The production of textile materials is continuously growing with increasing global collective purchasing power and there is an expectation to replace cotton and oil based textiles with more sustainable alternatives. To make progress towards this shift and to strengthen Sweden’s position several approaches have to be examined. This roadmap shows how this will be done until 2025.

The overall target by 2025 is to have an established production of commercial sustainable textile materials from Swedish cellulose and recycled cellulose. This is expected to have a positive environmental impact, and gives a potential to create new job opportunities in Sweden connected to Swedish and international textile industry.

By 2016: Establishing and development of new and existing test beds organised in a platform at the RISE institutes

By 2020: Development and pilots of textile production in close collaboration with the industry that will strengthen the knowledge transfer by increased mobility between industry and the RISE institutes

By 2025: Production of cellulose based textile materials and products thereof that strengthen Sweden’s future global competitiveness.
Background

In 2011, the Swedish Government commissioned Formas, VINNOVA and the Swedish Energy Agency to create a national strategy for the development of a bio-based economy to support sustainable development. This resulted in the strategic innovation program BioInnovation with the vision that Sweden makes the conversion to a bio-based economy in the first half of the twenty-first century. The European Commission is looking at cost-efficient ways to make the European economy more climate-friendly and less energy-consuming. By 2050, the target is that the European Union will cut most of its greenhouse gas emissions. Clean technologies are the future for Europe's economy [1]. Large investments are expected to be included in Horizon 2020, EU’s Framework Programme for 2014-2020 and the EU initiative Bio-based Industries Public-Private Partnership (BBI PPP).

The global textile consumption is expected to increase three times until 2050 and existing technologies need to be replaced by more sustainable alternatives to reach the climate goals. At the same time Swedish forest industry faces new challenges originating from declining demand for printing paper and growing global competition among producers. New value-added products are needed for the Swedish forest industry to stay competitive and sustainable forest-based textiles are great examples of such products. The Swedish forestry provides an excellent cellulose containing raw material, with no concerns regarding water scarcity, use of fertilizer and hazardous pesticides and competition for cultivated land used for food. However, development of new resource-efficient production processes with low or negligible environmental impact is necessary to realize the vision of a forest-based textile industry.

Today's textile materials

A textile is a flexible material made of primarily polymeric (natural or synthetic) fibres; the fibres can either be arranged 1) directly into a nonwoven, or 2) into a yarn that is used to form a fabric by for example weaving. In the following more detailed description the aforementioned division is used as there is a significant difference between how nonwovens and fabrics are produced where nonwovens might be seen as a simpler material but also more versatile and inexpensive than fabrics.

The total global yearly consumption of textile materials is about 100 million tons of which 10% is nonwoven and 90% is fabric. The global fibre demand, as calculated by England based PCI Fibres, shows that polyester is dominant and is predicted to take even more market shares until 2030. The production of cellulosic synthetic fibres is also predicted to increase and if the development of new cellulosic fibres is successful the growth rate might even exceed the forecast. Polyester is predicted to increase considerably, already today some of the polyester production is partly biobased and soon there will be 100% bio-based polyester products, e.g. PET bottles. The total Swedish export of textiles (incl. clothes) 2014 was 20.6 billion SEK and the import 43.0 billion SEK giving a net import of 22.4 billion SEK according to SCB.

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1 Fabric refers to any material made through weaving, knitting, spreading, crocheting, or bonding.
The global fibre demand as calculated by PCI Fibres in its forecast out to 2030.

Nonwovens

Nonwovens are a unique class of textile materials, formed by bonding more or less randomly oriented fibres by different techniques. Today, nonwovens have achieved an excellent position among the products of daily use like hygiene, medicine, and household; but also technically challenging products like air filter media, functional wound care, and battery separators. The global consumption of nonwovens in 2015 is predicted to 8.95 million tonnes, equivalent to $37.4 billion, and the growth for the period 2015-2020 is projected at 6.2% [2]. The Swedish export of nonwoven textiles 2014 was 1163 million SEK and the import 1123 million SEK giving a net export of 40 million according to SCB. Today there are several nonwoven producers present in Sweden, most of them are SME:s and are already using bio-based materials, like viscose, hemp, PLA, in some of their products.

Nonwovens are today mainly made from fossil based polymers but there is a strong market trend towards decreasing the carbon footprints and adapting nonwoven products to the bio-based economy [2]. Hitherto the only green alternative have been polymers made from renewable agriculture resources such as maize, sugar cane, and wheat; resources that have been questioned since they compete with food production, often involves high use of pesticides and fertilizers, and also contribute to an accelerated rate of deforestation. The interest for nonwovens based on sustainable forestry is still in its infancy but is predicted to explode when there is a commercial material available.

Fibre to yarn to fabrics

Yarns are made from fibres that can be natural like cotton or synthetic like polyester, fabrics are formed by interlacing the yarns by different techniques, a clear majority of the fabrics are made by weaving or knitting. The oldest known woven fabric dates back to 3000 BC and was found in Switzerland and since then, until the last century, the fibres used have been of natural origin, e.g.
Textile materials from cellulose

flax, hemp, cotton, and jute, where the fibre is extracted directly from the plant. In the late 19th century the synthetic cellulose-based viscose process was invented and in the mid 20th century the production of oil-based fibres like nylon and polyester started. The global textile fibre production 2014 was 96 million tonnes [3] where polyester and cotton are dominant, see below figure. The market share for regenerated cellulose is 5% but it is also the fastest growing segment during the last 5 years and is expected to continue to grow another 10% until 2020.

In the 60’s Sweden had several textile fibre producers, most of them used the viscose process, today there are none of those producers left. However, there are a few newly established fibre producers indicating a restart for Swedish fibre production. The production of fabrics by weaving or knitting seems also to be increasing, not only for technical textiles but also for apparel. According to SCB, the export of yarns and fabrics 2014 (excl. clothes) was 5.9 billion SEK and the import 10.8 billion SEK. For clothes the export was 13.6 billion SEK and the import 31.1 billion SEK.

Potential future applications for cellulose based textiles

Textile production as we know it today started with the beginning of the industrial revolution in Great Britain which also provided a great increase of the global cotton production. Today the focus is on developing new and sustainable production of textile fibres, for example organic cotton, lyocell, modern viscose, and bio-based polyester. It is also important to take care of the textile waste and recycle it as efficient as possible, for example by dissolving a used cellulose fabric and re-spinning it into a new cellulose fibre. The potential value chain for Swedish cellulose based textiles is depicted below. In the same figure the main product areas are indicated in the pie chart; 1) textiles for apparel, 2) consumer home textiles, and 3) technical textiles, the size of the pie chart segments represent the global production of each.
Humans have been using clothing for around 100 000 years to protect the wearer from weather, insect bites, thorns, etc. Over the years, clothing has evolved to serve as an expression of culture and social status, during the last centuries the apparel industry has developed more and more towards fast fashion. This leads to that a considerable fraction of all clothes are thrown away rather on aesthetical reasons than that they are worn out. Fast fashion has caused an increase in the environmental damage caused by the textile and this problem will certainly continue unless an enormous change is made in the attitudes of consumers. Swedish forest based textiles have a clear potential to be a more sustainable alternative to cotton, polyester, and ‘old-school’ viscose, and is also a natural part of the cradle-to-cradle life cycle in the above figure. For example jeans made from denim is a textile product where many new Swedish producers are searching for more sustainable alternatives. It is thus interesting to use jeans as a reference product for the potential of new cellulose yarns.

A technical textile is a textile where function is primary and aesthetic aspects are of minor importance with a range from simple packaging materials to leading edge technologies, for example spacesuit materials. Therefore it is not surprising that cellulose based textiles cannot replace all existing materials in technical textiles. However by developing new and tougher cellulosic fibres by new spinning methods or by using nanofibrillated cellulose it might be possible to expand the range where cellulosic textiles can compete with today’s materials. For example the fossil based polymers normally used in geotextiles, agrotextiles and building textiles can be possible to replace by modified cellulosic fibres. Nonwovens used in hygiene products, air filters, furniture, vehicles, etc. are today mostly based on polypropylene or polyester where the properties of the fibre are on a lower level and it might be possible to replace with a sustainable cellulosic fibre.
# Technologies and competences at the RISE institutes – an overview

| **KEY ENABLER:** | **TRL**<sup>2</sup> |  
| Adaptation of pulp is done to get desired properties of the cellulose pulp for the following processes. |

| **KEY ENABLER:** | **TRL** |  
| Dissolving of cellulose can be done in many different types of solvents. The purpose is to separate the polymers and get a spinnable solution. |

| **Spinning of nanofibrillated cellulose** is a new technique for man-made continuous fibres of cellulose that do not need to take the circuitous road via first dissolving the cellulose. |

| **Solution blowing** is used to produce a nonwoven directly from dissolved cellulose with potential for high volume production. |

| **Solution spinning** is used to spin a fibre from dissolved cellulose that is coagulated in a spin bath. |

| **Textile processes** like yarn spinning, twisting, carding, weaving, knitting, finishing, and plasma treatment to make a textile designed for a certain application or product. |

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2<sup>2</sup> TRL stands for Technology Readiness Level which is an indication of the technology matureness.
Technologies and competencies at RISE – Current & Future

The aim is to create a framework and structure for an all-embracing platform covering all steps from adaptation of pulp to forming and testing a textile material. To fulfil the present roadmap, the following R&D resources have been identified:

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**Adaptation of pulp**

By unconventional use of conventional pre-treatment, pulping and bleaching, it is possible to produce tailor-made cellulose fibres for selected value-added applications already in the fibre line. New concepts can be assessed by techno-economic evaluation. The concept of adapted pulps with high reactivity facilitates future business opportunities for cellulose pulp fibres, and contributes to sustainability by enabling energy savings, green solvent systems, and improved utilization of wood resources.

Cellulose pulps with improved and novel properties are currently under development, and methods for recovery of chemicals for new properties are studied. A prerequisite for efficient up-scaling is an open test bed for production of cellulose fibres from adapted pulp.

**Nonwoven in a paper machine**

Nonwovens can and are being produced on a paper machine using a wet-laid process. The drawback, however, is the relatively poor product, they are mechanically weak, which have limited
Textile materials from cellulose

the process from taking significant market shares and from being used for production of high volume products such as home textiles and car interiors. Technically speaking, it is feasible to produce materials with textile-like functionality by combining wood fibres with cotton fibres or other polymeric fibres. This has been demonstrated by Innventia through a series of lab studies. By combining different fibre types and a wet-laid technique and also combining it with state of the art techniques used in papermaking, such as stratified forming and micro-creping, it would be possible to revolutionize the functionality and product performance.

Another issue that must be addressed is that textiles are generally not recycled, only reused which creates large volumes of waste, e.g. more than 2 million ton of old textiles is landfilled or burnt each year. Several techniques and process for increased recycling of textiles is under development. Production of nonwovens in a paper machine is an important technique here since a significant amount of waste textiles could be utilised as a fibre source without need for dissolving the existing textile fibres first.

The FEX pilot paper machine and StratEx semi-pilot paper machine are already existing test beds that are excellent for developing, up-scaling, and demonstrating nonwoven materials using a wet-laid process. The key issue for achieving the described targets is stable funding for doing a large enough number of trials to fine-tune the process. Up-scaling always need significant practical trials, which are costly, and something the industrial companies can’t finance fully without support.

Spinning of nanofibrillated cellulose

At many locations around the world it has been shown that it is possible to make continuous fibres from nanofibrillated cellulose. One process that stands out in terms of achieving high mechanical performance is hydrodynamic alignment by flow focusing concept. Innventia has applied for a patent on this particular process. The question for the future really is whether or not processes for spinning nanofibrillated cellulose into fibres will be cost competitive or not. Currently the RISE institutes are working together with several industrial companies on how to up-scale the flow focusing technology and to make it cost competitive.

The technical possibility to spin fibres directly from nanofibrillated cellulose has been shown at numerous locations around the world. The key question is whether or not these new technologies can become cost competitive or not. The future research must therefore focus on up-scaling and techno-economic assessment. A crucial step that significantly would facilitate up-scaling and enable a critical evaluation of the cost competitiveness is an open test bed for production of textile fibres from nanofibrillated cellulose. Moreover, since this is a novel field with relatively low technical readiness and associated uncertainty, it is also important that industrial companies get support in financing work in this area.

Dissolving of cellulose

Finding sustainable and economically feasible solvent systems is extremely important. Around the world a lot of effort is put into developing processes for manufacturing of fully or partially dissolved cellulose dope systems using environmentally sustainable dissolution systems, for example cold alkali solvent systems. Until today, only a limited number of solvent systems have been successfully implemented onto an industrial scale and they often suffer from various environmental problems as well as energy and safety issues.
Through research and experience the RISE institutes have become successful in understanding the complex dissolution process, which requires much effort in adaptation for different pulp materials as well as specific temperature. Based on previous experimental experiences different impregnation methods as well as pulp/solvent ratios have been successfully implemented in the dissolution process to produce well dissolved systems for subsequent spinning with focus on high strength fibres. The process is not only dependent of the specific conditions used during dissolution but also on the adaptation of the pulp.

To obtain an economical and sustainable fibre production it is vital to have an effective recovery system of chemicals used for pulp dissolution and fibre coagulation. It should not generate large amounts of waste as in traditional viscose production or have high energy demand as in lyocell. Moreover, the dissolution procedure should be used for chemically dissolving post-consumer textiles and subsequent spinning into new textile fibres.

Solution blowing
The basis for solution blowing is the meltblown principle where fibres are stretched with a high velocity air stream. Hitherto, most of the research has focused on getting nonwoven with as fine structure as possible. Here is an evident opportunity to instead maximize the strength to make a biobased inexpensive material that can compete with existing fossil based nonwoven. The most important parameter to succeed with solution blowing is to have a correct viscosity of the cellulose solution. Solution blowing is today mostly used for synthetic polymers but several successful attempts have been made with cellulose solutions. The problems are similar to solution spinning, i.e. how to recover the solvent.

During the last years solution blowing has been proved to work for several different types of solvents, hitherto all attempts have been made in a laboratory scale. The future efforts should focus on scaling up to a pilot scale equipment in an open test bed environment that is based on an inexpensive solvent, e.g. cold alkali, and an effective recycling system to get the basis for cost-efficient production of cellulose based nonwovens. Such test bed can share a lot of equipment and knowledge with a pilot scale solution spinning test bed.

Solution spinning
In solution spinning, the cellulose solution is prepared in a suitable solvent and then extruded through a spinnere into a coagulation bath containing a non-solvent. The cellulose concentration and thus also the output is determined by the cellulose solubility and solution spinning pressure limitations. The polymer concentration used for wet spinning is lower than that in dry spinning due to that the solution is normally spun at lower temperatures. Current research is focused on finding effective solvent systems that are possible to recycle in an effective way.

To facilitate the development of new and more effective spinning systems there is a need for flexible spinning lines ranging from lab scale up to commercial pilot scale. Some already exists but to for example develop a modern viscose process complying with today’s environmental legislation a new spin line is needed. All open available resources, both existing and planned, should be organised in a common test bed to avoid redundancy and to maximize the knowledge transfer both within RISE and between RISE and the industry.
Textile processes

Textile processing is needed to convert the fibres or nonwovens into final products. A lot of different methods exist, all from carding staple fibres to surface treatments with atmospheric plasma. Today recycled textile fibres are reused in nonwovens for applications like sound absorbers, a lot of effort is also put into how to re-spin the textile fibres into a yarn. The challenge is to shred the textile into fibres and at the same time keep the fibre properties so that it is possible to use them in a new yarn. The existing techniques for shredding are old and to take the next step a test bed for textile shredding is needed at RISE.

A lot of work has to be done to develop and enhance certain properties of the cellulosic fibres, for example wear resistance, durability, colour fastness, dirt repellence, strength, the list is almost endless. Whereas the nonwoven materials are produced as a web the fibres have to be converted to yarns and fabrics to evaluate their textile properties. Thus there is a need for a test bed where the fibres can be carded either into a nonwoven or a precursor for yarn spinning (ring or/and rotor). The test bed should also include lab-scale weaving and knitting rigs, methods for impregnation (e.g. foulard), plasma treatment. Some of this equipment already exists at the RISE institutes and some exists at the academy, e.g. the Textile School in Borås.

Sources

4. Fiber year 2015
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Contacts

Main contact
Pernilla Walkenström  Swerea  pernilla.walkenstrom@swerea.se  +46 (0)31 7066323

Authors and contributors
Mårten Alkhagen  Swerea  marten.alkhagen@swerea.se  +46 (0)31 7066330
Åsa Samuelsson  Innventia  asa.samuelsson@innventia.com  +46 (0)768 767413
Fredrik Aldaeus  Innventia  fredrik.aldaeus@innventia.com  +46 (0)768 767188
Magnus Gimåker  Innventia  magnus.gimaker@innventia.se  +46 (0)768 767024
Emma Östmark  SP  emma.ostmark@sp.se  +46 (0)10 5166256
Agne Swerin  SP  agne.swerin@sp.se  +46 (0)10 5166031

The RISE Research Institutes of Sweden - Innventia, SP, Swerea and Swedish ICT - are a major R&D player in the bioeconomy sector, with a combined annual turnover in the field of 800 million SEK (85 million €). During 2014-2015 the activities were reviewed in the RISE-project RISE Bioeconomy. Areas with the greatest growth potential were identified and strategies for how to move forward were published in the following eight roadmaps for the period 2015-2025:

- The pulp mill biorefinery
- Textile materials from cellulose
- Materials from nanocellulose
- Bio-based composites
- Lignin-based carbon fibres
- Biofuels for low-carbon steel industry
- Food industry and pulp mill symbiosis
- Sensors for increased resource efficiency