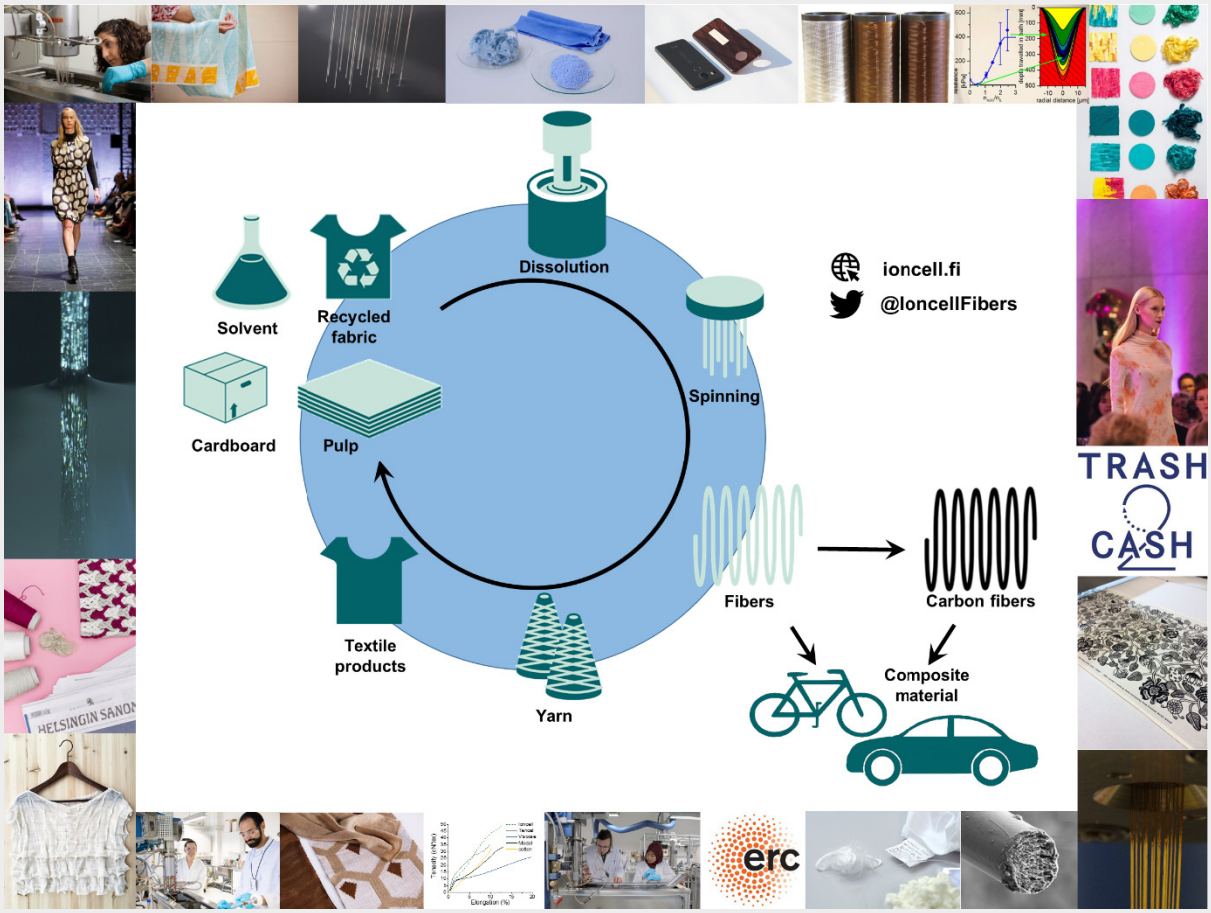
Aalto University



Ioncell-F

High-quality ligno-cellulosic fibres from wood pulp, waste paper and cardboard, and waste textiles

Impact case study
Department of Bioproducts and Biosystemes 2018

Aalto RAI 2018 Case Study

Field 3a: Chemical engineering and physics

Unit of Assessment (UoA): Department of Bioproducts and Biosystemes

Ioncell-F

1. Summary of the societal impact

Problem to solve: The increasing disposable income of the globally growing middle class, amplified by an estimated population growth of 20% over the next two decades, will trigger a hitherto unseen need for consumer goods. This also includes textiles and garments and will increase the annual per capita demand for cellulosic fibres from 3.7 to 5.4 kg by 2030. Cotton cultivation will not be able to meet this demand in the future, and so-called man-made cellulosic fibres (MMCFs) need to fill the gap. Currently, MMCFs are almost exclusively made via the viscose process, which necessitates tremendous amounts of CS_2 to form a spinnable cellulose derivative. The toxicity of CS_2 and its side products pose a severe risk on work forces and the environment, and strict regulations have led to the shutdown of almost all viscose mills in Europe and North America. Yet, the increasing demand for textiles has promoted numerous new installations in China and Indonesia where the legislation to protect the workers and the environment is less rigorous. The only commercial alternative for the production of MMCFs is the Lyocell technology using the solvent *N*-methylmorpholine *N*-oxide (NMMO). It can dissolve cellulose directly and does not require any other chemicals. However, it has notable intrinsic shortcomings, such as a reduced thermal stability and a considerable redox potential, limiting the application spectrum of the process. Both the viscose and the NMMO-Lyocell process require highly refined cellulose isolated from wood through various energy and chemical consuming pulping processes. There is an obvious need to develop an alternative process that bypasses the abovementioned drawbacks to satisfy the demand for textiles of future generations in an environmentally benign and sustainable way.

Offered solution: The Ioncell-F technology offers alternative Lyocell-type MMCFs. It is based on an ionic liquid (IL) solvent (1,5-diazabicyclo[4.3.0]non-5-ene-1-ium acetate, [DBNH]OAc) that allows us to dissolve cellulose at high concentration to form solutions, which have optimum visco-elastic properties to spin them in a Lyocell-type process to produce MMCFs with excellent mechanical properties exceeding all commercially available products. The solutions can be spun at moderate temperatures of 80°C, which preserves the macromolecular structure of cellulose and reduces the energy consumption. [DBNH]OAc was found to be such a powerful solvent that the cellulosic solute does not need to be sourced from high-grade dissolving pulp. Instead, low-value products, such as paper-grade pulp, can also serve as feedstock.

Impact: Due to their excellent mechanical properties, the fibres were not only suitable for textile and non-woven applications but also for technical uses, such as natural reinforcement filaments in composites or precursors for carbon fibres.

Last, the fashion industry is producing alarming amounts of textile waste, which at present is destined for landfills. The Ioncell process is capable of using waste cotton textiles as raw material to produce new, virgin fibres. This reduces the demand for costly dissolving pulp and also turns waste into a valuable feedstock. The Ioncell technology can solve problems at both ends of the textile chain. In fact, it offers the possibility to transfer the linear textile chain into a circular and sustainable economy.

2. Underpinning research/artistic activity related to Aalto activities

The development of the Ioncell-F process started in 2009 with a 5-year program financed through industrial partners and the governmental funding agency Tekes. After the breakthrough in 2013, funding for continuous development could be secured through a series of projects co-financed by the public and private sectors. This allowed for a number of PhD theses (2 completed, 2 almost finished, 6 ongoing). In addition, 3 postdocs, 1 Senior Research Fellow, and 1 Staff Scientist are currently working on the further development of the Ioncell process. Respective research activities both benefit and promote the multidisciplinarity of Aalto Univer-

sity. An intimate collaboration between the School of Chemical Engineering and School of Arts, Design and Architecture allowed us to lift the fibre development from the technical level to an applied state, including the manufacture of several prototype demonstrator products. Thus, research activities cover the entire textile chain, which has led to a broadening of Aalto's competence spectrum. Currently, a pilot plant is being designed with experts from the School of Engineering, and a yarn spinning line will be installed at the Aalto Bioproduct Center.

Thus, three Schools at Aalto University join efforts in Ioncell-F related research activities.

The Ioncell-F development was recognized with prestigious funding and awards, promoting the young university within Finland and across its borders.

- Horizon 2020-NMP-2014: *Trash-2-Cash:* Designed high-value products from zero-value waste textiles and fibres via design driven technologies (Grant Agreement: 646226; 2015-2018)
- ERC-2016-STG - ERC Starting grant: Unlocking the Entire Wood Matrix for the Next Generation of Carbon Fibers (WoCaFi, Grant Agreement: 715788; 2017-2021)
- European Paper Recycling Award 2015 by the European Recovered Paper Council for the utilization of waste paper and waste cardboard as raw material for high quality textile fibres.
- Global Change Award 2016 by the H&M Foundation for the utilization of waste cotton as raw material for high quality textile fibres.

3. References to research / artistic activities

The list below shows a selection from the 23 peer-reviewed articles that resulted from the work conducted between 2012 and 2017 (citation numbers taken from Scopus January 2018).

1. 'High performance man-made cellulosic fibers from recycled newsprint'. *Green Chemistry* (2018), 20(1), 160-169. DOI:10.1039/c7gc02896b (impact factor: 9.125)
2. 'Upcycling of waste paper and cardboard to textiles'. *Green Chemistry* (2016), 18(3), 858-866. DOI: 10.1039/C5GC01679G (impact factor: 9.125)
3. 'Renewable high-performance fibers from the chemical recycling of cotton waste utilizing an ionic liquid'. *ChemSusChem* (2016), 9(22), 3250-3258. DOI:10.1002/cssc.201600680. (impact factor: 7.226)
4. 'High-strength composite fibers from cellulose-lignin blends regenerated from ionic liquid solution'. *ChemSusChem* (2015), 8(23), 4030-4039. DOI:10.1002/cssc.201501094 (impact factor: 7.226, cited: 14)
5. 'Ioncell-F: A High-strength Regenerated Cellulose Fibre'. *Nordic Pulp & Paper Research Journal* 2014, 30, 43-57 DOI:10.3183/NPPRJ-2015-30-01-p043-057 (cited: 38, most downloaded article of this special issue)
6. 'Role of solvent parameters in the regeneration of cellulose from ionic liquid solutions'. *Biomacromolecules* (2012), 13(9), 2896-2905 DOI:10.1021/bm300912y (impact factor: 5.246, cited: 101)

4. Societal Impact, activities and roadmap for the case

The Ioncell development allowed for a symbiotic collaboration with the textile designer of the Department of Design promoting Aalto's interdisciplinarity. This generated new competences that cover the entire textile chain, from raw material to the final end-user product, turning Aalto University into one of Finland's leading textile research centers. Simultaneously, a strong textile network within and outside Finland was established, including other research centers (VTT and Tampere University of Technology in Finland; Kelheim Fibres, the Max Planck Institute for Dynamics of Complex Technical Systems, Rheinisch-Westfälische Technische Hochschule Aachen in Germany; Deakin University/ Carbon Nexus in Australia; Hong Kong Research Institute for Textiles and Apparel) and renowned textile companies in Finland (Marimekko, Reima, Nanso Group) and globally (Ikea, H&M, Kering). The interest of these companies and jointly produced prototype products that were presented in fashion shows, prize galas, and design exhibitions gave the Ioncell process international recognition.

This was acknowledged with funding for several projects to develop the Ioncell process further toward an actual business case. Currently, the main focus is on the solvent recycling concept to establish a fully closed-loop operation and, concomitantly, design and install a small continuous pilot fibre spinning line to demonstrate the scalability (see Section 6).

The development of a new versatile spinning process had an impact on multiple levels.

Immediate short-term impact: With other ongoing developments toward sustainable textile fibres, the Ioncell process contributed to an emerging awareness and consciousness amongst textile consumers regarding the global environmental impact of the textile industry.

Mid-term: In parallel with the development of the process, new knowledge along the entire textile chain is generated. This is leading to new textile expertise in Finland. Through courses and seminars for students, as well as for the non-academic audience, this knowledge is disseminated.

Long-term: The option of having locally produced garments from locally grown wood or from upcycled waste material offers the possibility to make the entire textile chain transparent. This will also hopefully attract other players along the value chain and lead to a resurrection of the textile industry in Finland to offer 100% locally and sustainably produced products for a global market. Thus, a textile fibre production bears great potential to initiate collateral business and job opportunities.

5. Sources to support the impact case

The following selection of links shall demonstrate the impact and dissemination of the Ioncell development:

- Webpages
  - Aalto University: Ioncell-F
  - ioncell.fi (includes background information, media coverage, contact details)
- Twitter: @IoncellFibers
- WO 2014162062 A1 (09.10.2014) Process for the production of shaped cellulose articles.
- Press conference at the 253rd ACS National Meeting and Exposition 2017: Upcycling 'fast fashion' to reduce waste and pollution
- Semi-finalist of the Helsinki Challenge 2017: Pitch Night June 6th 2017
- Extensive story in most influential Finnish daily newspaper *Helsingin Sanomat*: Researchers at Aalto University spin world's first yarn from newspaper - can this offer a more sustainable textile industry?

6. Future goals

Currently, several projects are solely dedicated to the further development of the technology (*SolvRec*) and to prepare for its commercialization (*ICom*). *SolvRec* (Technical Development of Ioncell-F with special Emphasis on the Solvent Recycling, 2017-2019) focuses entirely on the quantitative recycling of the ionic liquid to obtain a fully closed-loop operation. This project involves several academic and industrial partners across Finland with international experts supporting the development.

In parallel, a small pilot plant is being constructed and installed at Aalto University. The daily output capacity of 10kg of fibres will allow us to serve potential clients with quantities to get reliable feedback on the properties and prospective. This plant is fully financed by Aalto University.