at the kerbside and the fraction of textile material currently sent to Energy from Waste by councils in South Australia should ideally be diverted to recycling and processing. Sorting methods would be determined by which recycling option(s) are chosen.

A review should also be carried out to identify what role, if any, existing facilities such as Resource Recovery Centres and Material Recovery Facilities, might have in future collection and sorting operations in Adelaide and regional South Australia.

Measures to limit the disposal of certain waste textile streams to landfill could be investigated as part of the current South Australian Environment Protection Authority's review of the Environment Protection (Waste to Resources) Policy (2023). Charity stores should also be required to pre-sort any clothing items that are sent overseas to ensure only quality reusable material is exported and any recyclable fraction is diverted to on-shore recycling facilities.

Together with local, national and international stakeholders South Australia should develop a plan that aligns with the NCPSS Roadmap and outlines steps for how to develop a local textiles recovery and recycling industry. Gaps as well as opportunities for collaboration with national and international partners should be identified.

Consideration should also be given for support of a business association or cross-agency government working group which would provide support to sustainable and circular textiles stakeholders in Adelaide. Functions could include keeping stakeholders abreast of relevant national and international industry developments, seeking private investor support, developing supply chains and market development, liaison with the National Clothing Product Stewardship Scheme coordinating body, attracting new stakeholders to Adelaide, assistance with grant applications, training, promoting the local textiles recycling industry and enabling networking.

Conclusion

The speed at which the closed loop textiles recycling industry is advancing in Europe indicates that this emerging industry will become a global norm in the future. South Australia, with its track record of early adoption of resource recovery and recycling systems is recognised nationally and internationally for its achievements. It is well positioned to host a textiles recovery and recycling hub given its proven experience in funding partnerships between state and local government and the private and non-profit sectors, in resource recovery infrastructure development. Well-developed freight transport infrastructure (road and rail networks, air and port) provide further support for establishing a national textiles recycling hub in the state.

Before undertaking my research trip to Spain and Portugal, I did not fully appreciate the extent of the operations involved in the production of textiles. After seeing processes firsthand, I now understand the scope of work that would be involved with developing a similar industry in Australia. Whilst it would require a significant injection of funds and technical expertise, this should be considered within the context of the benefits of the environmental damage that it would help to avoid. Also to be considered, is the alignment with *South Australia's Waste Strategy (2020-25)* (GISA, 2020), which promotes the adoption of actions that can contribute to the development of a circular economy and the potential for creating local jobs and skills, and developing best-in-the-field technology.

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Appendix 1: Study tour itinerary

Date	Organisation	Location	Purpose of meeting	Links to company
4/4/23	Sysav	Malmö, Sweden (online meeting)	To learn about the Siptex facility, which uses four NIR and VIS spectroscopy TOMRA AUTOSORT® units for sorting.	https://www.sysav.se https://www.sysav.se/en/siptex
25/4/23	Coleo	A Coruña, Spain	To learn about and view fully automated PICVISA ECOSORT TEXTIL optical sorter textile sorting technology in operation.	https://picvisa.com/en
28/4/23	Valérius 360	Porto, Portugal	To learn about production of yarn containing recovered textiles.	https://valerius360.pt
3/5/23	Formació i Treball	Catalonia, Spain	To see semi-automated VALVAN FibersortTM technology in operation and learn about how a large manual sorting facility operates.	www.formacioitreball.org
8/5/23	Coleo	Mataró, Spain	To view the company's design operations and post-consumer recycled fibre textiles.	https://coleo.es
8/5/23	Modacc Clúster	Barcelona, Spain	To learn about how this private business association supports the local fashion and textiles sector in Catalonia.	www.modacc.cat