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VTT

VALUE CHAIN MAPPING FOR NOVEL AND RECYCLED TEXTILE FIBRES

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Sisällys

Foreword

The Regional Council of Helsinki-Uusimaa is partner in the Interreg Europe 2014-2020 BRIDGES project. The last phase of the BRIDGES project, 1.10.2021–30.9.2022 was dedicated to value chain-based development as an approach enhancing regional resilience. Value chains are well understood and applied instruments of multinational corporations. In the BRIDGES project we felt, however, that regional specialisation and the need to access innovation markets of and for both intermediate and final goods, implies longer term, more predictable collaborations, which can be well served by value chain initiatives. To reach such collaborations, the Helsinki-Uusimaa region selected the value chain of renewable and recyclable textiles. It is an advanced, innovation -based domain, exploring circular economy, and part of the Helsinki-Uusimaa RIS3 strategy. Its competitive advantage is in the advanced research results and research infrastructures already located in the region, and the potential of the raw material inputs across the whole country, for example cellulose.

The present report maps the strengths (peaks), weaknesses/challenges (valleys) and collaboration options of renewable and recyclable textiles. The results of the value chain mapping reveal that there is potential for re-locating textile production thanks to the direct access to research services and under the precondition of automating the production process. This implies a faster transformation of the economy and the development of a new specialised industry. Confirming this, in-shoring of cellulosic textile fibre spinning already started as Infinited Fiber Company announced plans to build its commercial-scale Infinna™ fiber factory. Potential for re-shoring the production of high-end luxury products, highly valued brand products and high-quality technical textile products and additionally, localised micro-factories offering repair and re-making services with sewing, printing small scale dyeing capabilities. Finally, near shoring and interregional collaboration have also been identified in terms of raw materials inputs, production of intermediate goods and joint development, in the Baltics, Sweden and Denmark, as well as Italy (Friuli Venezia Giulia, cellulose and specialisation alignment), France (textile, garment and research market) and Portugal (Centro and Norte, textile production and cellulose; also textile-specialised innovation intermediaries).

Our intention is to look deeper into the findings and explore development and growth options as part of our RIS3.

On behalf of Helsinki-Uusimaa Regional Council I want to thank Mrs. Ninetta Chaniotou, The Regional Council of Kainuu, Finland and Mr. Ari Lainevuo from Helsinki-Uusimaa Regional Council from BRIDGES Interreg Europe Project which made this important and most interesting value chain analysis come true. I want also thank Mrs. Taina Kamppuri from VTT Research of splendid investigation and research analysis.

Juha Eskelinen,
Director, Regional Development
Helsinki-Uusimaa Regional Council

Summary

This report is a final deliverable of the Interreg EUROPE BRIDGES project additional activities, approved under the 5th call on 31.5.2021.

This report summarises the mapping of the value chain for textiles and especially for novel bio-based and recycled textile fibres. The textile value chain is discussed in more general level and then the focus was in Helsinki-Uusimaa region, especially, the enablers and barriers for the creation of value chains for novel and recycled textile fibres in Helsinki-Uusimaa.

In addition to enablers and barriers, the analysis of the value chain included availability of raw materials and re- and nearshoring potential and the effect of external shocks in Helsinki-Uusimaa. The legislative and regulatory framework for textile industry is discussed in more general level and focused mainly on the EU Textile Strategy. The research projects in bio-based and circular textile fibres were listed as supporting background on active research and development.

1. Description and objectives

Helsinki-Uusimaa Regional Council is member in an ERDF funded Bridges project where one of objectives is to map value chains for selected applications relevant for certain geographical areas. For this work, the selected application is textiles and especially novel bio-based and recycled textile fibres. The textile value chain is discussed in more general level and then the enablers and barriers for value chains of novel and recycled textile fibres in Helsinki-Uusimaa region.

The goal for the work was to map the supply and value chain for novel and recycled textile fibres. The value chain from fibres to textiles was included, but as the technologies are mature and existing mainly outside of Finland, the goal was to consider reshoring as one option along the value chain.

VTT has strong background of Finnish textile industry and for example, VTT was involved in formulating the road map for Finnish textile industry for 2035. Additionally, VTT has strong background of the development of bio-based textile fibres and building a recycling ecosystem to Finland in several jointly funded projects, e.g. Telaketju actions[1].

2. Methods / realisation

2.1 Resources and project organisation

Project manager:	Taina Kamppuri
Project members:	Pirjo Heikkilä, Miika Nikinmaa, Ali Harlin
Project's steering group:	Ari Lainevuo, Ninetta Chaniotou

2.2 Methods

Supply and value chains were mapped by using VCR-mapping excel delivered by the customer. As timetable was short, no workshops was possible to consider. The mapping background was mainly collected during other projects and especially during the workshops and interviews with the Finnish textile actors. These projects were Roadmap for Finnish Textile Industry for 2035 funded by VTT with internal funding; and two national textile recycling projects Telaketju and Telaketju 2. The final reports of these are marked in the reference list. However, lot of background information was accumulated and gather during the fruitful discussion with the Finnish textile actors during the projects that enabled the writing of this report.

[1] Telaketju network's website https://telaketju.turkuamk.fi/

3. Background

3.1 Textile industry

Textiles is arguably the oldest and largest globalized industry. It is also an industry that has experiences a global race-to-the-bottom in terms of labor costs since the 1970s. These features may mean that the industries is not easily disrupted or impressed by technological advance. On the other hand, textile industry have adopted many technical solutions and scaled up them to industrial scale. This offers a potential for the global textile industry to lead the way once more and turn the textile production into more sustainable. The current operating logic, which has remained roughly the same for several decades, in mass-customized ready-to-wear textiles is a linear push model, in which customer interaction has been indirect and predictions on future demand have been rather inexact.

General global view on the textile supply chain with the value creation along the chain is shown in Figure 1. Economic value creation mostly happens in stage that is labeled "*Design and Branding*", which includes intermediaries, that is, for example wholesalers and retailers. In terms of value creation, the second most important is "*Logistics and Sourcing*". Only third is production, which covers materials and some stages of the manufacturing process. This holds true in Finnish textile value chain, also. For example, the cost breakdown of a Finnish brand's blazer showed that half of the final pre-tax price a consumer paid went to the retailer, one quarter went to the brand holder; all the rest – materials, components, manufacturing, and assembly as well as some logistics and packaging got the remaining one fourth (Tahvanainen & Pajarinen, 2014).

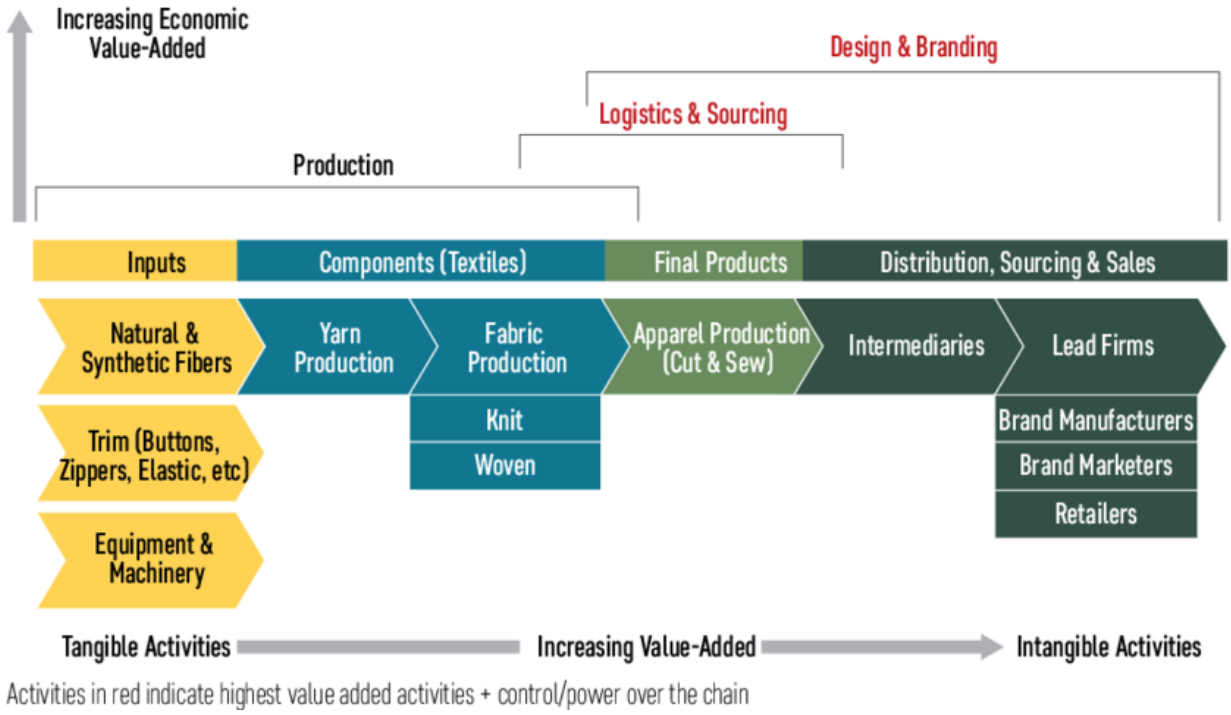
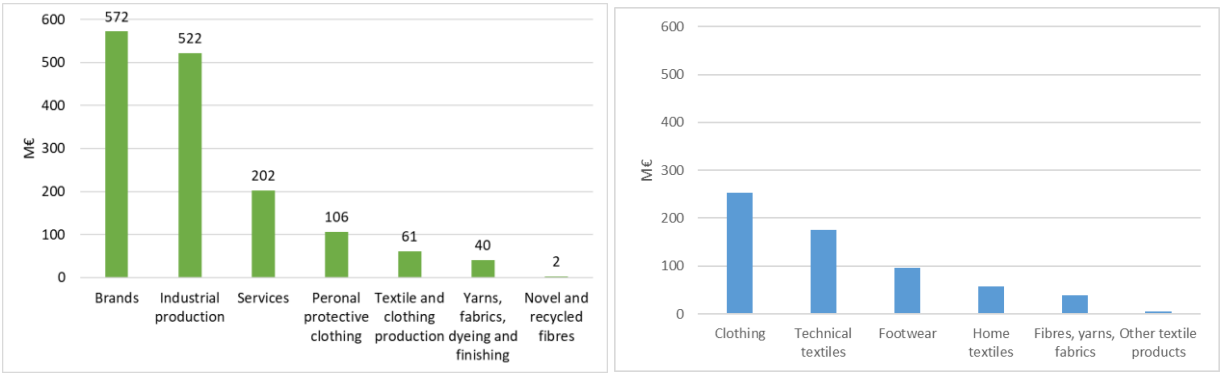


Figure 1 Textile supply chain with value creation adapted from Rouvinen (2021)

The global textile value chain is long and branched. This leads to challenges in finding the right partners. At the moment, especially for small actors in the value chain, the potential to have impact on the other players' sustainability and responsibility statements is very limited and even non-existent. The transparency of the value chain is limited, and it is difficult and even impossible to get needed data and information on the other actors in the value chain.

3.2 Finnish textile industry

Finnish textile and fashion sector covers a number of different actors and activities, such as retail and wholesale of textiles and fashion, maintenance of textiles and fashion, and other manufacturing related to the industry, including shoes, leather goods, fiberglass and mattress. In 2019, the turnover of the whole textile sector was EUR 4.4 billion[2]. The turnover and export of selected subsectors of the Finnish textile industry is shown in Figure 2. The retail and wholesale of textiles (*Brands*), both fashion and home textiles, that are not manufactured in Finland had clearly higher turnover compared to the turnover of those that were manufactured in Finland (*Textile and clothing production*). Clearly in export, clothing had the highest value. The manufacturing of technical textiles, such as nonwovens, hygiene products, medical textile products and other technical textiles, had high turnover and high export showing that Finnish actors are global players, especially in nonwovens.



a) *b)*

Figure 2 a) Turnover of different subsectors of Finnish textile industry in 2019, Heino et al. (2021). (Brands includes manufacturers of clothing, accessories and interior and home textiles, such as fashion brands that do not have their own production in Finland; Industrial production includes nonwovens, hygiene products, medical textile products and other technical textiles; Services includes rental, laundry and second-hand platforms; Personal protective clothing includes manufacture, wholesale and retail) and b) export in 2020[3]

The identified expected major future developments of the Finnish textile industry, grouped in the same segments than in *Figure 2a*, are collected in *Table 1*. These segments include active businesses, in the first four segments the business is strong, and there are products in the market and the business is mature. For those sectors the future competitive advantage is related to the use of automation, robotics

[2] Tilastokeskus / Yritysten rakenne- ja tilinpäätöstilasto & suhdannetilastot

[3] *Tekstiilin ja muodin tavaravienti ja –tuonti, Suomen Tekstiili ja Muoti* https://app.powerbi.com/view?r=eyJrIjoiMTA1NzA5MmYtMTNkYi00NzhjLWJkYjktMmJlYjY1Njc0MWI3IiwidCI6IjZlOTVmZjE2LWU5NjUtNDljMC05ZGI2LTZiNjg4ZDJjZDhmZSIsImMiOjh9. *This statistic is based on Custom's foreign trade statistic (Tullin ulkomaankauppatilastot)*

and different digital solutions. Additionally, different service models will emerge to fashion business. Service models are already in use in B-2-B systems, e.g. in personal protective clothing. The use of recycled and novel bio-based textile fibres will enhance the competiveness of apparel and technical textiles. For the segment named *Yarns, fabrics, novel and recycled fibres*, business is active but products are not in the market yet. Finland has world-class understanding on the use of biomass for value-added textile fibres, for the development of technologies to produce cellulose based textile fibres, and circular economy solutions from mechanical recycling to chemical recycling of cellulosic materials.

Table 1 Expected major future development of Finnish textile industry segments

Industry segment	**Current situation**	**Competitive advantage**
Brands, textile and clothing production	There is local textile production in Finland, but in addition, we have production partnerships in the Far East and Europe. New Finnish brands that are based on sustainability starts to emerge. New platforms to on-line shopping of sustainable fashion (for example Ivalo.com). Reuse business for high value fashion products is starting. No mass production in Finland. Gap between the possibilities and the current level of digitalization in Finnish textile companies.	There may emerge local production micro-factories that combine new technologies and production methods. The main development and competitive advantage is related to digitalization of manufacturing and supply chain logistics. Additionally, automation and robotics in production.
Industrial production	Production and converting nonwovens dominate technical textiles.	Competitive advantage is based on development of automation, online characterization (analogous to paper industry).
Services	Materials-as-a-service model has become a common practice in B-2-B. Service models for brands starts to emerge.	Digitalization of service models and different developments in logistics (automated transport systems etc.)
Personal protective clothing	Producers of personal protective clothing are forerunners in materials-as-a-service business. Also starting to include end-of-life service.	Designed for recyclability and end-of-life recycling. The main development and competitive advantage is related to digitalization of manufacturing and supply chain logistics. Additionally, automation and robotics in production.
Yarns, Fabrics, novel and recycled fibres	R&D and demo plants dominates. Investments for two industrial scale plants (IFC & Metsä Spring). Industrial scale production of Spinnova fibres is starting. Industrial scale mechanical recycling starting (LSJH).	This was selected for the focus of value chain analysis and further details can be found in Tables 2-4 and Chapter 4.

The competitive advantage in Finnish textile value chain are recycled and novel cellulose based fibres. The Finnish world-class emerging manufacturing technologies currently and in foreseeable future for novel cellulose based fibres are collected in *Table 2*. Additionally, there are alternative cellulosic fibre technologies developed in Finland, listed in *Table 3*. Helsinki-Uusimaa has had significant impact on the research and development of the novel textile fibres.

Table 2 Emerging manufacturing technologies for cellulosic textile fibres in Finland

Currently	**Future**
Wood based textile fibres / **Spinnova** • Textile fibres directly from wood pulp without dissolution • Industrial scale factory (Woodspin) in Jyväskylä and an industrial scale in-house yarn spinning facility are estimated to be in operation at the end of 2022	• Full scale production of textile fibres and ring-spun yarns • Likelihood to invest in Finland of second industrial scale plant is low
Regenerated textile fibres from recycled cotton- / wood-based cellulose carbamate / **Infinited Fiber Company** • cellulose carbamate plant in Valkeakoski • fibre spinning pilot in Espoo, nominal annual capacity 150 metric tons	• IFC has announced in June 2022 plans to build its first commercial-scale Infinna™ fiber factory at Stora Enso's Veitsiluoto industrial site in the city of Kemi in Northern Finland • Factory will have an annual capacity of 30,000 metric tons/annum and will use post-consumer textile waste as feedstock. • The plant's entire output is intended for export
Regenerated textile fibres from wood / **Metsä Spring** • Ionic liquid based fiber spinning of wood pulp (Kuura™ fibres) • MI test plant in Äänekoski	• Metsä Group is owned by Finnish forest owning members • Likelihood to invest in Finland for industrial scale regenerated fibre plant is foreseen to be strong

Table 3 Innovations developed in Finland for alternative cellulosic fibre technologies

Company/ Technology	**Short description**
Aalto University, Ioncell	Ionic liquid based fiber spinning of ligno-cellulosic material including textile waste.
Biocelsol (VTT/TUNI)	Enzyme-aided cellulose modification method for producing cellulosic textile fibres.
Fortum	Production of pulp from straw for textile fiber spinning.
Nordic Bioproducts Group, Norratex	Chemical cellulose modification method (AaltoCell™) for producing cellulosic textile fibres. Currently the IPR is outlicensed globally to Andritz Oy.

Additionally we have mechanical recyclers of textile waste, LSJH and RESTER. They are identified as forerunners in Europe. They are part of openly and actively built textile recycling ecosystem where both post-consumer and industrial waste streams are covered. Their opening lines have the capability for

removal of hard parts, such as zippers, buttons etc. included in automated line. In addition to them. Dafecor has almost 30 years history of tearing, opening, and using of textile materials in nonwoven and felt production. They have two plants one in Turenki and another one in Jyväskylä. *Table 4*

Table 4 Mechanical recyclers in Finland

Currently	**Future**
Mechanical recycling • 2 lines in Paimio • LSJH (post-consumer), 4000 – 5000 tonnes/year • RESTER (B2B), 4000 – 5000 tonnes/ year • Dafecor (B2B), operating business, capacity not known	In 2025: full scale mechanical recycling infrastructure including partly automated sorting for recyclables[4] • LSJH post-consumer, Topinpuisto Turku • 15 000 tonnes/ year • Collection of textile waste will cover whole Finland • 20.5 million EUR investment, BF RFF funding 5.2 million EUR

3.2.1 Export potential

Finnish technical textiles, especially nonwovens for hygiene and wipes, will have steady growth and they are expected to have export potential 300 M€ in 2035. Novel wood based fibres and recycled fibres are expected to have increased export potential in 2035. The growth will start after 2025. Additionally in 2035, Finnish export potential is strongly based on machinery and automation solutions, and possibly also in chemicals for textile recycling.

3.3 Circular textile supply chain

A simplified textile supply chain, with markings of the parts that are in Finland, is presented in *Figure 3*. Currently, in Finland, we do not have any industrial fibre producer and rather small operators in yarn (e.g. Novita), fabric (e.g. Lapuan Kankurit, Inka) and garment (e.g. Agtuvi Oy) production. Instead, we have industrial nonwoven producers (Suominen, Ahlström), and technical (Mirka) and hygiene application (Delipap, Mölnycke) producers. We also have strong brands and an industrial scale operators in mechanical recycling (Rester, LSJH, Dafecor). Additionally, we have pilot scale chemical recycling of cellulosic raw material to novel virgin fibres utilising cellulose carbamate process (Infinited Fiber Company, IFC) and emerging novel fibre producer with unique process (Spinnova). Chemical recycling of thermoplastic textile materials, such as polyester, polyamide, is missing from Finland.

[4] https://www.stjm.fi/uutiset/kuluttajapoistotekstiilit-maanlaajuisesti-uudelleenkayttoon-ja-kierratykseen-ensimmaiseksi-suomessa-2/

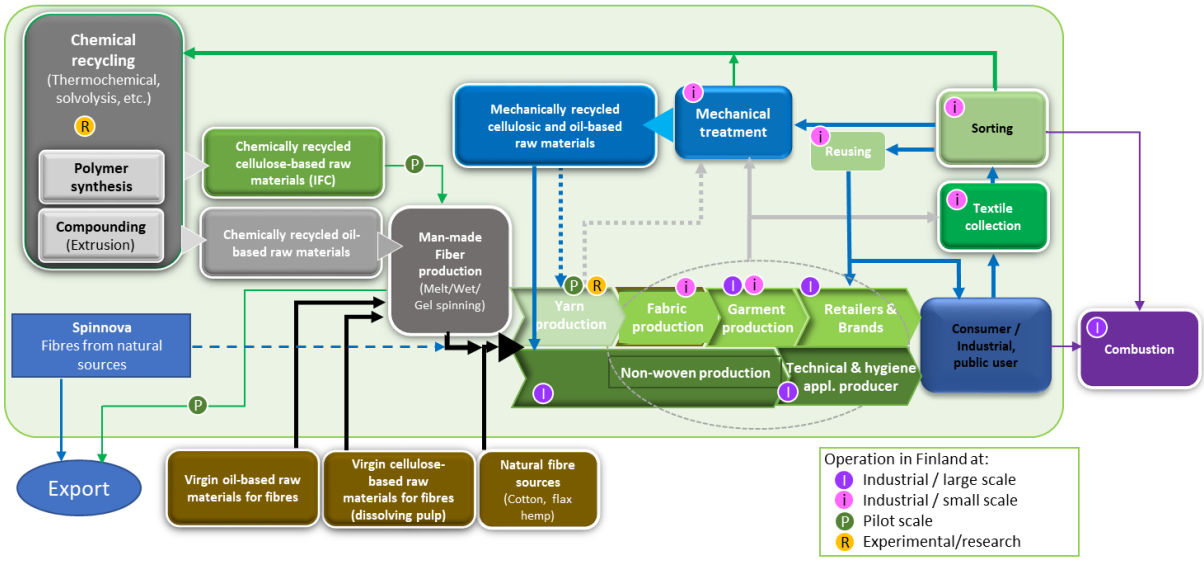


Figure 3 Simplified current circular textile supply chain where used textiles are circulated back to the chain either via mechanical recycling or via chemical methods. Green and blue boxes indicate existing and emerging parts in Finland, grey boxes indicate parts that are under development in research institutes not involving companies, yet.

4. Value chain analysis in textile fibre sector in Helsinki-Uusimaa region, Finland

4.1 Textile fibre value chain in Helsinki-Uusimaa region

The value chain analysis was focused in bio-based and recycled textile fibres in Helsinki-Uusimaa.

The value increases when the number of value chain stages increases from fibres to yarns, fabrics and finished products. It was estimated that from raw material to textile fibres the value will double, especially this is true for the bio-based textile fibres whose raw material is pulp. But the value of final garment was estimated to be six times higher to the raw material. However, the further processing steps from fibres ahead are labour intensive and Finnish textile industry actors do not see the future in mass production of labour intensive production steps, but in production partnerships in Europe. Additionally, the industrial value-added production may partially stay in Finland if we have strong brands that control the supply chain. The brands will get leverage from the novel textile fibres developed in Finland. For example, the Finnish textile fibre companies, near commercialization, share a common vision that their fibre brands will be strong enough to be visible in consumer product.

Helsinki-Uusimaa has and has had active research on novel textile fibres. This has had significant impact on the growth of business. Metsä Spring's Kuura™-cellulosic textile fibres originates from research and development in Helsinki-Uusimaa. Aalto University has actively developed two alternative cellulose fibre spinning technologies. The process of establishing a company to commercialise the Ioncell method is underway[5] and AaltoCell™ technology has licenced the IPR though Nordic Bioproducts to Andritz[6]. VTT's start-up Spinnova originates from Helsinki-Uusimaa, even though its current location is in Jyväskylä area. Infinited Fiber Company is another example of VTT's recent start-ups and their headquarters is in Espoo. Additionally, VTT is developing a water-based dissolution and wet spinning methods for cellulosic textile fibres called, Biocelsol, in Bioruukki. VTT Bioruukki is a piloting centre for new bio-based products and circular economy solutions with unique expertise, modelling and piloting capabilities under one roof. In the lab and pilot plant different actors of any size can develop and scale-up innovations and processes and thus accelerate their product and process innovation cycles.

All of these above technologies, listed above, will add the value of the raw material when upgrading it into cellulosic textile fibres. The investments needed to scale the processes from lab to plot to pre-industrial scale are needed (tens of millions of Euro). For example, Infinited Fiber Company has announced 400 million invest cost for their new the industrial scale mill in Kemi for Infinna™-fibres. The high investment costs limit and slow down business start-ups.

Along with new cellulosic fibres, recycling solutions are evolving. Many of the processes mentioned above can use recycled cellulosic materials either alone or in mixtures with virgin pulp as a raw material. For example, Infinited Fiber Company's technology is able to utilize used cotton textiles as their raw material. The chemical recycling of cotton textiles is thus almost a commercial method in Finland. Along chemical recycling of cotton, mechanical recycling solutions are emerging. The textile recycling hub is based in Lounais-Suomi (Turku-Paimio area).

[5] https://www.aalto.fi/en/news/pilot-production-line-for-ioncell-launched-a-top-made-with-the-stronger-than-cotton-ecofibre
[6] https://www.nordicbioproducts.fi/post/norratex-press-release

As Helsinki-Uusimaa is the most densely populated region in Finland, there is clear potential to collect raw materials, i.e. end-of-life consumer textiles, for recycling. The value of end-of-life textiles will grow the more accurately they are sorted. At the moment labour intensive manual sorting dominates. Additionally, manual sorting is the stage of the value chain, where subsidized work is often used. Manual sorting capacity varies, a skilled sorter can sort even 1600 kg textiles a day, but the amount usually varies between 200 - 600 kg per day (Heikkilä et al. 2021). The sorting has clear impact on price of the mechanically opened fibres. For example, a bale of mechanically opened cotton fibres may cost 240 - 380 €/bale. It is impossible to sort the mechanically opened fibres afterwards. Additionally, in the further stages of the value chain i.e. in the use of mechanically recycled fibres there are still untapped business opportunities for Helsinki-Uusimaa. The textile value chain for mechanically recycled fibres may the same as for novel fibres, but new innovations can create new business and entrepreneurships. The collection and sorting stage in the recycling value chain are stages where novel innovations can be the game changers. For example, collection system that can separate certain fractions in the moment materials enter the system and different digital, automation and robotics solutions.

The recycling value chain covers mechanical recycling and chemical recycling of cotton. However, restoring the quality of polyester fibres in mechanical recycling is challenging. This is the case with cotton also, but especially with polyester. Recycling facilities that recover synthetic polymers vis chemical routes from textile flows are missing in Finland. Globally, synthetic polymers are recovered, but mainly from plastics. Part of the end-of-life textiles that cannot currently recycled could be recycled in chemical stages. The brand new textile recycling centre utilising mechanical recycling in Finland gives leverage to the development of the chemical recycling of synthetic materials. The quality of fibres produced from chemically recovered polymers is comparable to virgin fibres. In addition, the chemical recycling route is the only possibility to separate different fibre types from the blended materials (e.g. cotton/polyester blends) and to utilise the fibre blends as raw material for higher value products. Tailor-made recycled materials, depending on the stages utilised the output can be lower quality and lower price or higher quality and higher price.

In addition, the separate collection of plastic waste covers whole Finland. Helsinki-Uusimaa has strong actor in the olefin recycling (Borealis Polymers). However, also plastic sector is missing the recycling of polyester (PET packaging). Thus there is a possibility to combine plastic and textile sectors to secure the material: amount of available PET enough for industrial scale plant. PET is one of the best chemically recycled polymers due to the technical ease and economic feasibility of the recycling operations. Many global companies already have well-established PET recycling businesses globally. However, research and development is needed, to bring the se material flows together and to find a feasible way to chemically recycle polyester from both fractions. Chemical recycling of synthetic textile fibres is an enabler for the closed-loop material flow and for conserving the natural resources in Helsinki-Uusimaa. It also leverages creation of start-ups and new business to Helsinki-Uusimaa region where research is already strong.

Additionally, innovations around other cellulose sources than wood pulp and technologies either to turn the source into pulp or directly use the natural fibres may create business and entrepreneurship in Helsinki-Uusimaa. At, the moment Fortum is leading the way by developing utilization of straw-derived cellulose. Additionally, in Helsinki-Uusimaa CH-Bioforce has developed a technology for fractionating biomass. These offer a new feedstock option for different innovative value chains, for example raw for cellulose based textile fibres.

The reinvention of the natural fibres that were used before the commercialisation of synthetic textile fibres may bring business to Helsinki-Uusimaa. For example, nettle fibres are commercially available, but fibre-nettle is grown and processed into textile fibres in Germany. Helsinki-Uusimaa based Finnish

company Knokkon Textiles Company Oy is using nettle fibres in their textiles products. Fibre nettle cultivation requires low energy inputs, it can be produced and processed locally and it can give a wide range of products, in addition to textile fibres it can be used for other applications, such as in cosmetics. The nettle fibre supply chain lacks actors who cultivates and produces nettle fibres. This may be an opportunity for agriculture in Helsinki-Uusimaa. In Finland we cannot cultivate cotton due to the climate reasons, but fibre nettle can be cultivated. Also flax and hemp can be cultivated in Finland, but nettle fibres are softer and the added value of nettle fibres in clothing applications may be higher. At the moment the price of nettle fibres is not competing with cotton. Technology innovations to remove high quality nettle-fibres from the plant may change the situation, but as a developing new fibre its commercial use probably will start from niche markets.

In many stages of the textile fibre value chain, different chemicals are needed. It is possible that chemical industry can create new business from developing chemicals for processing alternative cellulose sources, for spinning of textile fibres and for textile recycling. For example, in Helsinki-Uusimaa Kemira is actively developing their expertise in cellulose based textile fibre chemistries. In addition, chemicals may enhance the processing and quality in textile recycling operations. New approaches and inventions may provide new business opportunities for chemical industry.

4.1.1 Enablers and barriers

The return of the textile value chain to Finland takes place from two directions: the direction of fibre production and the direction of clothing design and branding. Research organisations in Helsinki-Uusimaa have actively developed novel cellulose based textile fibre processes as well as processing of alternative cellulose sources. This has already resulted on creation on business and there are still possibilities to make new inventions. According to recent study of Finnish Textile and Fashion, companies in the textile and clothing industry, including actors in Helsinki-Uusimaa, are willing to invest in international sales and marketing[7].

The Finnish textile industry have lost know-how and related machinery during the offshoring of the labour intensive processing steps. In addition, the textile education is almost disappeared and there may be lack of a skilled workforce. Finland is small country and the national market size is limited. Additionally, the Finnish consumer brands are not so large that the demand would cover the upstream supply of the value chain. International markets and exports are needed to keep the business in Finland and the Finnish textile industry is only possible through international networking. This hold true for actors in Helsinki-Uusimaa.

There is a need for an attractive investment environment for international investors in Finland. The review of taxation, predictability of regulation, streamlining of licensing processes and stability of the operating environment is required. The stability of Helsinki-Uusimaa's operating environment, predictable regulation and the smoothness of licensing processes are advantageous for business operations, but also issues to which international investors pay special attention. Fair contract basis between the actors are needed to ensure security of companies business at every stage.

The enablers and barriers of textile fibre value chain in Helsinki-Uusimaa are collected in *Table 5*.

Table 5 Enablers and barriers of textile fibre value chain in Helsinki-Uusimaa region.

[7] https://www.stjm.fi/uutiset/yrityskysely-tekstiili-ja-vaatetusalan-yrityksilla-investointihalukkuutta-kansainvaliseen-myyntiin-ja-markkinointiin/

Enablers	Barriers
New cellulose based textile fibre manufacturing expertise is available in Helsinki-Uusimaa. Companies investing in commercializing of novel cellulose based fibres are based in Helsinki-Uusimaa. Helsinki-Uusimaa has high population density and skilled work force. Increase of consumer awareness in Helsinki-Uusimaa. Education launched to train not only designers, but also consumers in circular and sustainable textiles. Good IT education in Helsinki-Uusimaa. Strong understanding and know-how of automation and machinery for other industries (e.g. Valmet) and clear interest in entering textile business area. Instead of mass production, creation of new micro-factories are seen as possible in Helsinki-Uusimaa. Readiness and ability for entrepreneurship Helsinki-Uusimaa is stable environment and follows EU's regulation. Investors value sustainability when making their investment decisions. Textiles are part of Finnish bio-economy strategy. Helsinki-Uusimaa has started separate collection of end-of-life textiles. Good networks from Helsinki-Uusimaa to the pilot-scale plants starting production of mechanically recycled fibres in Finland. Cellulose based textile fibres are recyclable via mechanical and chemical methods. Cellulose based textile fibres can enter the same recycling processes as cotton.	Processing steps before the spinning of textile fibres are located in places that are close to raw materials. Spinning processes for producing cellulose fibres are energy intensive. The location production mills are close to green and/or inexpensive energy sources. Production mills for novel cellulosic fibres are not located in Helsinki-Uusimaa, jobs creation in other parts of Finland dominates. It is difficult to find investors to invest in Finland and especially invest in labour-intensive production steps. Sufficiently large investments are hard to obtain in start-ups. Finnish brands that are needed to bring the products from novel fibres to consumer markets are small. Finnish textile value chain is lacking yarn spinning, weaving as well as finish such as dyeing that are needed for production of clothing. Compared to the foreign counterparts, Finnish brands are small and international competition is hard for small brands. Helsinki-Uusimaa's attractiveness as an investment environment. Textile education has been almost disappeared from Finland Technical knowledge about textile processes are lacking. Digitally skilled workforce for textile sector is challenging. Lack of repair and customization services and competence in general. Recyclability of final textile product is based on its design. Eco-design education is only starting

4.1.2 Availability of raw materials

In the forest industry, raw material can be transported within a radius of about 500 km from the plant that processes it. In case of alternative raw material sources for pulping, it has been estimated that the raw material should be transported within a radius about 100 km. This due to the high air content (light density) and lower total amount of cellulose in the alternative sources. As a result, it is unlikely that a pulp mill would emerge in Helsinki-Uusimaa, but business could emerge around alternative pulp raw materials. This would require harnessing the land area for the cultivation, and in densely populated Helsinki-Uusimaa land use may be more productive in other ways.

Helsinki-Uusimaa has started the separate collection of end-of-life textiles. Based on HSY's tweet (24.5.2022), they have collected 55 800 kg of end-of-life textiles during less than 5 months. This means that during one year the amount of collected textiles are 135 000 kg. Earlier case-study from South-West Finland showed that more than 30% from the collected textile waste was still reusable clothing, about 20% is such materials that cannot be recycled (for example outdoor clothing with laminated layers) and the rest was recyclable textiles. Based on these figures, it can be estimated that Helsinki-Uusimaa can produce about 70 000 kg of recyclable textiles annually. However, the separate textile collection has just started and there are only nine collection points only in the metropolitan area. It is expected that when number of the collection points will grow, they are more easily accessible and the amount of recyclable textiles will grow.

4.2 Reshoring

Reshoring is the partial or total return of production previously offshored to low-wage countries to the original country, to serve local, regional or global demand. Offshoring and job losses have affected Finnish textile industry, especially the labour intensive production steps, industrial scale yarn spinning and weaving were offshored in 1980's and 1990's. It is not likely that regional actors in Helsinki-Uusimaa will reshore these nor compete with the traditional mass production in textile assembly in future. More likely, the regional reshoring is focused on high-end luxury products, highly valued brand products and high quality technical textile products.

According to Stentoft et al. (2015) the general reasons for reshoring are: (i) cost, (ii) quality, (iii) time and flexibility, (iv) access to skills and knowledge, (v) risks, and (vi) other factors (such as incentives, core focus, shrinking market, and correction of a misjudged decision). For the regional textile actors in Helsinki-Uusimaa, from the above quality, time and flexibility, skills and knowledge may be relevant. Additionally currently, all the aspects of sustainability, responsibility and more transparent supply chain are encouraging nearshoring.

Nearshoring means relocating to a country that is closer geographically, in time zone or culturally, but without developed country costs. In EU actors, Turkey and Morocco are relevant countries to nearshoring textile production. There is all the missing steps from yarn spinning, weaving and dyeing, finishing of fabrics. In Helsinki-Uusimaa, logical nearshoring countries are Baltic countries when considering especially textile assembly, e.g. production of final garment. For the partnerships in recycling of textile materials, in addition to Baltic countries, Nordic countries, especially Sweden and Denmark, are desired. The partnerships in geographically near areas will reduce the freight costs and the speed-to-market.

4.3 Legislative and regulatory framework for textile industry

Textiles were identified as priority sector in which EU can pave the way towards a carbon neutral, circular economy in Green deal (2019) and Circular economy action plan (2020). EU Strategy for sustainable textiles was published in March, 2022[8]. In a competitive, resilient and innovative textile sector producers take responsibility for their products along the value chain. Circular rather than throw-away clothes have become the norm, with sufficient capacities for recycling and minimal incineration and landfilling. The vision for 2030 is that all textile products placed on the EU market are:

- Durable, repairable and recyclable
- made of recycled materials
- free from hazardous substances
- To a great extent made of recycled materials
- Free of hazardous substances
- Produced respecting social rights
- “Fast fashion is out of fashion” – consumers benefit longer from high quality textiles
- Profitable re-use and repair services are widely available

EU strategy for sustainable textiles offers excellent opportunities for Finnish companies. It is well in line with the Finnish vision for textile industry (Kamppuri et al. 2021), recycling targets in Finland (Heikkilä et al. 2021) and carbon neutral textile industry (Heino et al. 2020). Many of the proposed actions are already put in practise (e.g. separate collection of textile waste, use of recycled fibres in textiles) and are under research and development in Helsinki-Uusimaa and in Finland. In general, strategy encourages companies to thrive for the green transition and to develop circular business models. Some other regulations and their possible impact on Helsinki-Uusimaa textile fibres value chain are collected in *Table 6*.

The Commission staff working document, EU transition pathway for a more resilient, sustainable and digital textiles ecosystem, is under preparation[9]. It introduces scenarios for the transition pathways of the EU textile ecosystem. The aim is to identify with stakeholders what the digital and green transitions and increasing resilience mean for the textiles ecosystem and what measures and commitments are needed to accompany this transition. The Staff Working Document invites the whole industrial ecosystem and other stakeholders to take active part in co-creating a way forward. Currently, different actors were asked to give their feedback for the scenarios.

[8] https://ec.europa.eu/environment/publications/textiles-strategy_en
[9] https://ec.europa.eu/growth/consultations/transition-pathway-more-resilient-sustainable-and-digital-textiles-ecosystem_en

Table 6 Regulations and their possible impacts on actors in textile fibre value chain in Helsinki-Uusimaa.

Legislation/directive	Rationale	Impact
EU Waste Framework Directive (WFD)	Define the basics principles related to waste management for Member States of the European Union	By 1st January 2025 Member States shall set up separate collection for textiles (WFD, Article 12b DIRECTIVE (EU) 2018/851). Note in Finland, separate collection will start in 2023 and in Helsinki-Uusimaa (HSY pääkaupunkiseutu) has already started.
Single used plastic directive (SUP)	Concerns especially single-used nonwovens (e.g. wet and dry wipes, hygiene products)	Finnish nonwoven producers are actively seeking solutions to replace plastic materials in single used products. Promote research in Helsinki-Uusimaa.
Forest strategy (legal status in communication)	Framework for sustainable forest management, including "thresholds and ranges" to determine the limits of sustainability	May be barrier for textiles as it promotes use of forest biomass in energy and construction, increasing thus the use of wood. Promote research and entrepreneurship in developing alternative cellulose sources.
Ecodesign Directive, revision	Revised version covers textiles (among other products)	May promote Helsinki-Uusimaa in its strong design knowledge, education and entrepreneurship.

4.4 Research projects

For more than a decade, there has been research on new bio-based textile raw materials in Finland. Projects that promote the circular economy of textiles started to emerge in 2010's and there has been strong focus on development of textile recycling ecosystem. Table 7. The Finnish research projects, related to bio-based textiles and circular economy of textiles, are internationally remarkable. It is globally recognised that Finland has created significant expertise in textile recycling and in novel cellulose based textile fibres as well as a wide network of cooperation. This will help in finding sustainable textile solutions in line with the recycling and circular economy goals of Finland and the EU.

Table 7 Textile-related projects and activities carried out in Finland and / or with Finnish partners. The last two columns indicate whether the project is linked to bio-based textile solutions (B) and / or recycled fibres or the textile circular economy (C), modified from (Heikkilä et al 2022).

Name of the project (abbreviation), short description if applicable	**Financing model; implementer (s) or size of the consortium, etc.; duration**	**Additional information (retrieved June 2022)**	**B**	**C**
Sustainable and fit-for-purpose nonwovens (SUSTAFIT)	Business Finland; 18 partners; 2022-2024	Not started, no public information yet	x	x
Development of bio-based and antimicrobial materials and use as protective equipment (BioProt)	Business Finland; 16 partners; 2022-2023	www.lut.fi/en/projects/bioprot	x	
Value Chains for Sustainable Production, Use and Cycling of Textiles (Telavalue)	Business Finland; 21 partners; 2022-2024	www.telaketju.fi	x	x
Product as a Service pilots (PaaS Pilots)	SITRA; 3 partners + company co-operation; 2021-2022	www.telaketju.fi		x
Accelerating the development of sustainable bioproducts (ExpandFibre)	Business Finland, Veturi: companies Fortum and Metsä; 2020-2024	www.expandfibre.com	x	
From cellulose to new Finnish man-made cellulose fibers and sustainably colored textiles (FinnFiberColor)	Business Finland / ExpandFibre ecosystem; 11 partners; 2021-2023	www.expandfibre.com/news/item/finnfibercolor-project-develops-sustainable-solutions-for-man-made-cellulose-fiber-processes	x	
Value for Cellulosics (ValCel)	Business Finland / ExpandFibre ecosystem; 10 partners; 2021-2023	www.valcel.fi www.expandfibre.com	x	
(SynbioPro) Synthetic biology in the manufacture of materials and chemicals, includes also textile fibres	Business Finland/ ExpandFibre ecosystem; 7 partners; 2021-2022	www.expandfibre.com/news/item/finnish-science-and-industry-join-forces-to-develop-microbial-cell-factories-in-the-synbiopro-project	x	
Telaketju - Business from circular economy of textiles (Telaketju 2 BF)	Business Finland; 27 partners; 2019-2021	www.telaketju.fi		x

End-of-life textile refinement plant (Telaketju TEM)	Ministry of Economic Affairs and Employment of Finland; Lounais-Suomen Jätehuolto + other Finnish waste management companies; 2018-2020	www.telaketju.fi		x
End-of-life textile refinement plant (Telaketju AIKO)	Regional Council of Southwest Finalnd; Lounais-Suomen Jätehuolto; 2017-2018	www.telaketju.fi		x
Telaketju - Towards Circularity of Textiles (Telaketju Tekes)	Tekes; 19 partners; 2017-2019	www.telaketju.fi		x
Sustainable textile systems: Co-creating resource-wise business for Finland in global textile networks (FINIX)	Academy of Finland; 8 partners; 2019-2022	www.finix.aalto.fi		x
Future of Nonwovens (FoN) Development of airlaid nonwovens from bio-based and recycled fibers	Business Finland/ ExpandFibre ecosystem; 9 partners; 2021-2023	www.expandfibre.com/news/item/future-of-nonwovens-project-coordinated-by-vtt-boosts-biobased-nonwovens	x	x
Piloting alternatives for plastics (PAfP) includes foam and air forming of nonwovens from bio-based materials	Regional Council of Central Finland + 55 companies; VTT; 2020-2023	https://cris.vtt.fi/en/projects/piloting-alternatives-for-plastics	x	
New Cotton Project, chemical recycling for circular fashion	H2020; multinational 12 partners, 2020-2023	www.newcottonproject.eu		x
Circular Nordic Bio Nonwoven in MedTech Applications (NordicBio)	Business Finland & Vinnova; 8 partners Finland&Sweden; 2018-2020	https://cris.vtt.fi/en/projects/circular-nordic-bio-nonwoven-in-medtech-applications-2	x	x
Future Fibre Products (FFP2020) included foam formed nonwoven materials	Regional Council of Central Finland + 32 companies; VTT; 2017-2020,	https://cris.vtt.fi/en/projects/future-fibre-products-ffp2020	x	
Growth from recycled wool Kiertovillasta kasvuun	Häme Centre for Economic Development, Transport and the	www.theseus.fi/handle/10024/135581		x

	Environment; several companies; 2016-2017			
Novel processes for sustainable cellulose-based materials (Neocel)	EU BBI-JU; multinational 13 partners; 2016-2019	www.neocel.eu		x
Trash-2-Cash (T2C) New fibres from pre-consumer and post-consumer waste	EU H2020; multinational 17 partners; 2015-2018	www.trash2cashproject.eu		x
Relooping Fashion Iniative Tekstiilien kiertotalous (TEKI)	Tekes; 9 partners; 2015-2017	https://cris.vtt.fi/en/publications/the-relooping-fashion-initiative		x
TeKiDe Sustainable new textiles from waste cotton in Helsinki-Uusimaa	Helsinki-Uusimaa Regional Council 2 partners; 2016-2018	https://ec.europa.eu/regional_policy/fi/projects/Finland/tekide-technology-creates-sustainable-new-textiles-from-waste-cotton-in-helsinki-uusimaa	x	x
Opportunities and barriers in textile recycling Tekstiilijätteen kierrätyksen mahdollisuudet ja esteet (Texjäte)	Ministry of Environment, Finnish Environment Institute SYKE, UH Centre for Consumer Society Research, Häme University of Applied Sciences HAMK, UFF; 2013-2015	www.syke.fi/hankkeet/texjate		x

4.5 External shocks and impact on "business as usual"

One significant cause of concern for the global textile and apparel industry is the rising cost of essential raw materials such as crude oil and rising cost of food, which in turn raises the cost of labour. Inflation is expected to significantly impact sourcing and has direct effect on consumer prices. Textile and apparel prices are expected to rise, especially the rise of freight rates will have an impact, but also raise in raw material and labour costs may cause pressure to raise prices.

The crisis in Ukraine have strained relations between Russia and European Union. In general, the economic and other sanctions caused by the Russian-Ukrainian war may lead to a decrease in the export of textiles and clothing from several major exporting countries to Russia, and this part of the decrease may be fulfilled by China. However, since Russia's textile and apparel import demand accounts for a relatively small proportion in the world, the Russian-Ukrainian war may more affect global trade flows, while its impact on total demand may be relatively limited. However, the shortage of seafarers may disrupt the global supply chain. In addition, the war may have impact on cotton prices as Russia is major exporter of fertilizers.

The disruption of global supply chain may have an effect on regional actors in Helsinki-Uusimaa, especially availability and increased delivery time of certain trims (e.g. zippers, buttons, and sewing threads) may have a local effect. Already now, long waiting times of machinery spare parts has caused delays in industrial production. More likely the possible increase in inflation and increased raw material costs will have more impact on the region. There have been a global speculation about the cotton price and the effect of Ukraine crisis on the price. This may be an advantage on the actors in Helsinki-Uusimaa who already are using other bio-based materials on their textiles and on these who are developing cellulose based textile fibres.

5. Conclusions and summary

Textile industry is the oldest and largest globalized industry and the global textile value chain is long and branched. Finnish textile industry offshored labour intensive production steps during 1980's and 1990's. Today, Finnish textile industry covers a number of different actors and activities, such as retail and wholesale of textiles and fashion, maintenance of textiles and fashion, and production of technical textiles. As the Finnish forest industry started to seek more value to pulp, it promoted the research on cellulose based textile fibres. thus, for more than a decade, there has been research on new bio-based textile raw materials in Finland. Projects that promote the circular economy of textiles started to emerge in 2010's and there has been strong focus on development of textile recycling ecosystem.

Helsinki-Uusimaa has created significant expertise in novel cellulose based textile fibres as well as a wide network of cooperation. This has had significant impact on the growth of business. Many of the emerged start-ups are seeking and have announced on investments to scale up technologies for producing cellulosic textile fibres. Along with new cellulosic fibres, recycling solutions are evolving. Helsinki-Uusimaa has clear potential in collecting raw materials, i.e. end-of-life consumer textiles, for recycling. But also, in developing novel solutions for sorting textile materials (e.g. intelligent collector). Helsinki-Uusimaa has potential in combining PES side stream from plastic and textile value chains and to develop a research platform fro chemical recycling of PES that is currently missing from Finland. The ability to recycle polyester would promote not only textile but also plastic and chemical industries.

It is not likely that regional actors in Helsinki-Uusimaa will reshore mass production in yarns, fabrics and textile assembly in future. More likely, the regional reshoring is focused on high-end luxury products and high quality technical textile products. In Helsinki-Uusimaa, logical nearshoring countries are Baltic countries when considering especially textile assembly, e.g. production of final garment. For the partnerships in recycling of textile materials, in addition to Baltic countries, Nordic countries, especially Sweden and Denmark, are desired. The partnerships in geographically near areas will reduce the freight costs and the speed-to-market.

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