Circular Economy considerations with regards to the inclusion of Man-Made Cellulose Fibers in Europe's Single-Use Plastic Directive:

A multidisciplinary approach

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Abstract:

In order to reduce the amount of Single-Used plastic products, the European Union issued its Single-Use Plastic directive. The regulation focuses on the ten most commonly found plastic items found on European beaches, including Single-Use wet-wipes.

This product type often made of viscose or lyocell, which are Man-Made Cellulose Fibers. As wet-wipes are included in the directive, these material types are in threat to be considered as plastic in the European legislation.

On the other hand, some Man-Made Cellulose Fiber technologies are often considered to be desirable options in a Circular textile industry, partly due to their potential in textile recycling.

A multidisciplinary approach has been applied to discuss the relevance of the inclusion of Man-Made Cellulose Fibers into the Single-Used Product Directive, concluding in a systemic solution that considers Circular Economy in both plastic, and textile industries.

Full Report: 134 pages

Annexes: 50 pages

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List of Abbreviations and Chemical Nomenclature:

[DBNH]OAc	1,5-diazabicyclo[4.3.0]non-5-ene acetate (solvent in the Ioncell® process)
CE	Circular Economy
CED	Cupri-ethylanediamine
COP	Cross-Over Point
DBN	1,5-diazabicyclo[4.3.0]non-5-ene
DMC	Dry-Matter Content
DR	Draw Ratio
EC	European Commission
ECHA	European Chemical Agency
EMF	Ellen MacArthur Foundation
EU	European Union
G'	Storage modulus
G"	Loss modulus
G_1;G_2	Green cotton waste samples
IL	Ionic Liquid
MMCF	Man-Made Cellulose Fiber
NGO	Non-Governmental Organization
NMMO	N-methylmorpholine N-oxide (solvent in lyocell process)
R_1;R_2;R_3;R_4	Red cotton waste samples
RH	Relative Humidity

SUP	Single-Use Plastic
SUPD	Single-Use Plastic Directive
T_{spin}	Spinning Temperature
v_e	Extrusion velocity
v_{tu}	Take-up velocity
WP	Work Package involved in FINIX project (WP1,2,3,4,5)
η	Intrinsic viscosity
η^{0*}	Zero-shear viscosity
ω	Angular frequency
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
CS_2	Carbon Disulphide
NaOH	Sodium Hydroxide
H_2SO_4	Sulfuric Acid
CMF	Changing Markets Foundation

1. Introduction:

Plastic is one of the most important and ubiquitously occurring material in our every-day life. On the one hand, it has several essential functions; hence it is used from the transportation industry, throughout safe food packaging, even in medical innovations (EC, 2018). On the other hand, the plastic industry as it is today, with its take-make-dispose nature, has a tremendous effect on our environment. (EC, 2018; EMF, 2017)

The global use of plastics has reached 322 million tons in 2015, which is twenty times more than it was fifty years ago, and expectedly it will double in the next twenty years. In parallel, the generated plastic waste in the European Union (EU) today is almost 26 million tons a year. From this amount of waste, less than 30% is collected to be recycled, the remaining 31% and 39% are incinerated, or ending up straight in the landfill (EC, 2018).

Almost 60% of the EU plastic waste comes from packaging, from which, according to estimations of The Ellen MacArthur Foundation (EMF), 95% of the value cannot be used after a short, first-use cycle (EMF, 2017) The growing demand of these 'single-use' plastics (SUP) is further exacerbating the plastic waste generation every year (EC, 2018).

Apart from the massive CO2 demand which comes from the production phase and the pollution from waste incineration, the other major problem is the waste leaking into the environment. It is estimated that globally, between 5 and 13 million tons of plastics are ending up in the oceans yearly, damaging the marine ecosystems (EC, 2018; Jambeck et al., 2015). In the EU, this number is between 150 and 500 thousand tons of plastic waste, which are especially damaging vulnerable marine ecosystems, such as the one in the Mediterranean Sea (EC, 2018; Eunomia, 2016). The most common are also the SUP items, which take 50% of all found items on the European beaches (EC, 2018; Joint Research Centre, 2017).

As a response to these issues, in 2013, the European Commission (EC) released the Green Paper on a European Plastic Waste Strategy, in which they observed that although the leaking of plastic is a global problem, it has to be tackled locally. They also emphasized the problem of marine litter and stated:

"Plastic waste in the marine environment is unacceptable."

(EC, 2013)

Meanwhile, to tackle today's sustainability issues in general, the concept of Circular Economy (CE) has emerged worldwide and has been primarily promoted by the EMF. As opposed to the linear way of production and consumption, it offers a new way to design, make, and use our products staying within our Earth finite system (EMF, 2017). CE has also been recognized by the EU. In 2015 the European Commission released an action plan for CE, addressing the decrease of waste production and the development of a carbon and resource-efficient European economy, taking into account the product's whole life-cycle (EC, 2015). The first priority area of this document was also plastic, and it was aimed to create a "Strategy on plastics in the Circular Economy", which includes the above-mentioned issues. The European Strategy for Plastics in a Circular Economy creates a vision for implementing CE in the plastic industry. They aim to turn the challenges into opportunities, where the production and the design already take into consideration the needs of reuse, repair, and recycling (EC, 2018).

The new CE action plan of the European Commission is also addressing plastics as one of the key value chains to deal with. This document mentions the implementation of a new directive on the reduction of the impact of certain plastic products on the environment, so-called Single-Use Plastic Directive (SUPD). Apart from plastics, another key value chain discussed in the new CE action-plan is the one for the textile economy (EC, 2020).

It is claimed that textiles give the fourth highest pressure on the use of raw materials and the fifth for CO2 emissions, whereas on a global scale, only 1% of all produced textiles are recycled into new (EC, 2020; EMF, 2017). Textile products do not anymore merely satisfy a basic human need (Maslow, 1943), but they became fashion items, which subsequently changed the consumer behavior towards them and remarkably decreased their lifetime (Piribauer and Bartl, 2019). Apart from the great resource depletion and greenhouse emissions, water usage, and dangerous toxic chemicals can also be added to the bill of this industry (Allwood et al., 2019). These environmental issues can be substantially reduced by the decreased production from virgin materials (Dahlbo et al., 2017). The cyclical material flow model of CE is seen as an alternative for the current production and consumption model also in the textile

industry (Korhonen et al. 2018). The emerging new business models to promote reuse and new recycling technologies are ways to promote CE in this sector (EMF, 2017).

An important aspect of the textile industry is also the choice of raw materials, as it has significant impacts on the environment. Textile materials can be natural (e.g. cotton, hemp) or synthetic (e.g. polyester, nylon). Although natural materials are often considered a sustainable option, it is not always the case. As an example, cotton has tremendous use of water and pesticides. Meanwhile, most of the synthetic fibers cannot be considered environmentally friendly either due to their non-renewable resources (petroleum) (Thangavel and Duraisamy, 2014).

The notable effort of the EC to tackle today's sustainability issues and to promote CE is therefore proven in both the plastic and textile industries, although these transitions usually take time and much discussion. As a consequence of all industries being interconnected, it is inevitable that changes in one probably will affect another. This study aims to take into account the contradictions between CE attempts in two separate industries within EU regulations and discuss the emerging issues, taking the specific case of the SUPD and man-made cellulose fibers (MMCF), more specifically one type of them: Ioncell® fibers.

1.1. The Single-Use Plastics Directive:

With the objectives to reduce the environmental impacts of certain plastic products, particularly on the marine environment and to promote CE with encouraging more sustainable business models, products, and materials, the European Commission adopted The Single-Use Plastics Directive (SUPD), which came into force on 2. July 2019. (OJEU 2019). The SUPD - as a part of the European strategy for Plastics - has been favored by the vast majority of the members of the parliament, and it is an important step in order to achieve the EU Circular Economy (EC) goals (Morawski and Simon 2020).

Between 1950 and 2015, the yearly plastic production worldwide has grown more than 300 times (from 1.5 million t/year to 322 million t/year), from which most of the waste ends up in the seas and oceans. In order to tackle the vast amount of plastic leaking into our environment, the SUPD takes into consideration the ten most commonly found single-use items, such as single-use food containers and plastic cups or cutlery. These add up around 70% of marine litter that can be found on the

European beaches (Morawski and Simon, 2020). According to the directive, different measures are implemented for different product types. In some cases, consumption need to be reduced (e.g. cups and food containers), some of them have restrictions on market placement (e.g. plastic cutlery, plates, straws) and some of them got product and/or marking requirements (e.g. sanitary towels, wet wipes, tobacco products). The directive also includes separate collection and raising awareness into its measures (OJEU 2019).

1.1.1. Limitations of the Single-Use Plastics Directive:

Although the aim of the SUPD towards a cleaner environment and a more circular waste management system is not subject to doubt, clarifying the scope of the directive is a still-ongoing process. Although it is crucial in order to avoid misinterpretations of different definitions, it seems to be problematic. For example, as it is stated in article 3(1) of the SUPD, the definition of plastic is:

> *"A material consisting of a polymer as defined in point 5 of Article 3 of Regulation (EC) No 1907/2006, to which additives or other substances may have been added, and which can function as a main structural component of final products, with the exception of natural polymers that have not been chemically modified."*
>
> (OJEU 2019: L155/8)

This definition shows that there are so-called natural polymers (e.g. the cellulose from cotton), which are subject of exception until they have not been chemically modified. However, the meaning of these notions seems to be up to personal interpretations. Therefore, by 3. July 2020. the commission is aiming to publish the guidelines to clarify what has to be considered as SUP and has to be in consideration of the SUPD (OJEU 2019).

After a study titled "What is Plastic?" by Eunomia, a debate around man-made cellulosic fibers (MMCF) evolved (Morawski and Simon 2020). They argue that in the case of wet wipes, these types of fibers are alternative materials as a substitution for synthetic polymers. As such, they mean a serious risk of exploitation by the wet wipe market. For this reason, MMCFs such as viscose and lyocell should be included in the focus of the directive (Hann et al. 2020). However, according to the interpretations of

'plastic', 'natural polymer', and 'chemical modification', these materials must be discussed in terms of their classification.

The focus of Eunomia`s study is on lyocell and viscose, which are both textile fibers that originated from cellulose polymer (Hann et al. 2020). Apart from these materials, another MMCF type is Ioncell® fiber, which has similar production to the above-mentioned lyocell (Michud et al. 2016). This technology has been developed in the collaboration of Aalto University and Helsinki University (Finland), and it is in the focus of my study.

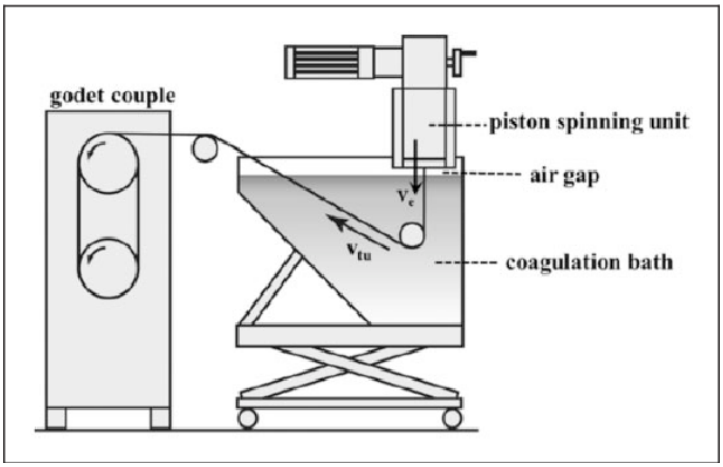
1.2. The Background of Ioncell® Technology:

Ioncell® is a process to develop man-made cellulose fibers (MMCF) using an ionic liquid (IL) solution as a cellulose solvent. The produced cellulose solution is spun into high-strength fibers by dry-jet wet spinning (Michud et al. 2016). The technology serves as an alternative to the N-methylmorpholine-N-oxide (NMMO) based lyocell process mentioned above to compensate for some of the associated disadvantages of this technology, such as the instability of the solvent (Michud et al. 2016). While we are facing the formation of toxic chemicals and gases during the production of viscose, in the lyocell process, the cellulose-NMMO-water also results in several by-product formations; therefore, a stabilizer is required in the reaction (Michud et al. 2016; Woodings C. 2001). In comparison, Ioncell® process is another lyocell-type process, which is utilizing a different direct cellulose solvent, that has demonstrated excellent dissolution properties and the ability to regenerate filaments with properties comparable or superior to cotton, viscose, and lyocell (Michud et al. 2016; Hauru et al. 2014).

As a first step of the process, cellulose derived from dried wood pulp is dissolved in liquefied IL, to a 13 wt% cellulose consistency. The mixture then is transferred into a vertical kneader, where the temperature, pressure and shearing rate is controlled. The dissolution process is typically conducted at 80 °C with the shearing of 30 rpm for 90 minutes. Subsequently, the resulting dope is subjected to filtration by means of a hydraulic filtration unit at 80 °C. (Michud et al. 2016).

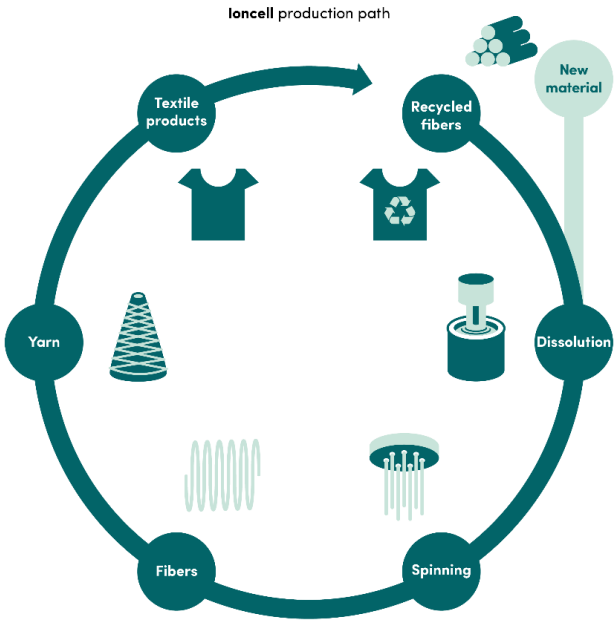
From the prepared dope then cellulosic fibers are spun using a piston spinning unit, as it shows in 1. Figure. First, the spinning cylinder is filled with the solidified solution, and then it is heated to the desired temperature (70-85 °C). Afterward, the dope is

extruded through a multi-hole spinneret into a water coagulation bath with a specific air-gap (Michud et al. 2016).



1. Figure: Illustration of dry-jet wet spinning unit used to produce MMCFs

After fibers have been spun, linear density (dtex), tenacity (cN/tex), elongation at break (%) and fiber orientation can be determined (Michud et al. 2016). From the formed fibers through traditional yarn spinning technology, yarn and eventually fabric can be produced. On 2. Figure the Ioncell® production path can be seen.



2. Figure: The production path of the Ioncell® process from recycled and new materials to new textile products (https://ioncell.fi/research/)

Recent studies have proven that Ioncell® technology can be used for the purpose of recycling textile waste, in the case if it consists mainly of cellulose-based materials, such as cotton, viscose, or linen (Asaadi et al. 2016; Haslinger et

al. 2019). As such, it brings an opportunity to move towards sustainability and CE within the textile sector. The research group of Ioncell® technology is working at Aalto University and also in collaboration with FINIX, (Sustainable textile systems: Co-creating resource-wise business for Finland in global textile networks) which is a multidisciplinary research project working on sustainable textile systems in Finland, and which gives a background of current research (FINIX, 2019). Thanks to Ioncell®'s textile-to-textile recycling potential, it takes a lead role in one of the primary purposes of FINIX: introducing new sustainable materials. As it is put in their website:

> "*Producing textile fibers from recycled cellulose-based material through the Ioncell® process, in the detection and removal of impurities from the material and providing a proof-of-concept of industrially viable textile-to-textile upcycling.*"
>
> (FINIX)

…are some of the aims of the research group.

1.3. The Background of FINIX Project:

Sustainable textile systems: Co-creating resource-wise business for Finland in global textile networks, so-called FINIX, is involving many stakeholders from different universities, organizations and companies. They are aiming towards one goal, to a more circular textile economy in Finland (FINIX, 2019). In order to do so, they conduct scientific research on their own field, with recognizing the interlinked aspects of sustainability. While co-creating a resource-wise business in Finland, they are promoting global sustainable development as well (FINIX, 2019).

FINIX's investigations not only involve different paths of textile recycling and fiber production from wood and agro-waste, but they are also creating business models that promote a long lifetime of textiles (just as sharing, repairing). Apart from these, they work on digital technologies, which can be a use for better traceability and additionally, their researches are ongoing about governmental innovations like proactive regulation and ecosystem governance models (FINIX, 2019). In combination, these researches are aimed to move towards a more sustainable global textile economy.

In its work, FINIX applies the design thinking approach and co-creation methods, which creates contributions between the findings of the multiple scientific fields. In this way, it is able to catalyze business collaborations and connections between the public sector and NGOs in order to reach innovations with united forces (FINIX, 2019). This could not be possible if they were working individually. FINIX is building new ecosystems between industries not only from the textile sector but academics, the public, and policymaking as well as large companies and start-ups from textile, forest, digital services, logistics and waste sector (FINIX, 2019).

3. Figure: The FINIX [Phoenix] linkages between the different disciplines towards a sustainable textile system (FINIX,2019), (https://finix.aalto.fi/)

FINIX project has five different main research areas, which splits them into four main work packages (WP). The first of these packages (WP1) is working on new sustainable textile materials, with particular focus on [1] innovative man-made cellulose fibers (Ioncell® textile fibers), [2] developing machine vision tools for the future, [3] researching the potential risks and behavior of chemicals in textile recycling and [4] defining quality criteria for textiles (FINIX, 2019). The second work package (WP2) focuses on [1] new design strategies with the means of fabric identification and tracking technologies, on [2] new business models trough co-innovation sessions with companies and finally, on [3] supporting sustainable consumer behavior with developing consumer guidance instrument (FINIX, 2019). The third work package (WP3) is specialized in impact assessments and assessing the environmental and socio-economic impacts of the new textile materials from WP1 and studied design

and business strategies from WP2 and 4. This WP also focuses on the socio-economic impacts on the developing countries, by ethnographic case study methods (FINIX, 2019). The fourth work package (WP4) is investigating different governance innovations how they can be part of the transformation to a circular textile economy. They work on a [1] unified policy framework using the work of both WP2 and the impact assessments of WP3, also [2] working on ecosystem development for sustainable textiles by means of the business models created in WP2 and organization design methods (FINIX, 2019). There is also a fifth work package (WP5), which is facilitating the interaction between the WP leaders and also on opening networks for FINIX. An additional work package (WP6) is also set for management purposes (FINIX, 2019).

This project is embedded in the work of FINIX, from the experimental research, through interview participants by experts of different fields. The research group has provided a substantial amount of material and also a background for the study.

1.4. Objectives and Research Questions:

With all this background information in mind, this study aims to investigate the discursive background of EU's SUPD and its possible effects on the evolution of Ioncell® technology and in more general terms on the circular textile industry. The study is nested into the project of FINIX, from which several stakeholders contributed to answering the following main Research Question (RQ):

> *"How would it affect Man-made Cellulose Fiber (MMCF) technologies, including Ioncell®, within a circular textile economy, if they are classified as plastic in Europe's Singe Used Plastic Directive (SUPD)?"*

This question arises in the following sub-questions (SQ):

SQ_1: "What is the reasoning supporting and opposing the involvement of MMCFs into the SUPD?"

SQ_2: "How does Ioncell® technology fit into the concept of CE?"

SQ_3: "*How does consumers' perception change if MMCFs fall into the category of plastics?"*

2. Theoretical Framework

2.1. The Conceptualization of Circular Economy

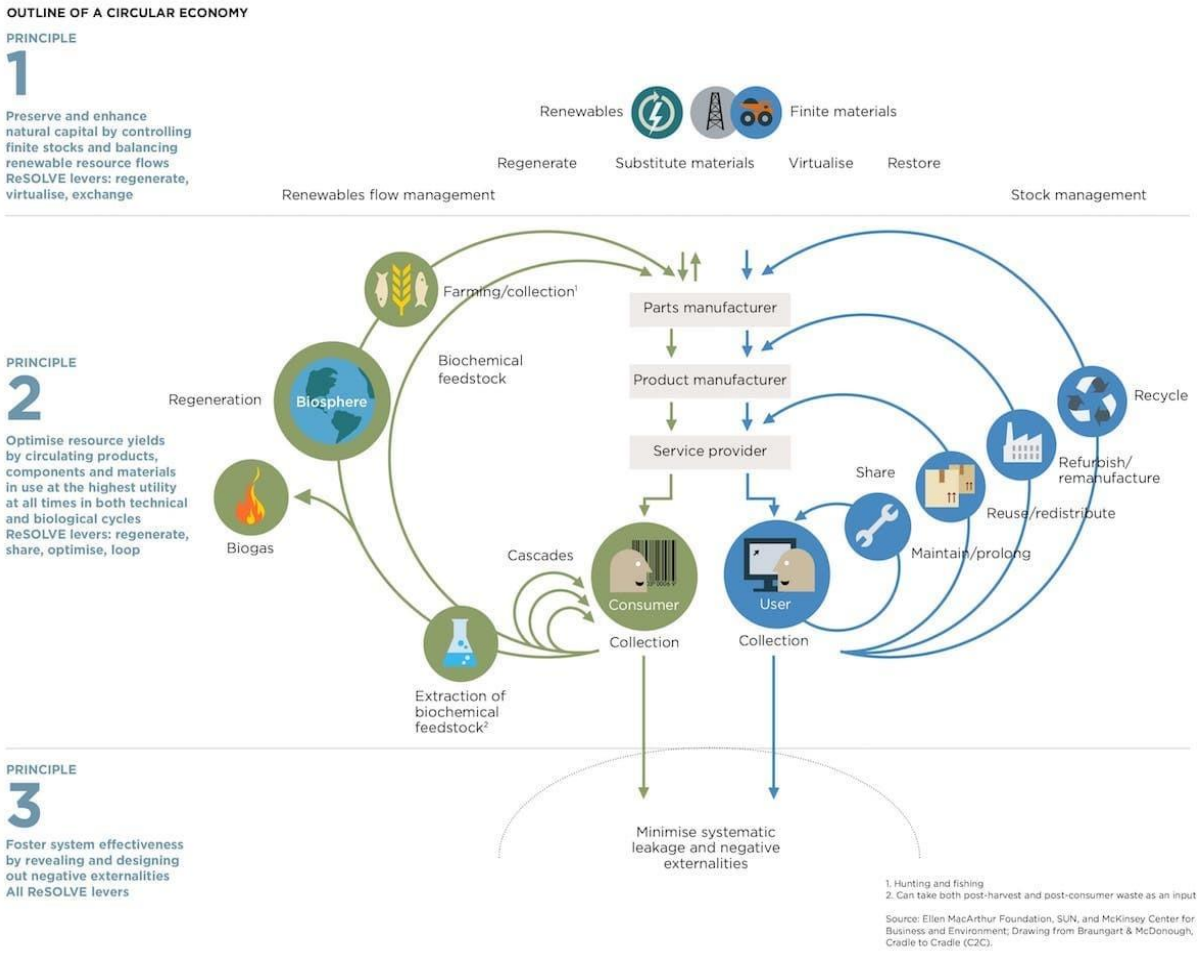
The concept of Circular Economy (CE) in order to promote sustainable development has arisen in recent years. It is a subject not only in policy-making practices (EC, 2015; Zhijun and Nailing, 2007) but also in the business world (EMF, 2013). Although it is a term that has been widely used, finding a common definition or tracing it back to one single initiator seems to be impossible (Korhonen et al. 2017; EMF, 2013a; 2013b). The concept is more like a development of the evolution of thoughts that had gained momentum already in the 1970s when the idea of Regenerative Design emerged by John T. Lyle (EMF, 2013). In 1976 Walter Stahel portrayed in his research a vision of an economy in loops and analyzed its positive impacts from job creation to waste prevention – he called it Performance Economy (Stahel, 2006; EMF, 2013). Following, in 2002, Michael Braungart and Bill Mcdonough introduced the concept of Cradle to Cradle, which took nature's biological metabolism as an example and developed a technical metabolism flow also for industrial materials (Braungart and Mcdonough, 2002; EMF, 2013). The abovementioned examples are only some from several studies and concepts (e.g. biomimicry (Benyus, 2002); natural capitalism (Hawken et al., 2008), which eventually draw the image of CE (EMF, 2013).

In the currently common linear approach of the economic structures, the resource consumption follows a 'take-make-dispose' pattern (EMF, 2013a; 2013b; Franco, 2017). After extracting the needed materials, companies manufacture products using energy and labor, which are then sold to the consumers and discarded as soon as they do not serve their purpose anymore (EMF, 2013a). In a linear economy the production is based on one-way processes, where preferably a high volume of production is reached with a low production cost (Webster, 2015). This production model is not only tremendously wasteful throughout the value chain and also at the end of the product's life but has a substantial role in natural systems degradation (Franco, 2017; EMF 2013a). These could be avoided by the vision of CE, which keeps a minimal to zero waste production and resource usage by re-usage, recycling, reproduction and repairing of the products (EC, 2015). Initially, the 3R- Reduce, Reuse, Recycle was dominating the CE literature, but it was extended to 6R, which also includes Recover, Redesign and Remanufacture (Gong et al. 2020; Govindan and Hasanagic, 2018).

Throughout the documents of Ellen MacArthur Foundation; their work on CE has evolved resulting in the following definition:

> *"A circular economy is one that is restorative and regenerative by design and aims to keep products, components and materials at their highest utility and value at all times, distinguishing between technical and biological cycles. This new economic model seeks to ultimately decouple global economic development from finite resource consumption."*
>
> *(EMF, 2013a; 2013b; 2014; 2015a; 2015b; 2015c; 2016; 2017a; 2017b)*

The Following figure is the outline of CE, commonly called "butterfly diagram" which shows the two types of material flows; the biological nutrients, which can safely re-enter the biosphere and the technical nutrients, which are designed to circulate as many times as possible without entering the biosphere (EMF, 2015a; 2015c; Braungart and Mcdonough, 2002).



4. Figure: The outline of Circular Economy visualized by EMF (EMF, 2015a; 2015).

CE is laid on three different principles, as it can also be seen in the figure. Firstly, it preserves and enhances natural capital by taking into account the finite stocks and balancing renewable energy flows. This not only means choosing renewable resources but also enhancing natural capital by creating conditions for regeneration of soil, for example (EMF, 2015a; 2015c). The second principle is optimizing resource yields by the circulation of products and materials in both technical and biological cycles (EMF, 2015a; 2015c). The products in a circular system are designed for reusing, remanufacturing or recycling, and therefore, they are kept in the circulation. The tighter the loops are, the more energy and other values are preserved; therefore, maintenance and reuse will be a more desirable choice than recycling (EMF, 2015a; 2015c). The third principle is enhancing the effectiveness of the system by designing out the negative externalities such as land use, pollution, or release of toxic substances (EMF, 2015a; 2015c).

Apart from the main principles, there are several other characteristics that apply to CE. In a perfectly circular system, waste does not exist, instead in the case of biological materials, it can be turned into soil by composting, and in case of technical materials, products are designed to be recovered with least energy input (EMF, 2015a; 2015c). Also, in the view of CE, diversity is an essential value, which is building strength, while the required energy for CE should be rooted from renewable energy sources (EMF, 2015a; 2015c). Another characteristic that the concept involves is the acknowledgment of the complex system, where different parts are strongly linked to each other, resulting in sometimes surprising consequences (EMF, 2015). Consequently, different fields and industries can be viewed from a CE perspective separately, though overall, the interconnections of these fields also have to be considered.

2.2. Circular Economy in the Plastic Industry

Thanks to the exceptional variety of their mechanical and chemical properties, plastics became the most ubiquitously used material in our everyday life (Simon 2019, EC, 2018; EMF 2016). Although plastics contribute to economic growth (STAP, 2018), there are many concerns related to the current way of how plastic economy works. According to Ellen MacArthur Foundation, there are three main issues that have to be addressed:

> *"The externalities related to the use of plastics and plastic packaging are concentrated in three areas: degradation of natural systems as a result of leakage, especially in the ocean; greenhouse gas emissions resulting from production and after-use incineration; and health and environmental impact from substances of concern."*
>
> *(EMF, 2016)*

Because the production of conventional plastics highly depends on virgin fossil fuels and also other resources like water, this industry has a substantial pressure on resource use (STAP, 2018), while after disposal the plastic waste leaking to the environment creates another reason for natural system degradation (STAP, 2018; EMF, 2016). These plastics stay in the environment even up to five hundred years before they break down (STAP, 2018). Moreover, most of the plastic products are breaking down to microplastics, which not only threaten marine biodiversity but also potentially damage human health (STAP, 2018; Blair et al., 2017; Browne et al., 2013).

In *The New Plastics Economy*, EMF identifies three substantial goals in order to tackle the above-mentioned issues and also to promote CE on the field (EMF, 2016). First of all, a change in the after-use plastic economy is needed by improving plastic recycling and reuse. Secondly, measurements have to be taken to reduce the amount of plastic leaking into the natural environment, and thirdly, plastics from fossil resources should be exchanged with innovative materials derived from renewable feedstock (EMF, 2016). Recent scientific researches and innovations have shown the way to achieve these goals (STAP, 2018).

As an alternative for fossil resources, there are methods to use Green-Hause Gases (GHG), bio-based sources, or biopolymers to produce plastics, commonly already from the waste of other industries, like sewage sludge, or food products (STAP, 2018; Solaiman et al., 2006). Using plastic waste itself as a resource is also an option that has been demonstrated with several examples. Plastic waste can be used for making building materials or in road constructions, even in the apparel or shoe industry, using PET waste for recycled polyester (STAP, 2018; Papaspyrides and Kiliaris 2014; Ahmetly et al., 2017). Chemical recycling enables certain plastics to be kept in the cycle infinitely, while others like polyethylene can be broken down by bacteria in bio-based recycling processes (STAP, 2018).

Keeping in mind the principles of CE, redesign of plastics is also necessary while considering a life-cycle approach. Promoting a cleaner production, avoiding unnecessary plastic use and discouraging single-use, as well as already designing products for extended use, easy separation, repair and recycling, are essential steps (EMF, 2016). Finally, enhancing circular business models to promote products as services, for instance with sharing and leasing, is also part of the CE concept (EMF, 2016).

2.3. Circular Economy in Textile Industry

Another fundamental consumer good industry, which is in the focus of this report, is the textile and clothing industry. Trading included, it accounts for 37 % of total European industrial activity (EURATEX, 2017) and has a substantial increase in consumption and production over the past twenty years (EEA, 2014; Dahlbo et al., 2017). Meanwhile, in the past few decades, consumer behavior towards textiles changed substantially. From basic human need products transformed into fashion items, which drastically decreased their life-time (Maslow, 1943; Piribauer and Bartl, 2019).

The current system of production, distribution and usage of clothes and textiles is similarly to other products, following the linear take-make-dispose model (EMF, 2017; Korhonen et al. 2017). The resources used in production are dominantly non-renewable, the produced textiles are usually used only for a short life-time, and after usage, most of the materials are either lost on landfill, or in a slightly better case used for incineration (EMF, 2017). This way of operation in the textile industry comes with massive challenges from the production phase until the end and even beyond the product's life-time (Lenzing, 2017; Shen et al., 2010; Micklin, 2007; FAO-ICAC, 2015, Roos et al. 2015). The main impacts connected to the industry are Green-Hause-Gas (GHG) emissions, resource depletion, water usage, toxic chemicals, human rights abuses and waste (Allwood et al., 2006).

Due to the aforementioned challenges, CE is an arising concept also in this industry. Aligned with the CE principles The Ellen MacArthur Foundation (EMF) visions a new textiles economy as following:

> *"One that is restorative and regenerative by design and provides benefits for business, society and the environment. In such a system clothes,*

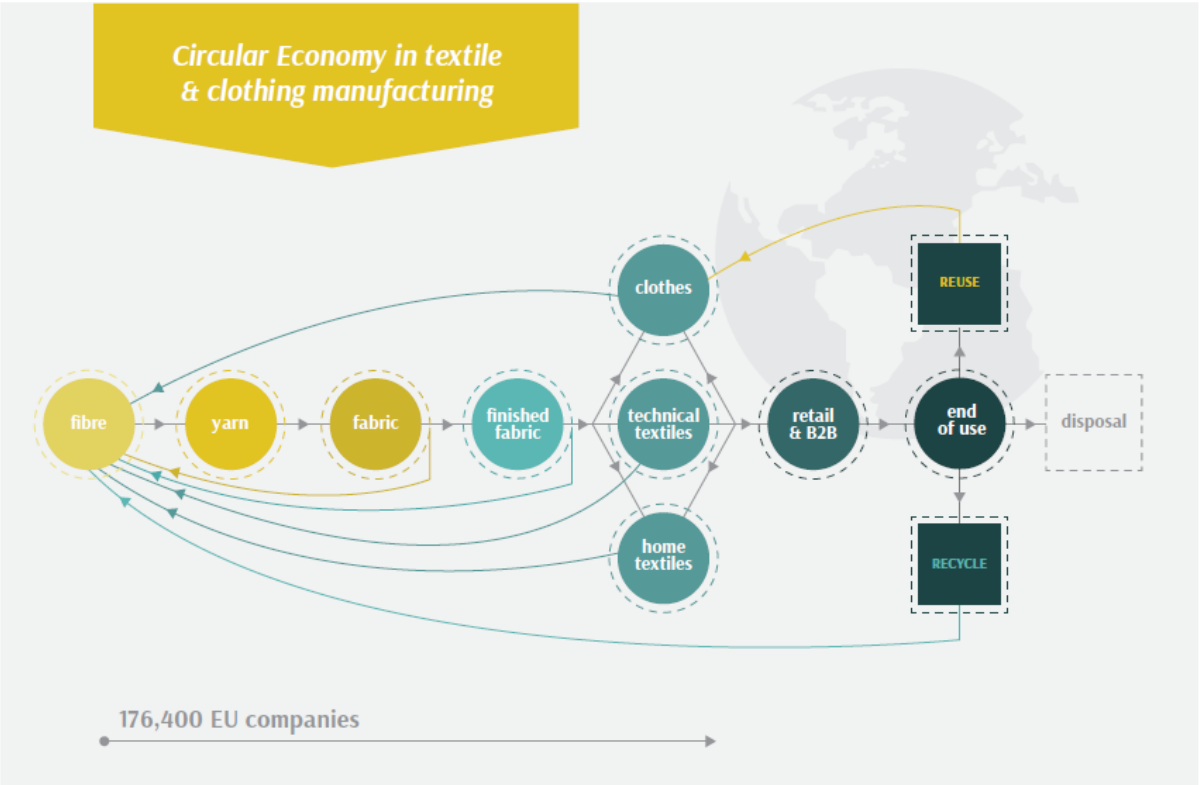
textiles and fibres are kept at their highest value during use and re-enter the economy after use, never ending up as waste."

(EMF, 2017)

In order to reach this view, EMF identifies four core ambitions that should be in the focus of the transition (EMF, 2017). First of all, the substances in concern have to be designed out at the production phase and microplastics should not be released from synthetic materials. These could be achieved by the development of new materials and production processes and also creating safe material cycles to use the existing alternative technologies (EMF, 2017). Secondly, the way of how products are designed, sold and used should be transformed, changing their perception from being disposable to be a durable product. This not only means designing the products for higher quality but also to implement alternative business models to promote the increase of their life-time (EMF, 2017). The fast-changing styles and needs while keeping the products in the circle could be addressed with models like clothing rental, resale, or repair services (EMF, 2017). Besides, it is also a goal of CE to make durability more attractive for the consumers (EMF, 2017).

The third ambition is a radical improvement in recycling, enabling it by design, collection and reprocessing (EMF, 2017). This means firstly that the design already has to be aligned with recycling processes by using well recyclable materials and avoiding material blends, which makes recycling difficult (Gam et al. 2010; Piribauer and Bartl 2019, Lv et al., 2015). Textile recycling refers to the reprocessing of textile waste into new textile or non-textile products (Sandin and Peters, 2018). Essential aspects of this ambition are the improvement of after-use collection and sorting technologies while rising demand for recycled materials (EMF, 2017).

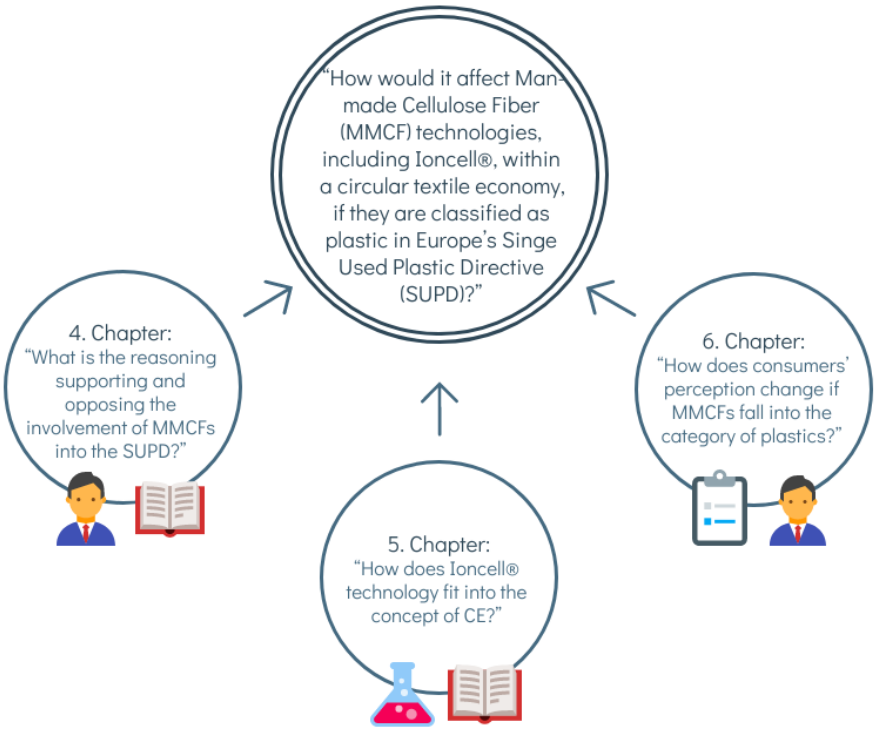
In a circular textile economy, resources are used effectively and derived from renewable feedstock (Franco, 2017; EMF, 2017). Recycling and maximizing product life-time already contribute to this ambition, and where virgin materials are needed, they are provided from renewable sources (EMF, 2017). Besides, by using more efficient production technologies, non-renewable resource usage can be further reduced (EMF, 2017). The following figure shows how the CE within the textile industry can be visualized (EURATEX, 2017).



5. Figure: Circular Economy in textiles&clothing industry visualized in EURATEX's yearly report (2017) (EURATEX, 2017)

3. Methodology

This research consists of three parts, which are represented by the three sub-research questions (SQ) and finally end up answering the main question. These parts call different methods in order to proceed in the investigation. First of all, the discursive background of the role of Man-Made Cellulose Fibers (MMCF) in the Single-Use Plastic Directive (SUPD) is analyzed (SQ1); hence a literature review of policy briefings and scientific documents is used and semi-structured interviews are carried out. The second part is the analysis of Ioncell® Technology and its recycling potential of post-consumer cotton-waste (SQ2). In this section, experimental work carried out in the laboratory of The Bioproduct Centre at Aalto University in Finland has been used in addition to a literature review. Lastly, SQ3 is focusing on the public perspectives of the discussed issue. This question is investigated via public survey, and also the opinion of the interviewed stakeholders is analyzed and discussed.



6. Figure: Schematic visualization of the main research question and the sub-questions in addition with the chapters they are answered and the methods used (Own figure)

Throughout the report, the SQs are analyzed and discussed individually, providing three main chapters aiming to investigate them. Then finally, in the conclusions, the main RQ is answered.

3.1. Literature Review

This method is used throughout this report on several different levels, and in each, different sources of literature had to be reviewed. Firstly, in the investigation of the concept of Circular Economy (CE), apart from scientific documents, mainly publications of The Ellen MacArthur Foundation (EMF) have been used, due to its systematic way of handling the concept and introducing it in several different industries. Then, scientific documents are also used to investigate the technological background of Ioncell® fibers and to understand the discursive background of MMCFs. Thirdly, to study the background of SUPD and investigate the discussions in the policy-making process, EU-documents and legislations have been used.

3.1.1. Ellen MacArthur Foundation Publications

The work of EMF has been in great use through the investigation of the theoretical background of CE. It not only goes deeper into the background of the evolution of the concept but also analyses and provides practical solutions for the different industries in transitioning towards CE. The foundation had a great role in establishing CE on the agenda of governmental and business stakeholders and also in academia, therefore, accelerating a systemic change towards circularity. Starting from 2010, several publications were released not only to introduce the principles of CE but to analyze the economic rationale (EMF, 2013a) and also go deep into the transition in consumer good sectors and global supply chains (EMF, 2013b; 2014). More recent publications are applying the principles of CE in different sectors, such as in the plastic and also in the textile industry (EMF, 2016; 2017a; 2017b).

The publications have been found and downloaded from the home-page of EMF: https://www.ellenmacarthurfoundation.org/

3.1.2. Scientific Literature

Scientific literature is used in different parts of the report from the introduction, through the theoretical background and in the analysis. The literature has been found mostly through library databases of The University of Aalborg (Denmark) and Aalto University (Finland). In addition, recommendations were asked from supervisors and

the interviewees throughout the data collection. In some cases, the snowball method has also been used. A major part of the literature analyzed is providing a background knowledge of Ioncell® technology from the early stages until recent studies. These publications are provided by researchers of Aalto University.

3.1.3. EU-Legislations

The searching engine of Eur-lex has been used to find policy publications around plastics and CE in the European context. These documents helped to map the background of the policy evolution that resulted in the SUPD; also the discourses around MMCFs within it. Publications of the European Commission (EC), policy briefings and action plans have been reviewed.

3.2. Semi-Structured Interviews

As part of the investigation of the discursive background around MMCFs and the effects if they are involved in the SUPD, five semi-structured interviews have been conducted. Hence the flexibility of this type of non-standardized interviewing, questions could be adjusted depending on the answers of the respondents and the flow of the conversations while focusing on a predetermined list of themes or questions (Saunders et al. 2009).

Most of the interviewees are researchers of FINIX, with expertise from different fields within the topic of circular textile economy. Other interviewees were company representatives of MUDjeans, a circular fashion company from the Netherlands, who are using cotton recycling technologies within their production and are also connected to MMCF technologies. In the following sessions the profiles of the interviewees can be found. The interview transcripts are attached in ANNEX I.

3.2.1. FINIX-Members

As it has been introduced above in the first chapter, Sustainable textile systems: Co-creating resource-wise business for Finland in global textile networks, so-called FINIX is aiming towards a more circular textile economy in Finland. It is a multidisciplinary research project working on several different fields. Their ambitions

involve introducing new sustainable textile materials, reaching digital innovations, exploring new design strategies, while focusing on circular economy management, and assessing sustainability impacts (FINIX, 2019). Experts of these different fields have been interviewed in order to investigate the questions of this report from their individual points of view. Although they have different perspectives depending on their expertise, they all work towards the vision of a new, circular textile economy promoted by FINIX.

Helena Dahlbo:

Senior Research Scientist in the Finnish Environment Institute (SYKE). She works in the Centre for Sustainable Consumption and Production, on waste and CE. Her work involves researches and development on material and garbage management recovery, sustainability assessments, and Life-Cycle Assessments (LCA) on waste treatment and recycling.

> *"I have been working the Finish Environmental Institute almost 30 years, in different waste management projects. (…) I am working with Life-cycle assessments or material-flow analysis, and these kinds of systematic tools to analyze different types of waste management or recovery options. I have been working on different types of wastes, mainly however municipal wastes, so not much industrial wastes, and in recent years plastics and textiles have been the two materials that have a lot been on my table."*
>
> (Helena Dahlbo)

Kaisa Sorsa:

Doctor of Science in Economics and Business Administration; Professor in Turku University of Applied Sciences (TUAS), Finland. Her expertise involves engineering and business, logistics, services and industrial management. She has publications about private regulation and self-coordination in environmental governance.

> *"I work in the Turku University of Applied Sciences which is partner in this consortium [FINIX] and our role is to investigate the role of pro-active regulation in the transition towards sustainable textile industry. I also want to see more broadly what is pro-active governance not only regulation but also other governance instruments that help in this transition. There is only I*

and another college in our university who is working with this, and he is focused on methodological issues."

(Kaisa Sorsa)

Herbert Sixta:

Professor at Aalto University, in the Department of Bioproducts and Biosystems. His research interests include pulping chemistry and technology, cellulose chemistry, the dry-jet wet spinning of cellulose solutions (Ioncell® technology) and cellulose textile chemistry, just to mention the most relevant ones for this research. As a MMCF expert, he took a great role in the discussions of their involvement in the SUPD.

"My industrial background was many years ago as a manager in a company that produces pulp fibers and also textile fibers. Then I moved to Aalto, where I was appointed professor in Biorefineries. I started to work on the improvement of classical and novel pulp techniques as a platform for biorefinery to valorize not only the cellulose, but also the lignin and hemicellulose factions. As a raw material sustainable biomass, typically wood but also annual plants are utilized. In 2009-2010 I started to work on MMCFs. (…) using ionic liquids as a powerful cellulose solvent. In the beginning the name Ioncell® was not yet used, but a few years later, when we had the breakthrough in the spinning of high-quality MMCFS, the process was denoted as Ioncell®. (…) The FINIX project is the latest project in a series of many projects in which we have gradually improved the Ioncell® technology."

(Herbert Sixta)

***Samuli Patala*:**

Assistant Professor at Aalto University in the Department of Management Studies. His main research interests lay in sustainable ways of operations and the organizational perspectives of sustainability issues. He studies institution and governance structures that affect sustainability transitions, with a particular interest in the transitions towards a CE.

"I work as assistant professor at the Aalto School of Business, and I am working with the FINIX project, basically my role in it currently is mainly one of the work packages, which is focused on governance innovation. This

basically includes most regulatory aspects of public sector governance, as-well as what we call ecosystem- governance. (…) More broadly I am interested in sustainability management topics, so I am also halfly involved in other projects for example in the area of renewable energy, and we also started a new project on impact investing recently which is related to the topic of sustainability."

(Samuli Patala)

3.2.2. Company Representatives

Two company representatives from MUDjeans have been asked for an interview for this project. The company was founded in 2013 with the perspective to change the common unsustainable and unfair way of operations within the fashion industry. Already from the beginning, they introduced a leased system to make sure that the garments they produce will turn back and can be recycled. In addition, they also provide a free repair service. Currently, they have a project to make a 100% recycled pair of jeans model, in which they are investigating those MMCF technologies which are available for chemical textile recycling. This and their attitude in moving towards a circular textile economy are the reasons why they were chosen for contribution to this research.

Dion Vijgeboom:

Co-owner and denim specialist of MUDjeans international since 2014, responsible for product design and operations within the company. His previous experiences involve working for G-star in product development and sourcing and before, managing a factory in Sri-Lanka.

"I actually studied strategic production management in the Amsterdam fashion industry institute (…) then I ran a production in a factory in Sri Lanka for four years, and after that I got involved in denim, I worked for G-star for ten years. (…) Towards the end of that period, I got more and more intrigued and challenged by finding what ways to do the production and the development of jeans differently. Related to the way how they are doing those things, I decided to leave the company and start as a consultant, I worked for several brands and factories always on the

sustainable topics. Then in 2014 I met with the founder of MUDjeans, and we decided that we could strengthen each other. (…) We are a super small team with ten max, so everybody does besides his core activities, which is in my case are the sourcing and the production of the denim but we also do many other things, sometimes related to marketing, finance, organization etc."

(Dion Vijgeboom)

Eske Hurenkamp:

Student of Fashion & Textile Technologies in Amsterdam, intern of MUDjeans international. She is currently working on her thesis in the company, which is developing the world's first 100% post-consumer recycled jeans.

"I'm student of Fashion and Textile Technologies (…) and first year of my studies I came across a presentation of SaXcell which is regenerated cellulose fiber, and they were talking about cotton waste recycling, and I was super interested. (…) I started following an owners program next semester for them, and I am getting more and more knowledge about the topic, and then I was thinking where can we actually make a big impact with such a future technology? Where do they use a lot of cotton? (…) I came across MUDjeans, and this is perfect, and actually they were also looking into using more recycled material, so I did my first internship there 2 years ago. (…) Now I am writing my thesis, and from this last research we ended up in this new project together with my university as well, to make the first 100% recycled jeans."

(Eske Hurenkamp)

3.3. Experimental Work

In the second part of this report, experimental work is presented in which the recyclability of post-consumer cotton waste is tested via Ioncell® technology. The aim of this part is to analyze the recycling potential of MMCF technologies and to find their role in the transition towards CE. The experimental results are part of an internship, which has been conducted between 2019. September – 2019. December by the

author of the report; in the Department of Bioproducts and Biosystems at Aalto University, Finland (Újhelyi et al., 2019).

3.4. Survey

Finally, in order to investigate the third sub-research question and analyze the public opinion, a survey has been conducted. To create the internet mediated questionnaire, the online platform of google forms has been used. According to Dillman, three types of data can be collected via surveys: opinion, behavior and attribute (Dillman 2007; Saunders et al. 2009) from which, in some ways, all types have been included in the questionnaire of this research. In cases to explore knowledge around the discussed terms, some opened questions (Dillman 2007) have been used, in which respondents had the opportunity to answer in their own way (Fink 2003). However, the majority of them were closed, or forced-choice questions in which a number of alternative answers or choices were provided to the respondents (Dillman 2007, deVaus 2002).

The target audience of the survey were mainly students and academic personnel from different universities in Europe and also social media group members with a general interest in sustainable fashion or textiles. The survey was spread on different social media platforms like Facebook, LinkedIn and Instagram in addition to the e-mails sent to students and academics. Overall, we received 119 responses in a one-month period (14.04.2020 – 14.05.2020.) and analyzed the statistical data of them. The survey can be found in the following link and also in ANNEX II.

https://docs.google.com/forms/d/e/1FAIpQLSeUqeiG4Qsvoyy8JPLKVy7wgYrAAKtLIW3dd9BXYormTHPdRA/viewform

4. The Role of Man-made Cellulose Fibers in the Single-Use Plastic Directive

With the aim of reducing the environmental impact of certain plastic products and promoting Circular Economy (CE) with endorsing sustainable business models, products and materials, the European Commission (EC) adopted the Single-Use Plastic Directive (SUPD), which was implemented on 2. July 2019 (OJEU 2019). The directive is part of the European strategy of Plastics (EC 2018) and has been significantly favored in order to achieve the EU CE goals (Morawski and Simon, 2020; EC, 2015).

Article 1 of the SUPD identifies its objectives as:

> Article 1
>
> **Objectives**
>
> The objectives of this Directive are to prevent and reduce the impact of certain plastic products on the environment, in particular the aquatic environment, and on human health, as well as to promote the transition to a circular economy with innovative and sustainable business models, products and materials, thus also contributing to the efficient functioning of the internal market.
>
> (OJEU, 2019)

7. Figure: Article 1 of the Directive (EU) 2019/904 (OJEU, 2019)

The directive recognizes that marine litter is a growing global and transboundary issue, therefore it sets as the first aim to reduce the quantity of generated waste. In doing so, it prioritizes sustainable and non-toxic products and re-use systems instead of single-use products (OJEU 2019). Another recognition of the directive, that for certain single-use plastic (SUP) products, there are no available sustainable alternatives yet, so most of them are expected to increase. Therefore, with regard to these products, member states are required to take necessary measures in order to reverse this trend. For those single-use plastic items which have readily available alternatives already, their placing on the market is required to be prohibited by the member states (OJEU 2019).

The directive also emphasizes life-cycle thinking about the products. When they are manufactured, already at the design phase, the production, the use phase and also the reusability and recyclability has to be taken into consideration (OJEU 2019). These above-mentioned issues are important considerations of the directive, but one and the most crucial in case of current research is the scope, which has not been completely clarified yet. As point (12) of the SUPD says:

> *"In order to clearly define the scope of this Directive, the term 'single-use plastic product' should be defined."*
>
> (OJEU 2019)

However, in certain cases, this task seems to be complicated and has to undergo several discussions. One example of these is the inclusion of wet wipes into the directive. As can be seen in the annex of the regulation, this product type is involved in the focus of different measurements, like marking requirements, extended producer responsibility, or awareness-raising. Details of the above-mentioned policy measurements can be found in Article 7, Article 8 and Article 10 of the directive (OJEU 2019). These products can be produced with one single or the combination of different materials, which can be natural or synthetic polymers such as polyester, cotton, or man-made cellulose fibers (MMCF) (Hann et al., 2020). Some of these materials are simply classifiable, but others, like MMCFs such as viscose or lyocell fibers are still under discussion if they should be classified as plastics (Hann et al., 2020; Nova Institute, 2019; DG environment and health, 2019).

4.1. Definitions Considered in the Single-Use Plastic Directive

Article 3 of the SUPD is introducing the definitions for the purposes of the directive. It lists eighteen terms in use in order to avoid misinterpretations, from which the first and also in case of this research, the most relevant is the definition of 'plastic'.

Article 3

Definitions

(1) 'plastic' means a material consisting of a polymer as defined in point 5 of Article 3 of Regulation (EC) No 1907/2006, to which additives or other substances may have been added, and which can function as a main structural component of final products, with the exception of natural polymers that have not been chemically modified;

(OJEU, 2019)

8. Figure: Definition of plastic by Article 3 of the Directive (EU) 2019/904 (OJEU, 2019)

This definition refers to the REACH regulation, which stands for Registration, Evaluation, Authorization and Restriction of Chemicals and in which polymers are defined as follows:

Article 3

Definitions

5. polymer: means a substance consisting of molecules characterised by the sequence of one or more types of monomer units. Such molecules must be distributed over a range of molecular weights wherein differences in the molecular weight are primarily attributable to differences in the number of monomer units. A polymer comprises the following:

(a) a simple weight majority of molecules containing at least three monomer units which are covalently bound to at least one other monomer unit or other reactant;

(b) less than a simple weight majority of molecules of the same molecular weight.

In the context of this definition a 'monomer unit' means the reacted form of a monomer substance in a polymer;

(EC, 2006)

9. Figure: Definition of polymer by Article 3 of REACH Regulation (EC) No 1907/2006 (EC, 2006)

Although the definition of 'polymers' is clearly referred to a source, other parts of the SUPD's 'plastic' definition allow some flexibility in interpretations. Due to the "*exception of natural polymers that have not been chemically modified*", the definitions of 'natural polymers' and 'chemical modification' also have to be clarified. Furthermore, Recital 11 of SUPD also specifies:

> "*plastics manufactured with modified natural polymers, or plastics manufactured from bio-based, fossil or synthetic starting substances are not naturally occurring and should therefore be addressed by this Directive.*"
>
> (OJEU, 2019)

In Article 3(39) of the REACH regulation 'naturally occurring' substances are defined as following:

> Article 3
>
> **Definitions**
>
> 39. substances which occur in nature: means a naturally occurring substance as such, unprocessed or processed only by manual, mechanical or gravitational means, by dissolution in water, by flotation, by extraction with water, by steam distillation or by heating solely to remove water, or which is extracted from air by any means;
>
> (EC, 2006)

10. Figure: Definition of substances which occur in nature by Article 3 of REACH Regulation (EC) No 1907/2006 (EC, 2006)

However, The European Chemical Agency (ECHA) points out that 'natural polymers' are not necessarily 'naturally occurring substances', and they should not be considered the same. A guidance paper for the implementation of REACH about monomers and polymers ECHA defines 'natural polymers' as following:

> "*Natural polymers are understood as polymers which are the result of a polymerization process that has taken place in nature, independently of the extraction process with which they have been extracted.*"
>
> (ECHA, 2012)

According to this definition, 'natural polymers' are a broader category than 'naturally occurring substances' as here extraction processes are allowed.

Another term that needs to be clarified with regards to the SUPD is 'not chemically modified substance' which definition also can be found in Article 3 of the REACH regulation.

> Article 3
>
> **Definitions**
>
> 40. not chemically modified substance: means a substance whose chemical structure remains unchanged, even if it has undergone a chemical process or treatment, or a physical mineralogical transformation, for instance to remove impurities
>
> (EC, 2006)

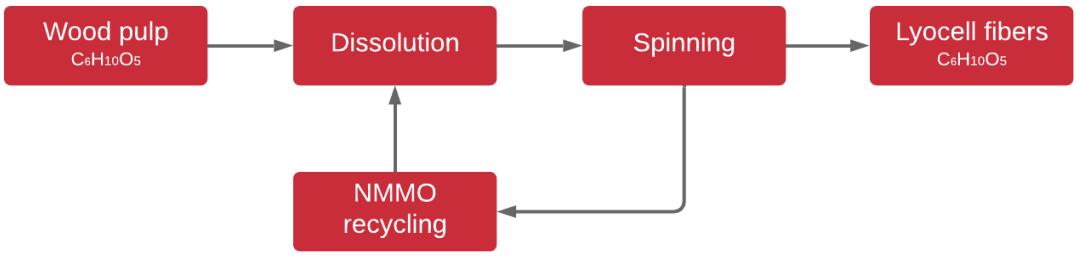
31. Figure: Definition of not chemically modified substance by Article 3 of REACH Regulation (EC) No 1907/2006 (EC, 2006)

Both the SUPD and REACH regulation provide several definitions needed to determine which products should fell into the scope of SUPD. However, the sentence "natural polymers that have not been chemically modified" seems to have several interpretations by the different stakeholders even after these definitions are implemented. In a strict understanding, if a polymer has not been chemically modified, there is no change allowed from the beginning until the end, even during the extraction process. In a less strict interpretation, a polymer is not chemically modified if there are no intentional changes through the manufacturing process, and in the least strict interpretation, only the end-stage of the manufacturing process should be considered (ECHA, 2020).

4.2. The Case of Man-Made Cellulose Fibers

The different ways to interpret the definitions of SUPD especially arisen in the case of MMCFs, namely lyocell and viscose, which are commonly used materials in wet-wipe production (Hann et al., 2020). In order to understand the discussions around these materials, we need to know their production process and chemical structure. In general, both lyocell and viscose are produced from cellulose, which usually is originated from wood-pulp (Hann et al., 2020).

In order to produce fibers from wood materials, the fiber needs to be dissolved to be spun later (Hann et al., 2020). In the case of lyocell, the solvent that is used for the dissolution of the polymer chains is N-Methylmorpholine-N-oxide (NMMO) (Hann et al., 2020; Potthast, 2019). After dissolution, the polymer is regenerated and the cellulose chains are aligned and stretched into fibers through a spinning process. The regeneration happens with the addition of water, in which cellulose is insoluble while the solvent power of NMMO is decreasing. Finally, pure cellulose remains (Hann et al., 2020; Potthast, 2019). Because cellulose is partially crystalline, according to the different crystalline domains, we can differentiate between the structures of Cellulose I and Cellulose II. While the first is the one that can be found in all native cellulose forms, the second structure is the result of the regeneration from any solution (Potthast, 2019). These differences between the crystal structures are strictly physical; chemically, the two cellulose structures are indistinguishable. In addition, the dissolution process is also a physical reaction (Potthast, 2019).In 11. Figure one can see a simplified flow of the lyocell manufacturing process.

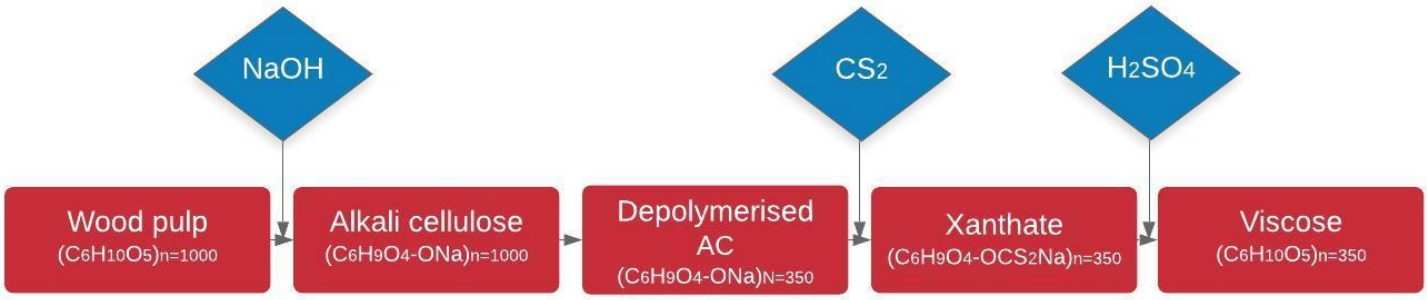


4. Figure: Simplified flow model of the lyocell manufacturing process (own figure)

As it can be recognized, lyocell manufacturing only includes physical processes from the raw material until the end-product, without any intended chemical reactions. However, it has been documented that side-reactions caused by the solvent and the high operating temperatures (~100oC) do occur during the process, but these can be reduced with the use of stabilizers (Hann et al., 2020; Rosenau et al., 2001).

In the case of viscose, the manufacturing process is more complicated although the raw material is the same. In the first step, alkali cellulose is synthesized, with the wood pulp being treated with sodium hydroxide (NaOH). This is a chemical reaction that changes the chemical structure of the material (Hann et al. 2020), as it can be

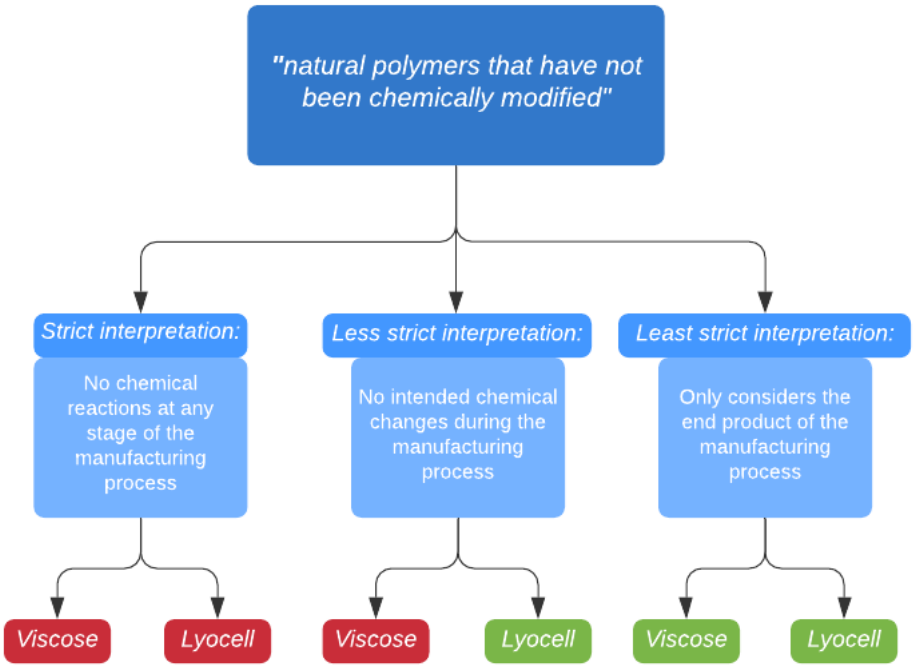
seen in the 13. figure. Then, the alkali cellulose goes through an aging process by means of oxidative depolymerization. In this reaction, molecular weight is decreased, while covalent bonds are breaking between the monomer units (Potthast, 2019). This step can also be seen as a chemical reaction because covalent bonds are broken. Then Carbon Disulphide (CS2) is added to transform the alkali cellulose into cellulose xanthate, which is soluble in NaOH and can be spun. Through the spinning process, the cellulose xanthate is transformed back into pure cellulose with the crystal structure of cellulose II (Hann et al., 2020; Potthast, 2019). 12. Figure shows the production flow of viscose fibers.



5. Figure: Simplified flow model of the viscose manufacturing process (own figure)

It can be followed on the figure that although the cellulose of the raw material goes through chemical reactions, those are temporary, and at the end of the process, it results in pure cellulose fibers.

Considering the ways of production for both viscose and lyocell fibers, the answer to the question if they should be included in the SUPD merely depends on how does one perceives the definitions provided in the directive. As was mentioned before, the term 'chemically modified' is bound to an interpretational range, and according to that range, lyocell and viscose should or should not be included into the directive, as it can be seen on the 13. Figure. Red color means the material should be included in the directive, while green means it should not according to the interpretation.



146. Figure: The different interpretations how "natural polymers that have not been chemically modified" can be understood in the SUPD (own figure).

According to the directive, no final decision has been taken about which of these scenarios should be followed. The different stakeholders have chosen between the interpretations depending on several factors, like biodegradability, flushability, production impacts, or other sector implications. These factors, which have been discussed endorsing or opposing the extent of the inclusion of MMCFs in the SUPD, are introduced in the following sub-chapters.

4.3. Biodegradability and Flushability

"If produced without using or retaining any substances of concern, cellulose-based fibres can be safely biodegraded."

(EMF, 2017b)

Although the Ellen MacArthur Foundation clearly expresses the biodegradability of MMCFs, this factor has arisen and proven to be a rather complicated issue around the inclusion of discussed materials in the SUPD. In general, it is defined as degradation caused by biological activity; therefore, the material must be capable of

degradation via microorganisms (Hann et al. 2020). According to Eunomia's report, the research methods available to test biodegradability can be sorted into two categories. One is the so-called 'in situ' research, which is conducted in real life, with natural scenarios, and the second method is in laboratory conditions where due to the strictly controlled environment, the results can be more precise (Hann et al. 2020).

Despite there are several different methods to test materials biodegradability, reaching consensus, and developing standard tests for certifications, seem to be complicated. It is especially tricky in the marine environment due to its diverse conditions (Hann et al. 2020). Currently, there are substantially fewer standard tests in the marine environment than in terrestrial, which is with the growing pollution of oceans, becoming a more crucial issue. One certificate which is existing for the marine environment, and which considers certain MMCFs, is the so-called OK biodegradable MARINE from TÜV Austria. Currently, Lenzing's Tencel as lyocell product and Lenzing's, Kelheim Fibres' and Aditya Birla Group's viscose material hold OK Biodegradable MARINE certification (Hann et al., 2020; TUV-AT, 2020).

While marine biodegradability tests are rather scarce, there are several methods tested in terrestrial conditions with successful results (Warnock et al., 2009; Park et al. 2004, Nam et al. 2016). For example, Warnock et al. conducted a study aiming to determine and compare the biodegradation rates of rayon (viscose), cotton and Tencel in aerobic Captila silt loam soil. It can be seen from the results that rayon has better values than cotton, but Tencel has worst in aerobic, moist and warm soil conditions (Warnock et al., 2009). Similarly, Park et al. also evaluated three different cellulose fabrics in a soil burial test with results that show greater biodegradability for rayon fibers compared to pure cotton. (Park et al. 2004). Another study from Nam et al. has compared the biodegradability of different non-woven materials which are used in wet-wipe production in moist, warm soil conditions. In this research, it can be clearly seen that synthetic materials like polypropylene or polylactic acid did not show any weight loss during the tests, while raw cotton and rayon fabrics had comparable results of degradation (Nam et al., 2016). These researches also have shown that the degradation of cellulose materials highly dependent on their degree of crystallinity and degree of polymerization (Park et al. 2004, Nam et al. 2016). Because the manufacturing process of viscose results in shorter cellulose polymers within and less crystalline fibers compared to cotton or lyocell, therefore viscose will be more capable for microbial biodegradation than the others (Park et al. 2004, Nam et al.

2016 The biggest argumentation that favors the inclusion of MMCFs in the SUPD regarding biodegradability is the lack of evidence and measuring methods, mainly in the marine environment (Hann et al. 2020). Although this is certainly a field that needs further research, mainly because of the growing plastic pollution in the oceans, this does not justify the differentiation between MMCFs and natural ones, for instance, cotton. As their chemical structure is identical, the terrestrial results have shown that the factors affecting the biodegradability of these materials are the degree of crystallinity and polymerization, which are merely physical differences of the polymer's structure (Park et al., 2004; Nam et al., 2016).

The biodegradation of materials discussed is undoubtedly a relevant question, which should be in the focus of the directive. As Professor Herbert Sixta in our interview has expressed, a clear definition of biodegradability should be connected to the definition of plastic. Although he also points out the difficulties in unifying and standardizing the numerous existing methods. As he says:

> *"(…) previous definitions established by the EU commission, namely what is a natural polymer, what is a chemical modification, and they want to stick to this previous definition, while biodegradability is not considered. Their [EU commission] argumentation was that there is no generally accepted method to determine the biodegradability, which is true, but one has to take into account the different environments where biodegradability is tested. Does it occur in the deep sea, in the shallow sea, in the land? So it depends on where this material is deposited and ends up, and how are the conditions affecting biodegradability? For me, it's rather an excuse for not linking the definition of biodegradability to the end use of these products."*
>
> (Herbert Sixta)

In addition, he also trusts the experts in the EU and that they can see the difference between a real plastic product which does not have biodegradability at all, and products that are innovative and are synthesized from natural materials with excellent biodegradability. He believes through these discussions that the commission would like to have a quick solution now for the SUPD to tackle the plastic pollution, and then later they will work on the refinements of the directive.

Another factor discussed in Eunomia's report is the flushability of the materials (Hann et al., 2020). Although there is no agreed industry definition for this term, it refers to whether a product is suitable for disposal through the wastewater treatment system and the toilet. Because around 93% of those materials that are causing sewer blockages are wet wipes, the flushability of this specific product type seems to be relevant (Hann et al., 2020; Dyson, 2016). Regardless of the lack of scientific definition, standards have been developed both from the side of the non-woven fabric industry and also from water utility associations in order to track flushability of these products (Hann et al. 2020). As in the case of biodegradability, in respect of wet-wipes made of MMCFs, it is challenging to reach a consensus, due to the lack of scientific evidence, and because there are no proven differences between the flushability of products made of cotton or MMCFs. However, a response to Eunomia's report from the non-woven industry's perspective points out:

> *"Flushable moist toilet tissues typically consist of a blend of viscose with short cut length (≤ 12 mm) or lyocell with short cut length (≤ 12 mm) and wood pulp manufactured. These tissues are designed according to strict criteria in order to avoid blocking sewages. Non-flushable wipes mainly consist of polyester fibres with higher fibre cut length (30 – 60 mm) and manufactured with different nonwoven production technologies to provide high fabrics strength for consumer use."*
>
> (Edana, 2020)

4.4. Production Impacts

From a life-cycle perspective, the environmental impacts from the production phase of the MMCFs also avowed to be a decisive factor in the discussions of their inclusion in the SUPD (Hann et al. 2020). The manufacturing processes of lyocell and viscose have been introduced before, and it could be seen that although they are substantially different, both of them utilize a range of chemicals. On the one hand, in the case of the lyocell process, the solvent used to dissolve the cellulose from the wood pulp is NMMO, which is a non-toxic chemical, and which can be and usually is recycled (Hann et al. 2020; Krysztof et al. 2018). On the other hand, the investigation of the production impacts of viscose is more complicated due to the several chemical

substances used in the process (Hann et al. 2020; EMF, 2017b). In addition, as both technology mainly utilizes wood as raw material, their contribution to deforestation also needs to be considered (EMF, 2017b).

In the viscose manufacturing process, NaOH, CS2 and sulfuric acid (H2SO4) are used to treat the wood pulp. These chemicals can have a severe effect on both natural ecosystems and human health when released in the different stages of the process (Hann et al. 2020; CMF, 2018). Workers exposed to CS2 can suffer from neurological symptoms, in addition to reproductive effects. Besides, H2SO4 and NaOH are also known as highly toxic chemicals (CMF, 2018). Although several hazardous substances are involved in the viscose production process, however, with proper management, these negative impacts can be minimized, if these chemicals are recaptured and neutralized or recycled after use (Hann et al. 2020, CMF, 2017). However, several incidences have been recorded when due to inappropriate management of viscose producers, maloperations have resulted in chemical leakage, damaging the surrounding ecosystems and human health (Hann et al. 2020, CMF, 2018).

Several stakeholders in our interviews would agree that from a sustainability point of view, the way of operations in the production phase as part of the life-cycle of the material is indeed an important issue that worth discussion. Prof. Samuli Patala and Helena Dahlbo for example think, whole life-cycle assessments instead of labelling are a way to evaluate the sustainability of discussed materials, which would give a pathway for policy-making. They put it in the following ways:

> *"(…) when it comes to policy-making to have a kind of evidence-based approach in a sense that for example you have been conducting LCA on two different products and see, what is the more sustainable choice. I think assessing the LC impacts of these products is a more fruitful way when it comes to policy-making rather than broad categorization, for example plastics versus textiles."*
>
> (Samuli Patala)

> *"(…) but we shouldn't put a label like this is bad and this is good on the material just because of it is a certain material, but they should be assessed in the context of where its used, how it's used and what its used*

for, and then assess those impacts from the system and look whether that is good or bad."

(Helena Dahlbo)

Prof. Herbert Sixta agrees on the importance of the impacts of the manufacturing processes. However, he also points out that SUPD is not about production phase, but about the end products and materials themselves:

"*Yeah, of course the process is as such is very important, but in a different way. Is it a green process? Is it a sustainable process? Does it cause GHG-emissions? Does it use toxic chemicals? Does it waste any kinds of energy or materials? The process has to be assessed separately, but this directive does not focus on the processes, only on the products as such (…).*"

(Herbert Sixta)

Besides, if the manufacturing process is considered in the directive, the production impacts of clearly non-plastic materials such as cotton shall also be considered and compared with MMCF technologies. In an expert meeting on the 'plastic' definition in the directive, some stakeholders have expressed their concern that if the directive includes MMCFs, then the industry will turn towards fibers like cotton, which has a more significant effect on the environment and that would be counterproductive (DG Environment and health, 2019). The use of agricultural land, high amounts of pesticides and other toxic chemicals can be accounted for the cotton farming activities, which has tremendous negative health impact on farmers and heavily polluting the surrounding water bodies (EMF, 2017b).

4.5. Other Industry Implications

While considering which materials should be included in the SUPD, the policy applications for the use of discussed polymers need to be considered in areas beyond plastic, as well. The sector which is primarily involved and might be the greatest extent affected by these decisions is the textile industry. MMCFs in this field are generally perceived as sustainable technologies for more reasons (EMF, 2017b). First of all, regenerated cellulose has a great potential to replace the more detrimental cotton

production (DG environment and health, 2019, EMF, 2017b). Additionally, some MMCF technologies have proven to be suitable in textile recycling (EMF, 2017b; Haslinger et al., 2019)

EMF, in its report, also supports the development of cellulose-based fiber production from recycled materials. It lists several successful companies, which are experimenting with the recycling of pure-cellulose based materials and use them in lyocell or viscose production (EMF, 2017b). These recycled fibers have a demand from the apparel producers side too, mainly from those start-up companies, whose goal is closing the loop with selling clothes of 100% recycled materials. One of these companies is MUDjeans, who is currently working on a prototype of 100% recycled pair of jeans using the mixture of mechanical recycling with chemically recycled cellulose fiber materials, as they have introduced it in our interview.

> *"(…) we have a fabric at MUDjeans which has 40% mechanical recycled fibers, and we would like to make this higher, but this is kind of the limit for mechanical recycled fibers, because otherwise it just gets too weak to make good quality products, so there is always 60% new organic cotton added, and we thought maybe it can be interesting the two technologies so mechanically recycled fibers and chemical recycled fibers (…)"*
>
> (Eske Hurenkamp)

Prof. Herbert Sixta himself is working with a lyocell-type of technology, Ioncell®, which he introduces and compare with other processes like lyocell in the following way:

> *"Ioncell® is a lyocell process and there is not so big difference to the classical lyocell process. We have a different solvent. The one that we use has some advantages over NMMO, we can do spinning at relatively moderate temperatures, it does not tend to so-called run-away reaction like NMMO; NMMO is a dangerous chemical, it undergoes run-away reactions, of course people know how to stabilize it, but you never know (…) thirdly, we have the feeling, but this will only become apparent on a bigger scale (…) that our process allows the production of fibers with better properties in terms of mechanical properties, and also because our solvent is quite inert, it is more suitable for use in textile recycling."*

(Herbert Sixta)

He also says that some of these types of MMCF technologies are actually the way to proceed towards a more circular textile economy, and he expects them to grow in the future.

> *"(…) so this is the future technology, I'm very sure, this lyocell type, and there will be maybe even other solvents, so we have now NMMO-monohydrate, we have ionic liquids, we might have even other ILs in the future. I think this situation will proceed in the future."*

(Herbert Sixta)

Certain MMCF processes appear to be innovative technologies, which have the potential to bring the textile industry towards more circular operations. However, the discussions around their inclusion into the SUPD seem to be limited to their single-use implications. Prof. Kaisa Sorsa points out the 'silo' pattern of the policy-making process neglects the connections and potential interferences between the different industries.

> *"So in a way plastics and textile have these kind of connections. And then when EU is preparing policies for plastics they should take into account in the same time the textiles. Now they are creating in silo, they only focus on plastics, while they should also consider textiles (…)"*

(Kaisa Sorsa)

4.6. Conclusions and Updates of the Discussion

Regarding the scope of SUPD and if wet-wipes made by MMCFs fall into the category of plastics according to the definitions, the discussions in the EC are currently ongoing. The previous sub-chapters lead us through the arising uncertainties of the provided definitions and the different levels of their interpretations. Stakeholder reasoning to interpret the definition of plastics in a certain way is also discussed. Article 12 of the SUPD provides specifications and guidelines on single-use plastic products, where it points out:

"By 3 July 2020, the Commission shall publish guidelines, in consultation with Member States, including examples of what is to be considered a single-use plastic product for the purposes of this Directive, as appropriate."

(OJEU, 2019)

Several stakeholders from the political, academic and the industrial fields have been involved in the discussions through workshops and scientific studies in order to reach a conclusion about the issues around the definitions. According to the discussed materials, biodegradability, flushability, production impacts and other industry implications have been considered. The main conclusion one can draw is that these factors most times are handled and investigated individually to the discussed materials, while the same factors regarding natural materials such as cotton are often neglected. Therefore, in order to find consensus, two pathways to implement the SUPD can be recognized, which are additionally emphasized by the interviewed FINIX members also.

- Taking into account the whole product's life-cycle and compare their impacts to each other, regardless of their materials are considered to be natural or potentially plastic materials.
- Considering only the final product, regardless of the production process, but regarding the material properties of the product when disposed. Compare and classify the final materials according to the discussed factors.

Eske Hurenkamp from MUDjeans adds that from a CE perspective regarding MMCFs, it is vital to consider the effect of the end-material in the natural environment, and she says this significantly differentiate MMCFs from synthetic ones.

"We are looking from the CE perspective right, and if we are only basically look at the processes from a linear perspective, maybe some processes look like they are the same. But if you look at the end-stage of any product, I think it's very important to ask the question what is the effect if it ends up in the nature, and is it biodegradable, is it fitting in natures closed loop? Because I think there is a big difference between MMCFs and synthetic fibers."

(Eske Hurenkamp)

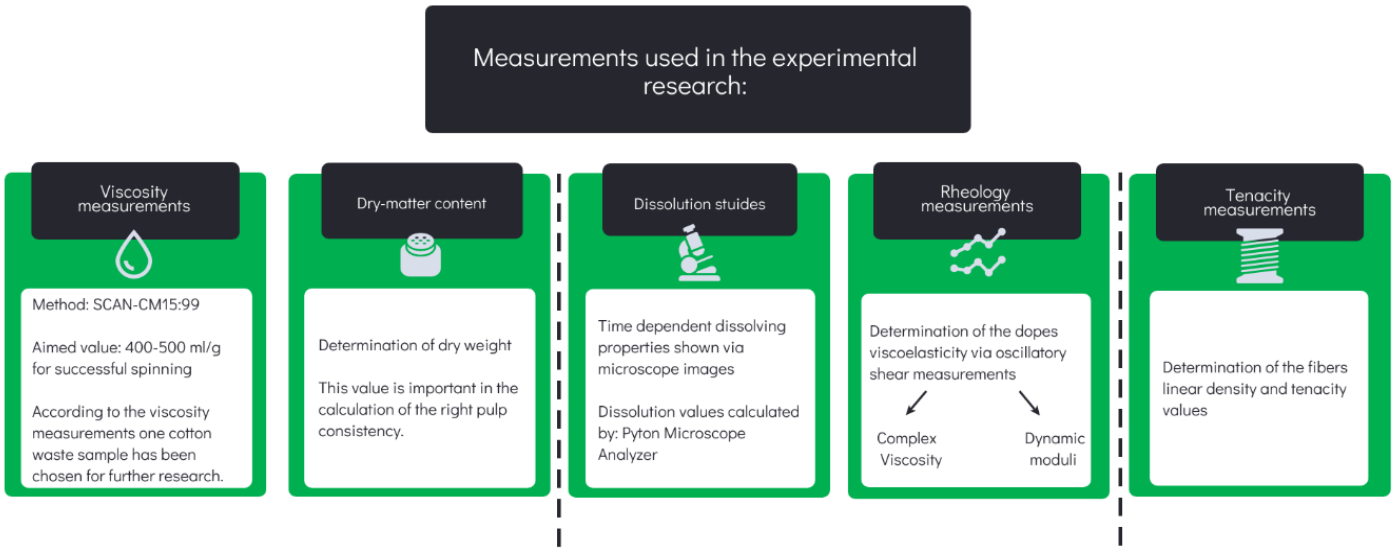
Prof. Herbert Sixta as an expert of cellulose-based materials and MMCFs in the academic field, has taken part in the discussions personally and has shared the most recent developments about if viscose and lyocell finally are about to be considered chemically modified and therefore, fall into the scope of SUPD. He says:

> *"Lyocell is now considered to be a natural polymer, viscose is not yet considered to be a natural polymer, but there are also arguments, by let's say the EU consultant companies, like the ECHA, they basically consider viscose also as a natural polymer. Why? Because they say the process which is used to convert pulp to viscose fiber is not relevant in terms of the properties of the end product."*
>
> (Herbert Sixta)

5. The Recyclability of Post-Consumer Cotton Waste via Ioncell® Technology – an Experimental Study

As one of the discussed Man-Made Cellulose Fiber (MMCF) technologies, Ioncell® technology has been tested in this study. The aim was to investigate the contingency of the chemical recycling of post-consumer cotton waste fabrics by means of Ioncell® technology and evaluate its potential role in a circular textile economy. The technology was developed as an alternative for other MMCF technologies, such as viscose and lyocell processes, in order to eliminate their drawbacks, like the formation of toxic chemicals or other by-products (Michud et al. 2016, Woodings C. 2001). Compared to these technologies, Ioncell® is using a direct cellulose solvent with excellent dissolution properties and has the ability to regenerate filaments with superior properties to cotton, viscose and lyocell without the formation of any by-products (Michud et al. 2016; Hauru et al. 2014).

Ioncell® technology, just like the other MMCF technologies, is originally utilizing wood pulp as its raw material to derive cellulose. On the other hand, recent studies have also shown that it can be used in textile waste recycling in the case of cellulose-based materials, such as cotton (Asaadi et al., 2016). Taking this as starting point, this chapter introduces an experimental work in which the Ioncell® process is utilized to recycle post-consumer cotton waste. Dyed cotton textile sample and a reference cellulose material have been ground, dissolved in ionic liquid (IL), and spun into new cellulose fibers, which finally went through tensile testing in order to compare and evaluate their quality. The introduced results are based on an internship project which has been conducted between 2019. September – 2019. December by the author of the report; in the Department of Bioproducts and Biosystems at Aalto University, Finland (Újhelyi et al., 2019). The utilized measurements done on the initial cotton waste samples, on the spinning dopes and finally on the prepared fibers are summarized on 14. Figure.



157. Figure: Summary of the measurements and their purpose used in the experimental part (own figure)

5.1. Experimental Methods

5.1.1. Raw Materials

A cotton and a reference cellulose pulp have been used in this study from two sources. First, post-consumer cotton waste has been used, which has been provided from Uusimaa Hospital Laundry for former research work at Aalto University (Asaadi et al. 2016; Haslinger et al. 2019). These originally white hospital bed sheets have been dyed by a doctoral candidate of the Department of Bioproducts and Biosystems for further study (Haslinger et al. 2019). Six patches of cotton waste have been chosen first, and after intrinsic viscosity and dry-matter content measurements, the most suitable ([η]=439 ml/g, DMC= 92,72%) sample was carried forward to the experiments. Additionally, as a reference cellulose source, Birch pre-hydrolyzed kraft pulp (Enocell4) ([η]=468 ml/g, DMC= 94,00%) from Stora Enso Enocell mill, Finland has been applied.

The ionic liquid used for cellulose dissolution 1,5-diazabicyclo[4.3.0]non-5-ene acetate ([DBNH][OAc]) was synthesized at Aalto University by means of an exothermic reaction. In order to keep a constant temperature, external cooling has been utilized. The needed ingredients for the synthesis were acetic acid from Merck, Germany, and 1,5-diazabicyclo[4.3.0]non-5-ene (DBN, 99%) from Fluorochem, UK.

5.1.2. Grinding and Viscosity Measurements

Red and green dyed waste cotton batches were selected (R1;R2;R3;R4;G1;G2) and ground by means of a Willey mill. Then intrinsic viscosity of the ground cotton was determined in cupri-ethylenediamine (CED) by using a capillary viscometer according the standard method (SCAN-CM15:99). The average intrinsic viscosity of the different batches was 400 ml/g; 345 ml/g; 386 ml/g; 475 ml/g; 432 ml/g; 439 ml/g respectively. The suitable viscosity values for dry-jet wet spinning without the need for pre-treatment are between 400-450 ml/g (Haslinger et al. 2019). Therefore, according to the viscosity measurements, G2 sample was selected for further study. The birch pulp, which was delivered in the form of sheets, was also ground by means of a Willey mill.

5.1.3. Spinning Dope Preparation

In order to be able to use, the crystallized IL needs to be liquefied at 70°C in a water bath. Then, the ground cellulose/waste cotton pulp was added to the IL, and the mixture was stirred at reduced pressure, with the shearing rate of 30 RPM at 80°C. After 90 minutes of stirring, most of the cellulose/cotton was dissolved. Then, in order to remove any undissolved particles, the prepared solution was press-filtered at the pressure of ~2MPa at 80°C (metal filter fleece of 5 µm absolute fineness, Gebr. Kufferath AG, Germany) by means of a hydraulic filter device. As the last step, the prepared spinning dope was shaped into the dimensions of a spinning cylinder and was cooled at 5-7°C minimum overnight in order to solidify. Two prepared dopes are analyzed in this study; an Enocell4 cellulose dope and a waste cotton dope, both with 13% pulp consistency.

5.1.4. Dissolution Studies

The cotton/cellulose dissolution of the dopes in IL has been observed throughout time using a Leica DM2500M optical microscope. Samples were taken during the dope preparation period every 30 minutes and also after filtration. Overall, four samples were prepared per dope and were analyzed between a glass slide and a glass cover on a hot stage (Linkam LTS420) at the temperature of 80°C. In order to increase the contrast between the solvent and the cotton/cellulose particles and to

improve the illumination of the undissolved traces, cross-polarized light was used. According to the pictures, dissolution values have been calculated by means of Python Microscope Analyzer. This software has been developed at Aalto University, and it uses the proportions of white and black pixels of the images to calculate the undissolved particles.

5.1.5. Rheology Measurements

Rheology measurements have been conducted on the prepared dopes by means of Anton Paar MCR 300 Rheometer, with parallel plate geometry (25mm plate diameter, 1mm measuring gap). The visco-elastic behavior of the spinning dope involves the dynamic moduli (storage modulus G', and loss modulus G"), and the complex viscosity. These have been determined over an angular frequency of 0,1-100 rad/s and with a dynamic frequency sweep between 60-100oC. The cross-over points (COP) of G' and G" at different temperatures and the zero-shear viscosity was calculated by means of Rheoplus software. With the validity of the Cox-Merz rules assumed (Cheng et al. 2012; Lu et al. 2015), this software determines the zero-shear viscosity from the complex viscosity data, and also the three-parameter Cross viscosity model (Sammons et al. 2008).

5.1.6. Fiber Spinning Trials

By means of a customized dry-jet wet spinning unit with a one-hole (monofilament) spinneret, single filament was spun from the prepared cellulose/cotton IL solutions. The cooled and solidified dopes have been heated in a spinning cylinder. The heating temperature depends on the dope properties, and in the case of both cellulose and cotton dopes, it was between 70-75 ^{o}C. From the cylinder, the solution is extruded through a one-hole spinneret - with a diameter of 0,1 mm, and a length of 0,2 mm – into a water coagulation bath with 15 ^{o}C temperature. The distance between the spinneret and the water, so-called air-gap was chosen between 0.4-0.6 cm. With a 0,01 ml/min extrusion velocity (v_e) the filament was guided through the bath, and then reached the godet couple with adjusted take-up velocity (v_{tu}). Filaments were spun and collected at different draw-ratios (DR=v_{tu}/ v_e) until the reachable highest DR value. The collected fibers were washed three times in water at 80^{o}C, and left for drying at least overnight.

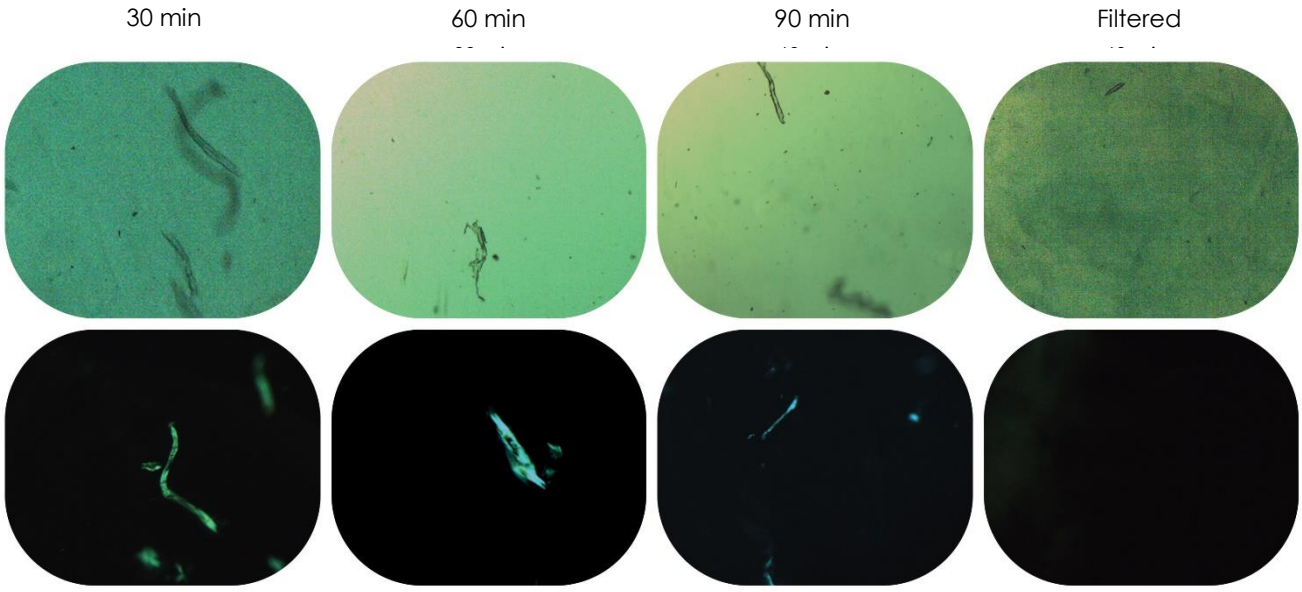
5.1.7. Tensile Test of Spun Fibers

The prepared fibers were stored in 20 °C with 65% relative humidity (RH) overnight for further fiber tests. The mechanical properties have been determined by the use of a Favigraph instrument (Textechno, Germany). In conditioned dry mode linear density (dtex), tenacity (cN/dtex) and elongation at break (%) were measured. The test parameters were the following: 20cN load cell, 20 mm gauge length and 20mm/min test speed. Per sample from all reached DRs, twenty measurements were done. Depending on the linear density of the given sample, pretension weights between 50-250 mg have been used.

5.2. Results and Discussion

5.2.1. Dissolution Studies

A cellulose (Enocell 4) dope as a reference and a waste-cotton dope were prepared and analyzed for this study. While dope preparation, microscope samples were prepared after every 30 minutes and additionally after filtration. Using a heated stage microscope, both non-polarized and cross-polarized images were taken, and the dissolution values of these images have been calculated. On 15. Figure images of the time-dependent dissolution of the cotton-waste dope can be seen.



16. Figure: Time dependent dope dissolution shown via heating stage microscope pictures

Both the cellulose and the waste cotton dopes have shown high values, and after filtration the dopes reached more than 99.9% of dissolution. The calculated dissolution values can be seen on the following table.

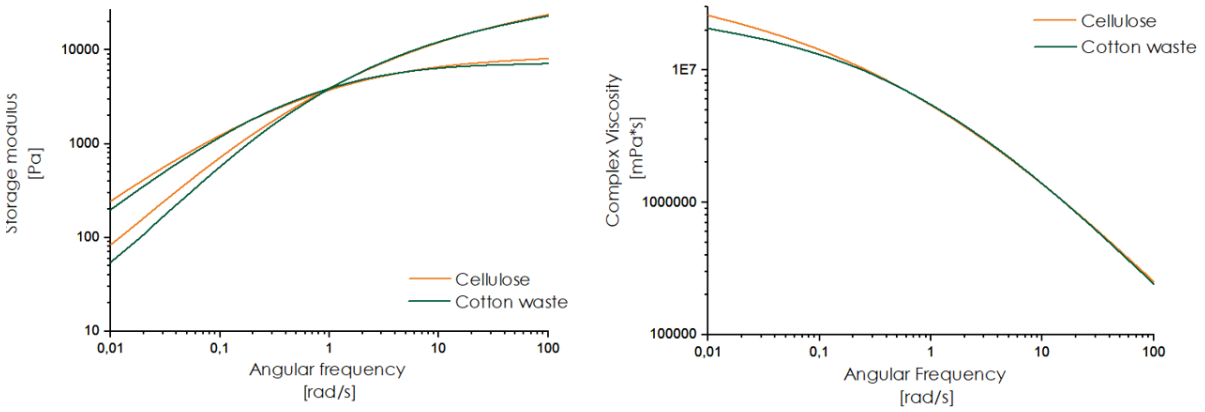
Sample	30 min	60min	90min	Filtered
Cellulose (Ref.)	97,98%	99,73%	99,91%	99,92%
Waste cotton	99,38%	99,59%	99,74%	99,91%

1. Table: time dependent dope dissolution values of the prepared dopes

5.2.2. Rheology of Spinning Dopes

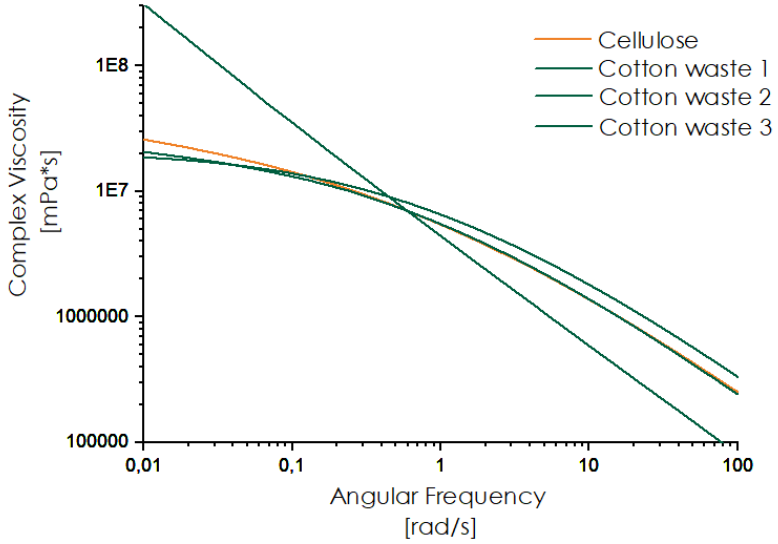
The rheological properties of dopes are essential information for the prediction of their spinnability (Michud et al. 2015, Ma, 2018). To determine the visco-elastic properties of the prepared solutions, oscillatory shear measurements have been conducted, as described in the previous section. The complex viscosity and the dynamic moduli by means of frequency sweep at rising temperatures were recorded on both the reference and the waste cotton dope.

According to Michud et al. for the best spinning performance of the dope, the zero-shear viscosity needs to be between 25,000-40,000 Pa*s; the COP of the G' and G" should be between 0,8-1,5 rad/s, while the dynamic moduli of this COP is between 2000-6000 Pa (Michud et al., 2015, Ma et al., 2018). On 16. Figure the complex viscosity and the dynamic moduli curves of the 13% cellulose and the waste-cotton dopes can be seen at the spinning temperature (70°C). One can recognize that the figures for both dopes are very similar and that both dopes fell into the optimal values for good spinning performance.



17. Figure: Rheological properties of the reference and the waste cotton dopes at 80 oC

However, it needs to be pointed out that the operation with the waste cotton spinning dope was complicated. This dope had to be prepared three times, and the different versions have shown different, sometimes unrealistic rheological properties. The repeatedly prepared dopes were all measured, and the complex viscosity curves of them are presented on 17. Figure.



8. Figure: Complex viscosity curves of the dopes that gave different results per sample compared to the reference dope at 80°C

As a consequence, it can be suspected that the cotton waste dope shows unpredictable behavior because of its dyeing. Regardless of the defiant spinning properties, both the cellulose and the waste cotton dopes were prepared for spinning trials.

5.2.3. Spinnability of the Dopes and Fiber Spinning

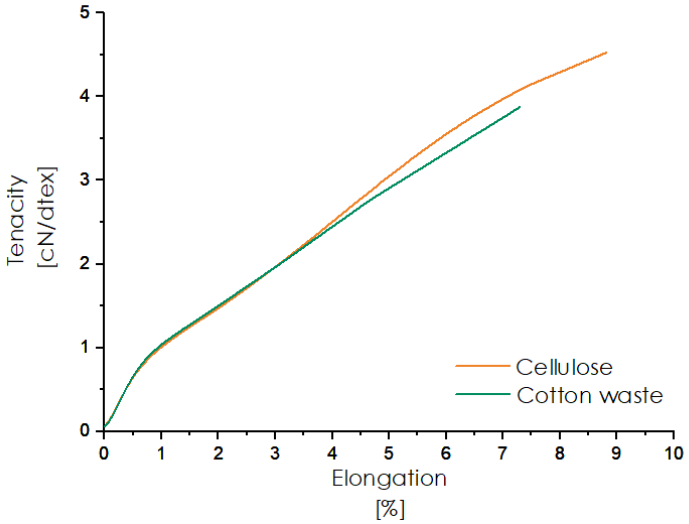
As it was mentioned before, the dope's spinnability greatly depends on the visco-elastic properties, but also on other factors like the dope's chemical composition, the IL that has been used (Ma, 2018). Therefore, the spinning of both prepared dopes was further carried out. The solutions were spun by means of a small dry-jet wet spinning unit equipped with a single-hole spinneret. The fibers were collected at different DRs, including the maximum value that could be reached. The highest reachable DR shows how well spinnable the given dope is: under DR 2 we talk about non-spinnable solutions, between DR 2-8 dope has poor, between 8-14 it has good, and above DR 14 it has excellent spinnability (Ma, 2018; Asaadi et al. 2016). Regarding these values, both the reference cellulose dope and the dyed waste cotton could reach good spinnability with DR 14 and 8, respectively, at 70-75 °C temperature. The following table shows a summary of the spinning circumstances for both dopes.

Sample	Spinnable	T_{spin}[°C]	η^0*[Pa.s]	ω[rad/s]	G[Pa]	MaxDR
Cellulose(Ref.)	Yes	75	35360	1,19	3630	13
Waste cotton	Yes	70	28000	1,00	3907	8

2. Table: Spinnability and rheological properties of the dopes at the spinning temperature

5.2.4. Mechanical Properties of the Spun Fibers

In conditioned dry mode, mechanical properties such as linear density (dtex), tenacity (cN/dtex) and elongation at break (%) were determined of all collected fibers at different DRs. The measured fiber properties are dependent on the previously discussed rheological properties, on the DR of the current fibers, and the total orientation of the cellulose chains (Ma et al., 2015). On 19. Figure stress-strain curves can be seen of the prepared fibers. They show the tenacity values in relation to the elongation of the fibers with DR 8. The reference cellulose fiber is definitely stronger than the one spun from cotton waste, as it shows higher elongation, and slightly higher tenacity values too, although the cotton waste fibers were also reaching sufficient quality.



*19**9**. Figure: stress-strain curves of the prepared fibers at DR8*

5.3. Conclusions of the Experimental Research

The current laboratory research aims to present the recyclability of post-consumer, dyed cotton-waste with the means of dry jet-wet spinning process. Cotton and wood pulps were dissolved in [DBNH]OAc and were spun by utilizing Ioncell® technology successfully. A reference cellulose source and cotton waste were compared throughout the entire process, starting with the preparation of the dope with dissolution studies, rheology measurements of the dopes, spinning trials and quality measurements of the staple fibers.

The dope preparation and the dissolution studies showed no relevant deviation between the reference and the waste cotton samples, both of which were smoothly dissolved in IL and reached 99% dissolution after only 30-60 minutes. The rheological properties neither have proven significant divergence between the two materials, although the dyed cotton waste dopes and their visco-elastic measurements had to be prepared several times, because of unreliable results. Therefore, it can be concluded that the dyes can disturb the visco-elastic measurements, and potentially the spinnability of the textiles.

Regardless of the different rheological properties of the cotton waste samples, both they and the reference cellulose source were spun successfully between 70-75°C. As the last step, the mechanical properties of the prepared fibers were investigated. Overall, we can conclude, that although the fibers spun from cotton waste samples have somewhat lower elongation and tenacity values than the

reference fibers, they are suitable for recycling using Ioncell® technology and achieve the values typical for lyocell-type fibers.

One way to implement Circular Economy (CE) in the textile industry is material recycling. Another way is to replace cotton production with other, more sustainable and less resource-intensive technologies (EMF, 2017b). Given the earth's carrying capacity, with a substantially growing population, decreasing and replacing the use of virgin materials is crucial in order to satisfy the increasing consumer needs of textiles (The Fiber Year Consulting, 2015; Oerlikon, 2010; Sandin and Peters, 2018). Ioncell® technology is one of those MMCF technologies that are capable of producing cellulosic fibers from other cellulose-based materials, thus replacing the use of fresh cotton, and that are also suitable for material recycling. In addition, Ioncell® fibers are produced without the use of any toxic or hazardous chemicals, and without the formation of problematic by-products (Michud et al., 2016; Woodings, 2001).

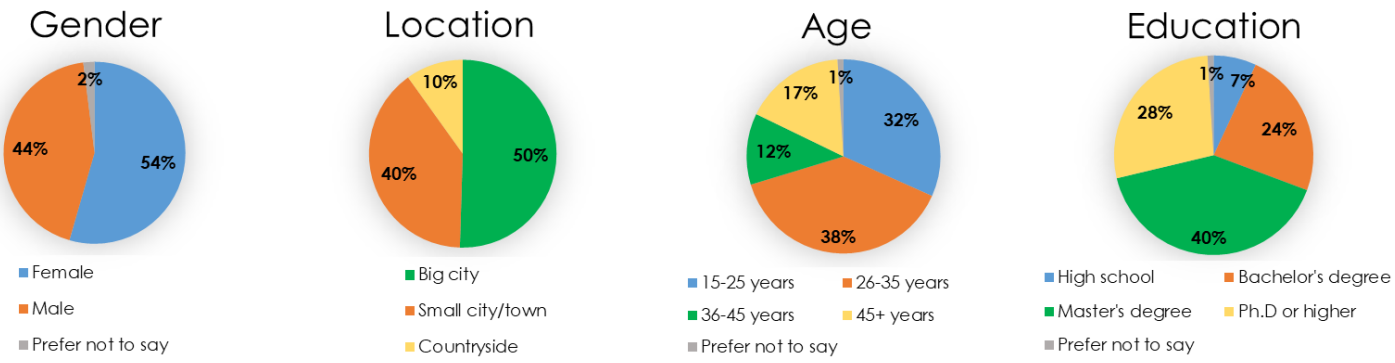
Although Ioncell® seems to be a promising technology, it has not been established on a large scale yet. In our interview with Prof. Herbert Sixta the struggles through the development path have been discussed, including the selection of IL as a cellulose solvent, the high prices of the materials, and the foreseeable obstacles that might arise with a continuous closed-loop operation of the production process. Overall he points out the advantages and disadvantages of the process and his positive prediction for the future of the technology:

> *"On the other hand, there are also disadvantages; one big disadvantage is of course that the technology is not yet established, so we are lagging behind the Tencel technology, and the Ioncell® technology needs more energy to remove water, because we have to basically remove all the water, while NMMO tolerates or even demands a residual amount of water of 13 m%, which is 10% more than with our process. So there are pros and cons. (…) of course you can always find problematic steps, I don't want to deny that and energy is one key aspect, it certainly has to be shown that the energy is derived from sustainable sources, that's obvious, the fiber yield is very high, due to the overall very mild conditions which in turn keeps the extent of side reactions very low; in other words, basically all the raw materials can be converted into the final product."*
>
> (Herbert Sixta)

6. Investigation of Consumers' Perception

In order to investigate how consumers and the public perceive the discussed terms which are used in the Single-Use Plastic Directive (SUPD)and answer the third sub-question of the research, a public survey has been carried out as it has been described in the methodology. The results of the questionnaire in addition to the personal opinions of the interviewed stakeholders, are analyzed and discussed in this chapter.

In a one-month period (14.04.2020 – 14.05.2020.), 119 respondent's answers have been received from which 101 finished with all questions. The nationalities of the respondents varied between several European countries, with an immense proportion from both northern eg. Denmark, Finland and southern countries eg Italy., but responses have been received from the Czech Republic, Hungary, Germany, Romania and Switzerland as well. General information, such as gender, living location, age and education of the respondents can be seen on 20. Figure.

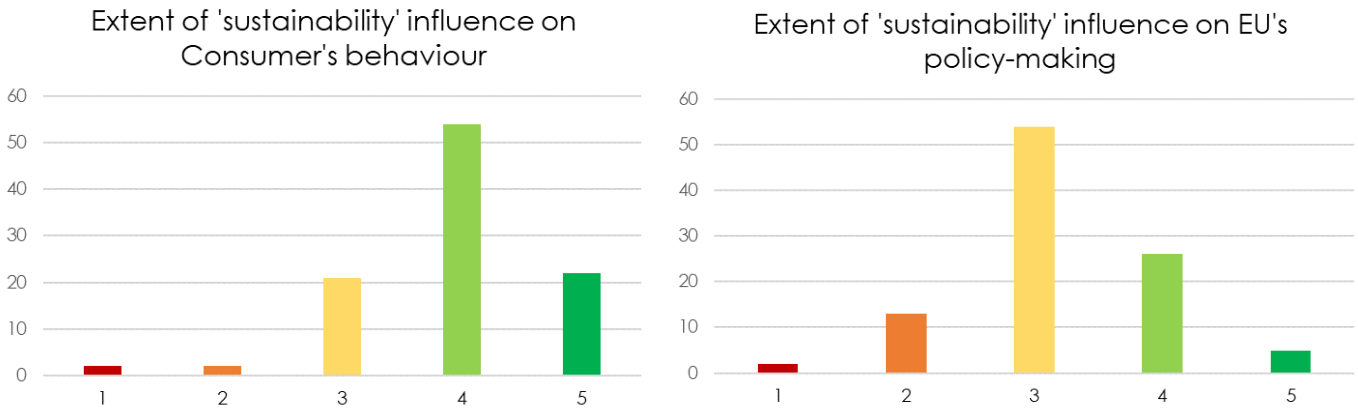


20. Figure: General information of the survey respondents

As Saunders et al. emphasize the importance of the flow and order of questions being logical to all respondents (Saunders et al. 2009), particular attention has been paid to the survey layout. The questions regarding the general information excluded, the survey can be divided into two sections. The first section aims to investigate the public opinion about EU policy-making regarding plastics, and to find out how consumers perceive the single-use products included in the SUPD, while the second section directs to the respondents' knowledge of sustainable fashion industry and different textile material choices. The aim of the following sub-chapters is to analyze and compare the quantitative data gathered from the survey, with the qualitative interviews, and identify the relevant connections.

6.1. Sustainable Decisions

For the sake of investigating the public knowledge and perception of the EU's environmental policy-making and circular textile economy, first, the understanding of sustainability needed to be explored. Therefore, the first question focused on what consumers associate with the word 'sustainability'. Most of the respondents gave relevant answers. A lot of them referred to the terms 'environment' 'development' or 'future', and several also pointed out the three pillars of sustainability (social, economic and environmental) (Basiago, 1999). In addition, most respondents claimed to be at least a certain extent influenced in their product purchase decisions by the concept of sustainability. The ratios of this extent can be seen on the left side of the following chart, where 1 means to be hardly, while 5 stands for being greatly influenced.



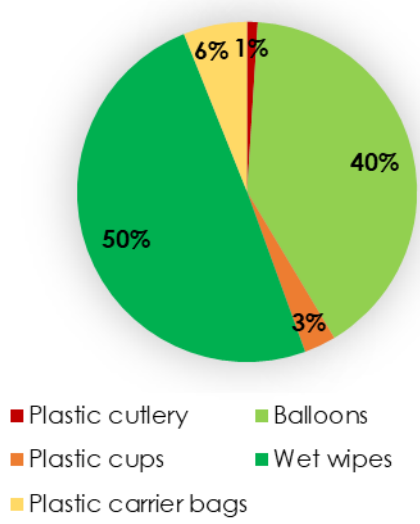
101. Figure: Comparism of consumers' behaviour and EU's policy making about the extent of being influenced by 'sustainability'

Additionally, it worth comparing how much consumers claim to be influenced by sustainability in their decisions and the extend they think the EU considers the concept in its policy-making. It can be seen that they perceive less sustainability influence on the policies, then themselves.

The respondents' positive attitude towards sustainability is also shown in the second section of the survey. To a more specific question, which focuses on consumer behavior in the apparel industry, 85% of the respondents claim they would pay more for the option that seems to be more sustainable for them.

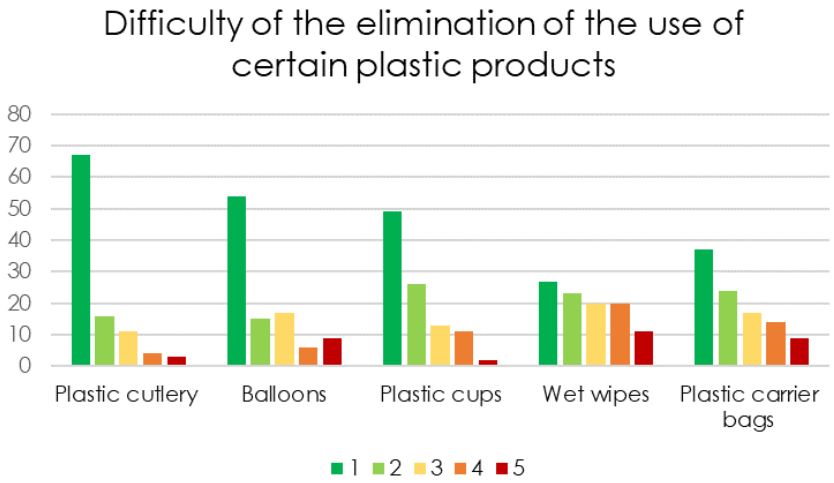
6.2. Single-Use Plastics

The next questions of the survey are referring to five product groups (plastic cutlery, balloons, plastic cups, wet wipes, and plastic carrier bags) as examples included in the SUPD. Although all of them are part of the directive, the first question aims to find out which products seem to be exemptions in the view of the respondents. 22. Figure shows that wet wipes, which are the reason for discussions around man-made cellulose fiber (MMCF) materials, seem to be the least fitting into the category of 'single-use plastic' in the opinion of the consumers.



2211. Figure: Consumers' perception about which product type is least likely included in the SUPD

Correspondingly, from the selection of the same product types, consumers believe wet wipes are also the hardest to eliminate from their everyday life. The next figure shows their responses when the difficulty of the elimination of certain products from their lives is asked. 1 shows the easiest, while 5 stands for the hardest to eliminate.



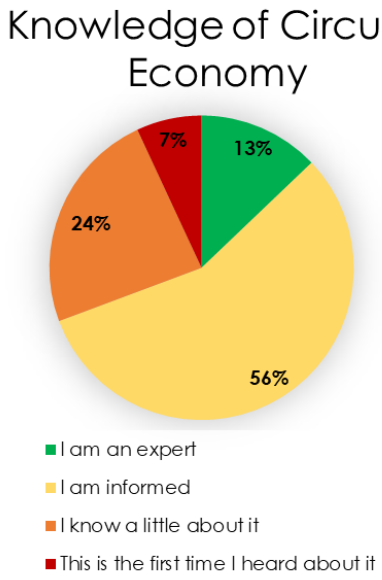
123. Figure: Consumers' perception about how difficult certain product type to be eliminated from their lives

However, it is also worth pointing out, that overall most survey respondents claim for all product types to be easy to eliminate from their everyday life, which is in great

controversy with the calculation of EU's yearly generated 26 million tons of plastic waste (EC, 2018).

6.3. Circular Economy in the Textile Industry

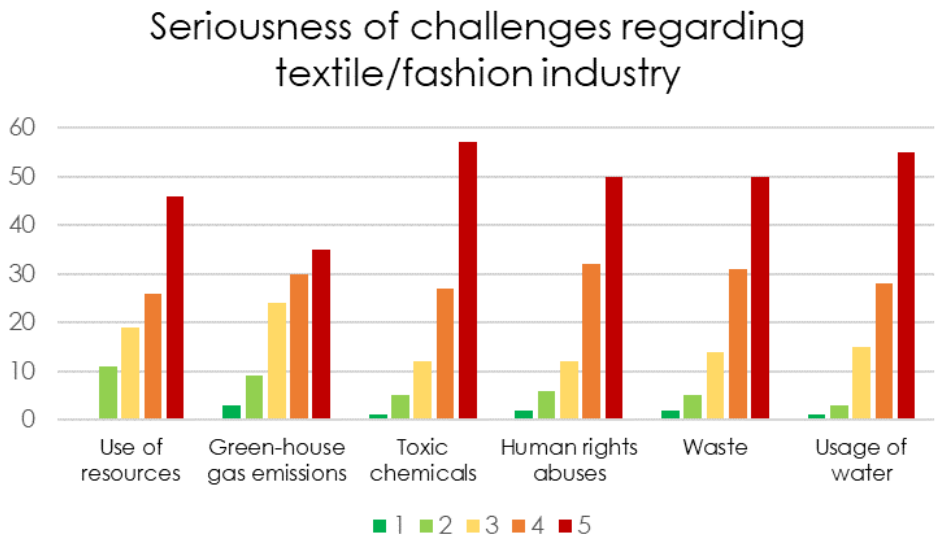
The focus of the second section in the questionnaire moves towards the investigation of consumer's knowledge of CE within the textile industry, and how sustainable the different textile materials are considered. First of all, it was essential to gather information about how informed are the respondents regarding the topic of CE, and how do they see its implementation in the textile sector. Therefore, the first two questions of this section focus on these issues.



24. Figure: Consumers' knowledge about the topic of Circular Economy

As the pie-diagram shows, the most significant portion, 58% of the respondents have claimed to be at least informed or 13% to be an expert about the topic of CE, while the remaining almost third (31%) never heard, or knows very little about it. Additionally, to promote CE in the textile industry, numerous time the 3R was mentioned (Reduce, Reuse, Recycling) (Sakai et al., 2011) and different aspects of it, like developed sorting systems, design for recyclability, second-hand clothing, promoting durability, or providing repair services.

Subsequently, the respondents have been asked to rank the challenges associated with the textile/ fashion industry (Allwood et al. 2006). It can be seen that although all of the issues are considered greatly serious (5) in the view of most respondents, toxic chemicals and usage of water seems to be the most significant concern. The following figure shows how consumers rank the significance of the listed issues, where 1 stands for less, and 5 for greatly serious challenges.



25. Figure: Consumers' perception about the extent of seriousness of certain challenges in the textile/fashion industry

Furthermore, regarding the EU's policy towards CE, the opinion of the interviewees has been asked about the new action plan (EC, 2020). Both Samuli Patala and Kaisa Sorsa agreed that the plan is quite ambitious, promotes system thinking in multi-level governance, and greatly considers the opinion of the public, however, both of them point out that the lack of harmonization in the implementation in different member states might be an issue.

> *"I mean overall I think the EU's CE plan is very ambitious compared to the global level, and I think it's very great plan for going forward. (…) And I think at least the way it will probably implemented in Finland, it is very close to the vision of the action plan. But it is hard for me to say how it is with regards to other countries. And also if we are talking about CE what is prior to this new plan, it's probably there is lot of national level differences with some other countries."*
>
> (Samuli Patala)

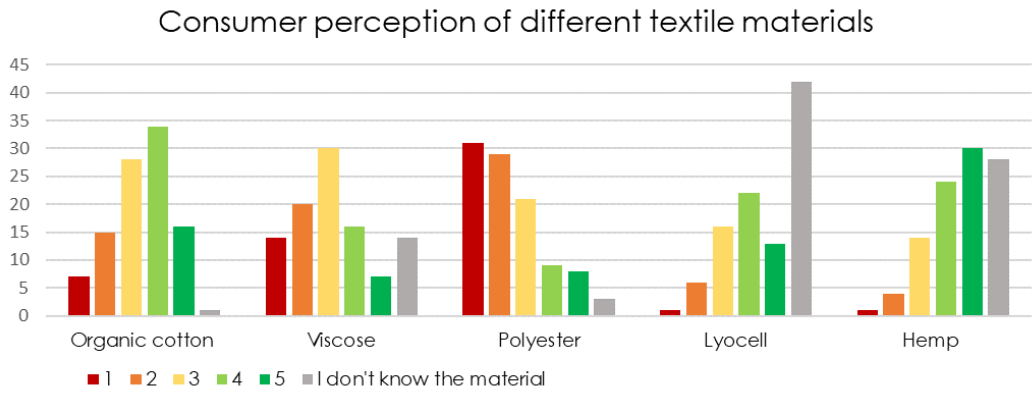
> *"I think it is effective in a way that the action plan has promoted a systemic approach across the entire value chain, so that is very important in order to make the transition happen. (…) I think different member states have implemented CE policy on their own way, it can happen that there is a lack of harmonization and integrated recycling plans across the EU. On the local level there are varieties how some countries are interested in*

implementing those rules properly, and some others don't put enough attention."

(Kaisa Sorsa)

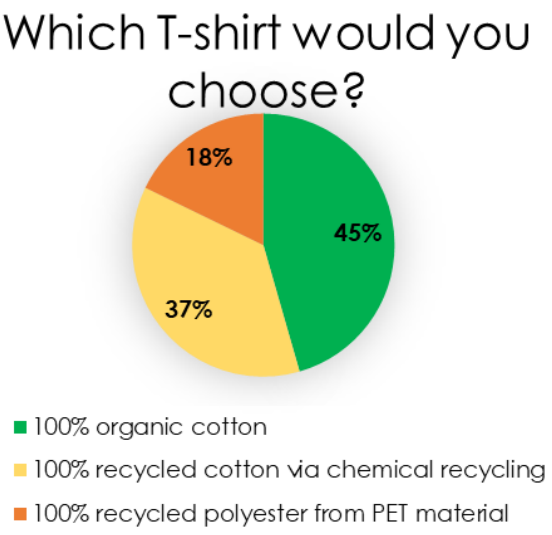
6.4. Perception of Different Textile Materials

The case of different textile materials included MMCFs and how they are currently perceived by the consumers is investigated with the last questions of the questionnaire. First, we focus on five subjectively selected textile materials, which include two natural materials with different production impacts (organic cotton, hemp), a clearly synthetic material (polyester), and the two discussed MMCFs (viscose, lyocell).



136. Figure: Consumers' perception about how sustainable are different textile materials

26. Figure shows how these materials are perceived currently by the consumers, where 1 stands for least sustainable, while 5 means most sustainable materials. Polyester clearly has proven to be considered the least sustainable from all, mainly compared to natural textiles like organic cotton or hemp. On the other hand, a considerably high number of respondents (25%) chose low sustainability value (1-2) in the case of organic cotton, which resembles the concerns of the impacts in the production phase of the material. Regarding MMCFs, the values for viscose are rather low; after polyester, this material has been chosen to be the second least sustainable, while lyocell is considered to be a great choice regarding sustainability in the opinion of those consumers who had knowledge about the material. However, more than 40% of the respondents admitted they did not know about lyocell.



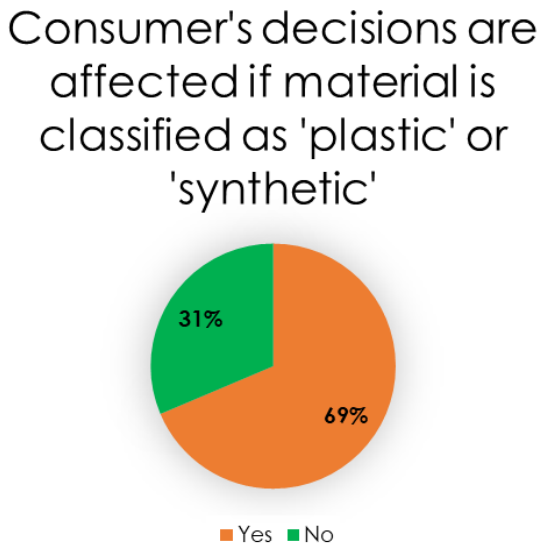
27. Figure: Consumers' choice of material in case of a T-shirt purchase

Although the results of the previous question have shown the arising concerns around the environmental impacts of cotton production, most of the respondents (45%) would choose the cotton t-shirt above recycled one as it can be seen on 27. Figure. The other choices were 100% chemically recycled cotton, which refers to those lyocell type of MMCF technologies that are accessible for cotton recycling, and 100% recycled polyester from PET waste materials (McCollough and Sun, 2019). These recycled materials were chosen by 37% and 18% of the respondents, respectively.

The previous figure also shows that the terms used in the case of describing MMCF technologies for recycling seem to be an important factor when consumers' perception is considered. In the above-mentioned question, '100% recycled cotton via chemical recycling' is used, which might have an altering effect in the respondents' perspective, and makes them choose the organic cotton instead. For this reason, other names can be used in promoting these technologies, as it can be seen in the case of MUDjeans, who are using 'molecular recycled' instead of 'chemically recycled' when describing the used MMCFs in their jeans. Dion Vijgeboom has expressed in our interview, that the reason for modifying the used term is the negative connotation of the word 'chemical':

> *"I mean people associate with the word chemical with nasty things, whit toxicity, those kind of things, so from that perspective at this stage it makes more sense to create interest, to name it in that way."*
>
> (Dion Vijgeboom)

Similarly, the survey respondents have been asked if their decisions of sustainable clothing would be affected if certain materials would be classified plastic, or synthetic. It is noticeable on the following pie diagram, that the great majority of the respondents connect these words with negative connotations, and therefore most of them have answered with yes for the last question.



28. Figure: Answers of consumers about if their decisions would be changed if the material is called plastic or synthetic

Likewise, the negative undertone of these terms is also pointed out by the interviewees of the study. As an example, Helena Dahlbo has recognized the phenomena and, to some extent, agrees with it, although she also emphasizes that it is not the material that should be 'judged', but the way it is produced and consumed.

> *"(…) plastic is seen as a bad material at the moment, because we have made it look as a bad material, of course we have big problems and I don't want to say that we shouldn't emphasize on plastics (…) But when we discuss the plastics and other materials I think the problem is if we start to judge, and say plastic is bad and other materials are not. I think the material itself is not bad (…) with the majority of the materials, it is not the material itself is the main problem, it is the way we use it and the way we don't circulate it and things like that."*
>
> (Helena Dahlbo)

Accordingly, both Samuli Patala and Kaisa Sorsa would make a point about if MMCFs are classified as plastic, they would negatively affect these technologies, regardless of their sustainable implication in the textile industry.

> *"More broadly I think the plastics is kind of societally considered the big bad, at least for the environment currently, so I think there is definitely a threat there if some new applications of MMCFs are classified as plastics*

even if they have places for them in an alternative categorization and fit into sustainability."

"(…) anything that kind of has strong connotation of being synthetic and man-made can be perhaps, something that is off-putting some very eco-oriented consumers."

(Samuli Patala)

6.5. Conclusions of Consumers' Perception and Possible Solutions

In the current chapter, consumers' perception of sustainable policy-making within the EU, knowledge and perception about the SUPD and CE in the textile industry has been investigated. In addition, a range of textile materials as examples of natural, synthetic and MMCFs are examined how sustainable they are seen by the public and the interviewees as consumers. As the survey's target audiences were academic personnel and students, or those who are members in social media groups of sustainable fashion or textiles, general knowledge and interest in sustainability has been expected and proven. The vast majority of the respondents (96%) have claimed to be to a certain amount (3-5) effected by sustainability in their decisions.

As a result of the consumer's interest and attitude towards sustainability, the success of a technology is highly dependent on how sustainable it is perceived by the public. Currently, regarding the discussed materials, inconsistency can be recognized, the perception highly depends on which exact material is in focus. Viscose, for instance, has reached nearly as low values as polyester, while lyocell has fairly higher values in how sustainable they are perceived by the consumers. However, it is worth to mention that innovative technologies like lyocell are less known yet for the majority of the respondents.

Because MMCF materials are in threat to be included in the focus of SUPD and therefore categorized as plastic, the perception of this material category and the connotation of the word 'plastic' is also investigated in the survey and within the interviews. Overall, it can be concluded that words like 'plastic' and 'synthetic' have a severe negative undertone in the view of those eco-oriented consumers who have an interest in promoting more sustainable technologies. In addition, we can recognize that the use of the word 'chemical' similarly affects adversely the perception of MMCF processes used for recycling.

In order to overcome this issue and reach a common understanding, several interviewed stakeholders have pointed out the importance of clear communication between the different fields, policy-makers and those who comply with the policies and also between producers and consumers. As an example, Dion Vijgeboom says if MMCFs would be classified as plastics, it would undoubtedly be a setback for the technologies, but they as a company would be able to communicate it:

> *"I think that we would still be able to market this as a company and to explain this to our customers. Because we anyhow a very transparent and we have a narrative, we constantly tell what we are doing, so in this case we would also be able to explain it, but it would definitely prevent this technique from having the perception that it deserves on a bigger scale."*
>
> (Dion Vijgeboom)

Furthermore, Kaisa Sorsa also emphasizes the significance of transparency in a multi-level governance:

> *"(…) if private sector companies and actors can be more transparent, and also improve their accountability then maybe this multi-level governance can become more reality. Because all stakeholders should understand why these roles are made for whom, for what purposes and how they are implemented and monitored and what are the sanctions if they are not applied what happens then, so all the life-cycle of the rules and regulations should be clear and well implemented, well monitored."*
>
> (Kaisa Sorsa)

Herbert Sixta agrees, that from the policy-makers side the regulations should be clear and understandable to be accepted:

> *"(…) when you get directives from the politicians which are not understood then they are not accepted by the public. So this is very clear and the same applies also to materials, so we need to have clear instructions, what to do, regulations what not to do, then I think the scientists have a clear regulation where to go and then they will find solutions."*
>
> (Herbert Sixta)

7. Conclusions

On 2. July 2019. the Single-Use Plastic Directive (SUPD) has been introduced to promote Circular Economy (CE) by the European Commission (EC) (OJEU, 2019). Apart from several product types being in the focus of the directive, single-use wet-wipes have arisen some issues in the implementation of its 'plastic' definition. Man-made cellulose fibers (MMCF), such as viscose or lyocell are commonly used materials in the production of these product types; therefore it has been debated if above-mentioned materials should be included in the SUPD.

Considering the arisen issue, this research aims to investigate the following question:

> *"How would it affect Man-made Cellulose Fiber (MMCF) technologies, including Ioncell® within a circular textile economy, if they are classified as plastic in Europe's Singe Used Plastic Directive (SUPD)?"*

In order to explore the potential effects of the inclusions of this material type into the directive, first in the 4. chapter the discourses of different stakeholders are investigated, and the following sub-question is answered:

> *"What is the reasoning supporting and opposing the involvement of MMCFs into the SUPD?"*

In this section, biodegradability, flushability, production impacts and other industry implications are discussed as important factors regarding the inclusion of MMCFS in the directive.

In the 5. chapter experimental research about the recycling potential of an example MMCF technology, so-called Ioncell® is carried out, in order to examine its relevance within the concept of CE and answer the second sub-question:

> *"How does Ioncell® technology fit into the concept of CE?"*

Regarding this part of the research, one can conclude that post-consumer cotton waste can be recycled by means of Ioncell® technology. This finding proves the recycling potential of certain MMCF technologies and their importance in the circular textile economy.

Thirdly, in the 6. chapter, the effect in consumers' perception of the particular material types if they are included in the directive is investigated via qualitative and

quantitative methods. A survey has been conducted and compared to the interviews in order to answer the third sub-research question:

"How does consumers' perception change if MMCFs fall into the category of plastics?"

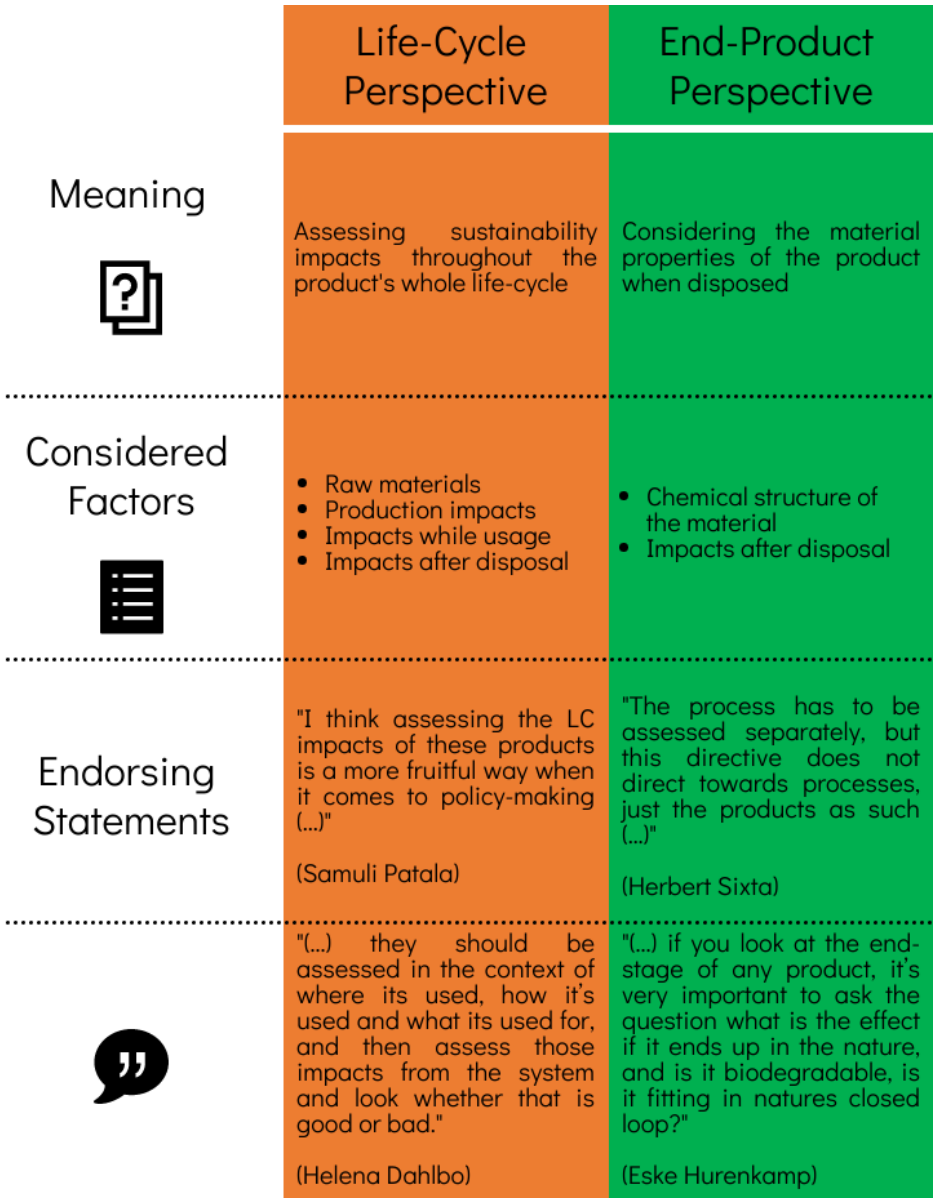
This chapter leads us to the conclusion that specific terms as 'plastic', 'synthetic' or 'chemical' have a negative connotation in the consumer's perception, which needs to be considered when discussing certain issues.

The three substantially different sub-research questions and the methods used to investigate them intend to advocate a multidisciplinary approach, which is also promoted by the research group of FINIX: to look at the particular issue from different perspectives and investigate all aspects of it. In this way, contradictions between two separated industries could be found, and the potential interferences were analyzed and discussed.

Overall it can be concluded that decisions in regulations in one industry can have unintended effects in others, which are often neglected in the policy-making process. In the case of this study, it emerged that if MMCF technologies are to be classified as 'plastic' in the SUPD that would have a detrimental effect not only in the non-woven wet-wipe industry but also in the textile sector. Certain types of MMCFs that potentially can be used for textile recycling (as it was shown with Ioncell®) are currently seen as innovative technologies that are beneficial in a circular textile economy, would suffer counterproductive effects. This has been expressed by the interviewees and also can be seen in the result of the public survey.

After a deep analysis of the discussions supporting and opposing the inclusion of MMCFs into the SUPD, two path-ways have been suggested to overcome the issue as it is shown on the 29. Figure. One is considering and comparing life-cycle impacts of products regardless of their materials, here presented as the life-cycle perspective, while the other is considering the end-material, its chemical structure and its effect on the natural environment regardless of the production process. The latter being named the end-product perspective. The first path-way also means moving the spotlight from the product material itself and instead of concentrating on the categorization of the materials, it proposes to focus on the product's overall impact and the way of its production and consumption. For instance, in the case of single-use products a more significant issue can be related to the substantially short lifetime and not necessarily

the material itself. The second path-way suggests considering the product's material; therefore, clear definitions regarding plastic and natural materials are needed concerning only their chemical structure. Both of these path-ways have been endorsed by different interviewed stakeholders.



29. Figure: Two path-ways suggested to policy-makers in the decision making process regarding the inclusion of MMCFs into the SUPD

In addition, it has been suggested that regarding similar issues in reaching a common understanding between the policy-makers with those who comply with the policies and between producers and consumers, clear communication, transparency and accountability are the keywords. Definite policies with public involvement into the policy-making process and transparent industries ultimately would lead to trust between the different stakeholders and better information exchange between them.

8. Reflections

The further section aims to reflect upon the process of how this research has been conducted, the decisions made throughout and the outcomes of it. Primarily the study aims to explore the aspects of the discussions and the decision-making process in the case of inclusion of Man-Made Cellulose Fibers (MMCF) into the Single-Use Plastic Directive (SUPD). This is a currently ongoing issue, for which stakeholders have not reached a final consensus yet. The topic has proven to be rather interwoven, involving a diverse group of stakeholders from different fields and additionally, several industries. Due to the complexity of the subject, a systemic approach is needed and targeted throughout the research to find solutions. The concept of multidisciplinarity has been kept in mind when selecting the substantially distinct research methods for the investigation, in order to have a wide range of sights of the issue. With the collected data and discussions, current research also has an ambition in giving guidance about the cause and effect relations for policy-makers regarding their decisions and propose some solutions about a certain subject. In the following sub-chapters first, these recommendations are discussed and subsequently, the limitations of the report are suggested for consideration.

8.1. Recommendations

Based on the data analyzed and the findings, some recommendations to policy-makers have arisen to consider. Regarding this specific subject, two path-ways have been identified and suggested in order to reach solutions. The first, life-cycle perspective, it refers to the consideration of full life-cycle assessments to be able to find the most sustainable ways of production and consumption. It has to be emphasized that although taking into account all factors of a certain issue should be the most desirable way of policy-making, it requires a whole system change. For instance, in the case of SUPD, as its name already suggests, we are talking about single-use plastics, therefore apart from the consumption pattern (being a single-use product), there is a great focus also on the material. In the first-mentioned path-way, the material itself would be only one aspect of many and as such, the directive instead of 'single-use plastic', could be called 'single-use product' directive. In current circumstances, this solution is fairly improbable. On the other hand, the second path-way, the end-product perspective, that keeps in focus the material of products and

calls for clear definitions and policies regarding that. As in this path, the materials are in focus, whether it is plastic or not, shall be decided regardless, for instance, its impacts of production processes.

This research intends to draw a specific question regarding the current EU policy-making and to give some solutions to it. However, it is a sole example that lets one presume that similar uncertainties can arise in any policy decision-making process in general. Some patterns have been identified, and solutions recommended to overcome these. As one interviewee, Kaisa Sorsa points out, the silo-like policy-making process often neglects considering the interferences between different industries. This phenomenon can be due to the lack of communication between stakeholders, which can be originated from the lack of trust between them. To overcome these issues, the enhancement of clear communication, transparency and accountability have been suggested, not only between policy-makers and those who comply with policies but also between producers and consumers.

8.2. Research Constraints

The first constraint that has to be considered regarding the research is the time limitation. More time given to the elaboration of the report might give more comprehensive, or even different outcomes. Additionally, regarding this aspect, the COVID 19 pandemic has had a great effect on the time and resources available. Due to this issue and the uncertainties it caused, further work for the elaboration of experimental investigations at the laboratory of the Department of Bioproducts and Biosystems at Aalto University was not possible. Therefore, the scope of the research has been moved from a technical study towards a more theoretical one using other research methods besides the laboratory experiments. Furthermore, the experimental results presented are partly sourced from an internship report, which was conducted out of the given time-frame for this thesis (Újhelyi et al. 2019).

Second, the theoretical background of Circular Economy (CE) used in this research is nearly exclusively based on the CE conceptualization of the Ellen MacArthur Foundation (EMF), due to its rather comprehensive work on the subject. However, EMF is not the one and only source that has a substantial role in the evolution of the CE concept. Examples are the Performance Economy from Walther Stahel (Stahel, 2006), the concept of Cradle to Cradle from Braungart and Mcdonough (Braungart and Mcdonough, 2002) or natural capitalism (Hawken et al., 2008), just to

mention some. All of which have their strengths and weaknesses regarding the CE concept.

In relation to the perception of CE and sustainability, it is worth mentioning the phenomena of rebound effects. It means if a product or process is widely considered to be 'circular' or 'sustainable' by the consumers, it will likely increase the usage of them, which can have a counterproductive effect overall. In our specific case, if MMCFs are considered to be a sustainable choice of material in the production of wet-wipes, it can encourage consumers to increase their use of products made of MMCFs, instead of reducing their use of these products. This study by no means intends to deliver the message of consuming single-use products made out of any type of material is a sustainable choice.

Some limitations with respect to the chosen research methods also have to be considered. Commonly mentioned restrictions of qualitative data collection through semi-structured interviews are related to the forms of bias (Saunders et al. 2009). One type of it is the interviewer bias, which refers to the situation when the interviewer's tone or way of asking creates a bias in the interviewees' respond or when he/she imposes his/her own believes on the interviewee. Additionally, the interpretation of the responses can also be bias (Saunders et al. 2009; Easterby-Smith et al. 2008). This phenomenon has been minimized as much as possible throughout the research. On the other hand, the interviewees were selected subjectively due to recommendations and personal impressions. Each of them is in favor of a circular textile industry as parts of the research group of FINIX, or representatives of a circular apparel company, and most of them are also in favor of certain types of MMCFs. With more time given, it could be beneficial for the research outcome to investigate the personal opinion of some stakeholders who are enhancing the inclusion of MMCFs into the SUPD.

With regards to the experimental part of the research, the process of Ioncell® has been tested for textile recycling, due to the personal contact with the research group of this technology. However, it has to be mentioned that there are other lyocell types of processes on the market that are available for the same purpose. One to mention is SaXcell, which has been mentioned by Eske Hurenkamp from MUDjeans. Additionally, the recycling potential of Ioncell® has been proven solely in controlled laboratory conditions; therefore, the findings might not completely represent what would happen in the 'real world', which arises some validity considerations. However,

presumably, the technology can be tested in closed-loop operation in the foreseeable future.

There are some limitations worth mentioning regarding the conducted survey, as well. First, as Foddy points out in order to reach valid and reliable results:

> "*(…) the question must be understood by the respondent in the way intended by the researcher and the answer given by the respondent must be understood by the researcher in the way intended by the respondent*".
>
> (Foddy, 1994)

Questions have been prepared with the consideration of this requirement; however, in some cases, how a certain question has been understood by respondents, might have been left for their interpretations. Second, the results received through the survey have to be handled with the attention of the so-called attitude-behavior gap. This phenomenon especially worth considerations regarding researches about sustainable consumption (Chan and Wong, 2012; Billeson and Klasander, 2015). In theory, the attitude-behavior gap refers to the gap between the attitude and behavior of an individual regarding the discussed topic. It means the consumer might have a sustainable attitude, which can be shown by the survey, but in reality, this attitude might not be transferred into his/her behavior (Billeson and Klasander, 2015). Therefore, the survey results might not wholly represent reality.

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ANNEX I.

Semi-Structured Interview Transcriptions:

Samuli Patala

(Conducted: 2020.04.16.)

Krisztina:
I would like to ask you to introduce yourself and tell me what is your current project that you are working on, and how are you connected to FINIX?
Samuli:
Well, my name is Samuli Patala, I work as assistant professor at the Aalto School of Business, and I am working with the FINIX project, basically my role in it currently is mainly in one of the work packages, which is focused on governance innovation. This basically includes most regulatory aspects of public sector governance, as-well as what we call ecosystem- governance. This is basically how for examples firms and other might be also public sector organizations developed these other type of governance, which might not be the classical type of regulations among this group of organizations.
Krisztina:
This might help answering the current questions too.
Samuli:
Yeah, so basically this area of ecosystems is something that we were working on previously, so for example with Minna, who is having the project, we had a wider study before when we looked at three different CE issues and the governance has been developed in this CE systems. this is one of the ideas that also let you, this topic being included in this project. I would say this is my core area, that I am working on in this project and more broadly I am interested in sustainability management topics, so I am also halfly involved in other projects for example in the area of renewable energy, and we also started a new project on impact investing recently which is again related to the topic of sustainability management, and sustainable business but perhaps a bit unrelated to the CE topic although it can also have links there.
Krisztina:
Yes, of course! Everything is connected in this area I believe in many ways, and it is

always nice to find the connections. Okay, but then can you tell me how much are you involved in the EU legislation, how much do you know, how much are you following what is happening regarding CE in the EU?

Samuli:

Well, I would say it's been mostly kind of, it has come through this project, so I've been following for example the new developments, for example the new action plan for CE, as implementation that came out in the beginning of this year or last year.

Krisztina:

It was this year, yes.

Samuli:

But it developments prior to that specially EU legislation, I was not following it that closely. There been some regulatory issues regarding CE that have come up before in my prior research, but I cannot say 100% sure were those to the EU regulations or national level regulations.

Krisztina:

You mean national level in Finland, right?

Samuli:

Yeah. So for example what I was researching before was this kind of industrial symbiosis, which is basically one form of CE where one firm can utilize another firms' by-products or waste in their processes. And one of the commonly mentioned barriers in that was that this regulatory processes to classify something as something that can be reused, or recycled can sometimes take quite a lot of time, so basically to get the permits to use some sort of waste materials sometimes.

Krisztina:

Do you think that there are other ways to tackle these issues, because obviously it is quite slow as you could see in your research and also in the EU all the regulations they have to go through so many different steps, and all the stakeholders, all the national parties? Do you see any ways to make it more effective?

Samuli:

Like kind of make the process faster you mean?

Krisztina:

Yes, kind of, yes.

Samuli:

Well, that is a really difficult question I would say, I mean overall I think the EU's CE plan is very ambitious compared to the global level, and I think it's very great plan for going forward. I don't know much about the specifics of how for example the EU level larger actions are formed, so it is a bit difficult to say how it could be improved, but for example if you compare political process to let's say business process, it's of course takes more time, there are a variety of interests that you have to consider, for example in the EU you have many different levels of governance. It is something that is not only based of knowledge, it is quite difficult to make such processes very fast.

Krisztina:

Okay, but then overall, you said that the action plans and the CE policy in EU is ambitious and its truly one of the breakthrough regarding this topics, but do you think it is effective enough, the implementation at least, or do you have any experiences with it?

Samuli:

Well, if we are talking about the implementation of the EU action plan, it is definitely something that is kind of under work. I mean I have had some contact with the development of the new CE strategy in Finland, it's basically to the action plan. And I think at least the way it will probably implemented in Finland, it is very close to the vision which is visioned in the action plan. But it is hard for me to say how it is with regards to other countries. And also if we are talking about CE what is prior to this new plan, it's probably there is lot of national level differences with some other countries. In some countries it was implemented how it was visioned, but probably there were other countries where the implementation might be more lacking.

Krisztina:

Then we can say, that from at least the commissions side, at least from EUs side it was ambitious and the aim of the action plan, and the whole policy on CE and grabbing the concept of CE has all the best intensions and it is going on well.

Okay, and so you are working with FINIX so maybe you also see a little more solutions, so more ways to tackle this question around Circular textile industry for example, and if you compare the CE action plan in the EU on the textiles if you see what was written in it about textiles, do you think it can have improvements, or was it enough what they put as measurements, and what they written in the action plan?

Samuli:

Well some comments in general what came to mind with the action plan, is I think it is addressing a lot of the right issues in regards to facilitating CE. So some of the issues that I have also seen in my previous researches is the lack of information in general between different parties, so to use the industrial symbiosis as example, it's very common that firms might have a good deal of knowledge but what kind of like CE opportunities within their all industries, but then when we are talking about this cross-industrial recourse links its more typical that there is lack of information between different parties. Then I don't remember the specifics but I remember there were several places where this information sharing, and the good types information systems were highlighted in the new action plan. I think that is a very important aspect and it also relates to the research within FINIX is still very much in the early stages, but as you probably know from the topics that we have in the project information system providing for example traceability information on textile production, that are really relevant to the project, and I think in this way the action plan was really supportive. The other aspect I thought in the report, especially with regards the textiles were the consumer focus, so basically writing more ways for consumers to assess information on sustainability aspects and basically the rights of the consumer to for instance… Probably in this case it is not so much about rights, but ways that consumers can for example reuse, recycle, resell their textile product.

Krisztina:

So kind of opening the eyes of the consumers, and that they have choices overall on the consumption side.

Samuli:

Yes, because the consumption side is one of the big issues in the textile industry, because of the very wide-spread fast fashion business model, and short lasting textile products are still something that well for many people is still kind of the prevailing way of buying and using clothes, so I think any kind of wider solutions for Circular textiles economy needs to address the consumption side.

Krisztina:

You mentioned the short life-time of the textile industry, and as another part of my project I have the single-use plastics, which sounds like a very separated topic from the textile industry, and from what FINIX is doing, but actually this whole thing came up because of Ioncell® that we had a huge discussion around this topic, which is why I am having the topic as my master thesis. Do you think that one field of expertise and

one directive on plastics could in any ways effect another industry like textile industry? Have you seen examples of that in other fields, or can you imagine it?

Samuli:

Well yeah, that is a very interesting point that something I would not be thinking about when I say the questions and well obviously the micro-fibers part is something that relates to textiles especially synthetic textiles, and well the first idea that came to my mind is that they might have been used in a way that these micro-fibers are released, which might also speed up the transition towards alternatives to some of the materials that are wide-spread in the textile industry. When I was thinking about the contradictions part that you mentioned that something that is difficult for me to imagine at least at first. And I'd be actually really interested to hear what are the potential contradictions that maybe you have come up with.

Krisztina:

Yeah, the thing is that of course the micro-fibers are part of the problem, but all these MMCFs and now then I will introduce you little bit, but Ioncell® and lyocell it is and also viscose is a MMCF, so basically these fibers are coming from biomass, and then throughout a chemical or a molecular process they become another cellulose fiber, so the end-material is cellulose again, but in SUPD there are still discussions around what is plastic, what is natural polymer and what is chemically modified, and these are the questions which actually put in jeopardy all the MMCFs, even those which are really useful for cotton recycling like Ioncell®, and which are fitting very much into the perspective of CE, and well this is in a plastic directive, which came up with the wet-wipes because these products are now commonly produced with MMCFs, and there are many who are doubting or worrying about these issues, and would like to categorize these materials plastic, or synthetic. That is how this whole problem came up and it is still ongoing discussion, so there are no specific answers yet, for these definition of plastics or chemical modification, but my research mainly is finding out what would be the effects on these technologies in the textile industry, if all these materials would be classified as plastic in the EU.

Samuli:

Yeah, well that definitely make sense, I wasn't actually thinking about the wet-wipes, in relation to the textiles, because we had been talking about the clothing and the fashion industry so much in the projects, that sometimes these other applications of textiles kind of get left out of your thinking so that is definitely one area where I think it

could apply when we talk about the Single-use plastics. Well in general I would think if there is more wide-spread categorization of MMCFs part as plastics, it would probably be a threat to business applications in these areas, because if you look at the wording in the action plan if you look at the plastics part it is very much the elimination and reduction of different harmful materials, and the introduction of alternatives, like organic or bio-based plastics, and then if you basically looking within the textile category it is more about introducing ways to basically recycle the materials in a more effective ways, and it talks less about the elimination. More broadly I think the plastics is kind of societally considered the big bad, at least for the environment currently, so I think there is definitely a threat there if some new applications of MMCFs are classified as plastics even if they have places for them in an alternative categorization and fit into sustainability.

Krisztina:

Yes, actually this is the thing which, not only the plastics, but throughout my research I've done interviews even today with a very circular jeans producing company and through mapping the public opinion already with the world chemical there is a big problem, like people are afraid of the term something being chemically modified, or chemically processed, and it is weird, because chemistry can do magic in a way, and people are very much afraid of it.

Then, can you come up with some solutions or ideas, or can you see the differences on public opinion on purely these terms and the policy-maker's perspectives, how can it be somehow smooth, how can we bring them to the same understanding?

Samuli:

Do you mean like diverges between the public opinion and the policy-makers in the EU? Yes, that is a good question, because my general hunch is that in the EU I think the policy-makers are quite good in assessing the public opinion when designing the new directives and like just one example, I have to say that I don't have much knowledge about technical background, but if you compare the regulation on GMOs between the EU and USA, they are very different. I think the reason for this is that there has been basically a very broad societal suspicion towards GMO products in the EU and this is reflected in the policy level. So I think that this potential divergence might be rather between policy-making and perhaps the industry rather than the policy-making and the societal opinions.

Krisztina:

So what you are saying is that the EU is actually pretty good in understanding the public and making the policies in a way, that it keeps considering the public opinion, and maybe in this case, it could be happening from the other side also, that they already know, that if something would be classified as plastic it would be undesirable in this case.

Samuli:

Yes, like this is barely a comparism to north-America but if you think about what we consider as societal opinion is perhaps the interest of the society versus perhaps the interest of the business world and if I simply look at the for example sustainable regulation which usually picks these two aspects kind of against each other, I think the policies in the EU, of course there is a lot of lobbying going on from the business world, but the policies in the EU are still much more considerate of the societal interest compared to the north America. That is my perspective. Maybe another example is the European data regulations which are much more about the consumer protection rather than business interest compared to the US.

Krisztina:

But this sounds actually positive in a way that it might be that at the end after all these discussions will come out in a positive way, or the technologies will come out in a way as it is desirable for them.

Samuli:

Yeah, but then especially when you have new emerging technologies and there is the issue of how they are categorized in a way and how they penetrate the market and the regulations around them, I think there is important that there is good dialogue between the firms that are introducing these technologies and the policy-makers or the researchers that are working on these technologies. This dialogue especially when it comes to a solution that has clearly beneficial sustainability characteristics, so like in this case I think. Also I think there has been very good studies on for example the Ioncell® technology that basically explain that it has lot of sustainability benefits compared to the other options.

Krisztina:

Well it came in my mind, that the solution for this whole topic could be that we look at it in a different way, because when we are talking about the SUPD we are very much focusing on the base material of the product what we are talking about and not on the consumption pattern that it is single-use so somehow I can see a ways that

it is not single-use plastic but single-use product directive and then we are not forced to go through these discussions; do you see that it would kind of implement a system change in our consumption patterns and our way of thinking? Because we can think about plastic as a material, but can we think bad about a product been used only once?

Samuli:

Yes, basically, I think now clearly the issue of Single-use plastics is something clearly considered something that is bad, because these are basically materials that will take very long time to degrade, and they have harmful impacts to the environmental ecosystems and they are also single-use which is a very ineffective use of resources. But if there are materials that are even if they are single-use but if they can be recycled effectively, I think that is something that could then also change consumer perceptions, because if you look at some new options for straws for example, they now use new biodegradable materials. Well it depends a bit on the application, but I think this is something that is important also to consider is the recyclability of these products. Maybe they have short life-time but if they can be effectively recycled then the issue of single-use material or synthetic material is something that is perhaps less of a sustainability issue.

Krisztina:

As a consumer yourself, if you think about these words of chemistry or plastics or synthetic, do you feel any negative connotation with these terms?

Samuli:

Well, I did my master degree in engineering so I don't have basically a fear of chemical processes sort of speak, but I mean I know also because I studied marketing previously, that these are hugely important on how consumers see something, so even if I don't personally see these being an issue, I definitely recognize that in a broader consumer base especially where sustainability is bias towards something that is kind of natural products, so anything that kind of has strong connotation of being synthetic and man-made can be perhaps, something that is off-putting some very eco-oriented costumers.

I am thinking for instance between chemical and mechanical recycling technologies, I am not sure if it is necessary for a company that is using chemical recycling and then producing products, do they need to label it as chemical recycling? Can they simply

talk about recycling? Or a product from recycled material? Because that is something that is usually good between most costumers.

Krisztina:

That is true, but if we are talking about recycling, there are many emerging technologies also to recycle PET for textiles, which is a plastic material, and everybody who would also buy those clothes for sustainability reasons, but it is still plastic. And then the recycling of cotton into another MMCF would be kind of in the same category of products. It is recycled just as PET is recycled into polyester, but both of them are plastic. Do you think that these two should be handled in the same way?

Samuli:

This is a very good question, I am very much in favor of especially when it comes to policy-making to have a kind of evidence-based approach in a sense that for example you have been conducting LCA on two different products, and see what is the more sustainable choice, and I think assessing the LC impacts of these products is a more fruitful way when it comes to policy-making rather than broad categorization, for example plastics versus textiles, when it comes to these new types of technologies. So if there is something that is from recycled PET, and it has less environmental footprint overall as if it can be demonstrated through LCA, i think the policies should also reflect this, so it should be possible to have also then let's say facilitate this type of technologies through the policies as well can be demonstrated. But then of course when it comes to the consumer behavior because there these categorizations are very strong, and labelling what kind of terms are used there, so if there is a new type of material, that is something that is new for consumers, so it takes a while till its brake-trough, and then I think it's up to the firms making these products to make the message, and demonstrate the sustainability.

Krisztina:

well one thing about again the chemical and the mechanical recycling technologies is that I am not sure that the question is actually right. What I found out now is that with mechanical technologies we can reach a point for example MUDjeans can recycle 40% of their material. So in one pair of jeans 40% is recycled, but the rest is still organic cotton, because you have to mix the materials in order to get back the same quality. So with mechanical recycling you cannot be so efficient, and that is why they are aiming to create a 100% recycled jeans, for which the way is using chemical recycling, so for 100% recycled they need both technologies. I very much see how they look at

the whole question also and of course it would not be beneficial for them if these materials are classified as plastic, but they seemed to be pretty positive and transparent.

Samuli:

Yeah, I'm just thinking of reading some of these discussion around Ioncell®, I think one of the reasons why it is associated with viscose I think, is because it is in the same category of this MMCF technologies, but I think viscose is currently considered quite unsustainable because it uses lot of chemicals in the process. I think these kind of differentiations for example if there are media articles on these new technologies I think it is kind of important to make this distinctions, so the consumers don't develop negative ideas about these new technologies, because of associations.

Krisztina:

Thank you! Do you have any additional comments about the topic?

Samuli:

No, I hope I could be helpful with your thesis.

Helena Dahlbo

(Conducted: 2020. 03. 27.)

Krisztina:

I would like you to introduce yourself, what are you working on, what is the current project, and how is it connected to FINIX?

Helena:

I have been working in the Finish Environmental Institute almost 30 years, in different types of waste management projects. So looking at problems connected to waste management, how to recover different types of waste, what kind of alternative technologies there are, and what kind of environmental impacts these different alternatives have. That is my main issue. I am working with Life-cycle assessments or material-flow analysis, and these kinds of systematic tools to analyze different types of waste management or recovery options. I have been working on different types of wastes, mainly however municipal wastes, so not much industrial wastes, and in recent years plastics and textiles have been the two materials that have a lot been on my table. There has been more work on plastics recently, and now with FINIX I'M getting into the textile problems or issues again. We had a project on textile wastes a couple

of years ago where we generated the first kind of material flow analysis of our Finish textile wastes and what is happening to them, how much of them is collected, how much is reused or recycled, and then how we could improve the situation, and then we also did a LCA on different scenarios for the different solutions.

Krisztina:

That is really interesting actually, so what were the solutions which you mainly analyzed?

Helena:

We had 3 scenarios for the overall textile waste flow, the first one was the current situation or the situation back then in 2015-2016 when we still had the landfilling, no I mean the statistics were from 2013, when we still had landfilling of wastes, also organic waste was landfilled. Since 2015 that hasn't been legal any more in Finland. So we had a current situation what is happening to textile now, only 20% was separated, and of that amount, was it 15% was directed to reuse either domestically in Finland or sent abroad, and some 2-3% which was recycled as material, and the rest was sent to waste. In the scenarios what then we built for the future, for both of them we increased the amount of separate collection so we saw that it's the only possible way that we can recover more textile materials, that we can make the separate collection more intense, then in one of the scenarios this separated and collected textiles were reused as such and in the other version was mostly recycled. So these are the sort of alternatives we came up.

Krisztina:

In which way was it recycled in this scenario? This work of yours I haven't encountered.

Helena:

Yeah, the report is in Finnish from this project, but we have written a scientific paper. I can send it afterwards.

Krisztina:

Don't worry actually its purely curiosity what was the recycling method, and also of course it is also connected to my research.

Helena:

yeah, we modeled both mechanical and chemical recycling options in the recycling scenario. So from literature we had data on chemical recycling processes, but we didn't have any very precise data, and there were a lot of uncertainties in that calculation. But anyway the comparism showed that if we reuse most of the textiles

then the environmental benefits are greater than with recycling or incineration, but also with recycling we have greater benefits then incineration. So in that sense we should avoid energy recovery of the textiles.

Krisztina:

Okay, but then if I understood right, you have a view both on the plastics and also the textiles within the FINIX project, right?

Helena:

Yes, in a different project I've been working on plastics.

Krisztina:

Okay, but then you have a view on it. So the next question was already introducing the action plan. So regarding the new CE action plan of the EU, do you see any contradictions on the policy on textiles and the policy on plastics?

Helena:

Well, I have to say that I have not studied the latest action plan very closely, but I had a glance on it. At the first glance I didn't recognize any contradictory on the policies. In both of them we strive towards more sustainable and durable products, increased recycling and longer life-periods for both plastic and textile products, so I think they are quite similar. Do you have something special in mind there?

Krisztina:

Yes, actually as my topic is mainly about the SUPD, because if I go deeply into the policy, it doesn't really seem contradictory in a way with the new CE action plan, but basically what is happening within this two fields, is that on one side SUPD is going towards sustainability, and it is really good, and it has lot of details which are working. Although regarding wet-wipes, there is this contradiction with MMCFs. Because MMCFs are basically one of the main chemical recycling technologies also, just as Ioncell®, and these fibers are about to be categorized as plastics, because they are chemically modified let's say. So these are the discussions basically, what is happening if from one material we are getting out the same material actually, but meanwhile we are going through chemical reactions, then that same material would be plastic. So that's why from a broader perspective, get closer to these questions, because I would be curious of your opinion on this whole. How would it effect the circular textile economy? I see that it is not directly connected, because we are talking about plastic and single-use products, and these are not very much involved in the textile industry, and how do we deal with textile wastes, but then at the end if

one material is categorized as plastic, it would also have an effect on textile economy. at least that's what I assume.

Helena:

Yes, I haven't thought of it that way, but of course we already currently having textiles made of plastics, increasingly so, like polyester and things like that, so we have the problem already I think. Still we should be able to recycle and recover more textile flows, no matter if they are plastic or cotton, in material. Then if it is going through chemical recycling, in the current processes they use they mainly concentrate on cotton, but I think that they are studying the options to use these processes also for plastic based materials.

Krisztina:

What do you think where is the turning line, on what is plastic and what not?

Helena:

Yeah, I looked at the SUPD definition on that, and I honestly am not a specialist in the material science or technologies so I can't answer that. But I think here, when we discuss the plastics and other materials I think the problem is if we start to judge, and say plastic is bad and other materials are not. I think the material itself is not bad, of course there are materials like asbestos and probably some other that are dangerous to our health as such, but with the majority of the materials, it is not the material itself is the main problem, it is the way we use it and the way we don't circulate it and things like that. So I wouldn't label the materials, well of course you need some labelling, to be able to for example recycle plastics, and bio based materials and things like that, but we shouldn't put a label like this is bad and this is good on the material just because of it is a certain material, but they should be assessed in the context of where its used, how it's used and what its used for, and then assess those impacts from the system and look whether that is good or bad.

Krisztina:

So actually what you are saying is that regardless if we are calling MMCFs plastics or not, the main point is that we shouldn't connect any word with negative connotation, but we should go more deeply in. But then what do you think about the major public, if someone would say okay this is plastic, might be recycled, but this is plastic, do you think that everyone would be able to handle it neutrally?

Helena:

well not currently because plastic is seen as a bad material at the moment, because we have made it look as a bad material, of course we have big problems and I don't want to say that we shouldn't emphasize on plastics, we should work in order to cut down the production of plastic, and also make the circulation in a closed loop, so we do have a lot of work to do, and it's good that people are now paying attention on the plastics use, but in the same time we shouldn't say that we now can't use plastics but we can use these biodegradable materials, but we don't know anything of the overall systemic impacts of those biodegradable materials, so we should first make an assessment of which one is best or has less environmental impacts in that specific use. But I know that currently for most people plastics are threat. But in a way its good so that they consider their consumption and hopefully they start to consider their overall consumption, not just the plastics, because we need to reduce the consumption of other materials as well.

Krisztina:

This is the thing with the SUPD in my opinion, that it could be called Single used product directive, because it should be directed on the consumption behavior and not on material necessarily.

Helena:

Yes, I fully agree with you.

Krisztina:

Okay, I would be curious how much are you involved or you know about the ioncell® technology, do you think it is prominently more circular then other MMCF technologies, or is it only one of them?

Helena:

Well, I don't know that well all these technologies, but I think circularity is a bit sort of strange term when you consider a technology. I think the impacts of this technology depends of course on how they use energy, and how much and what kind of chemicals they are using, and then I think the circularity comes from how the technology is used, if it is used for recycling fibers, or textiles, then I understand it is circular, then of course some are thinking that CE should also go towards bio based materials, so in that sense it is more circular then perhaps others, but compared to viscose and lyocell, if I'm correct they both use cellulose materials, as their raw material so in that way I couldn't say which one of those is more circular.

Krisztina:

I see, I assume it depends on the technology itself. So overall, being aware of this question or problem which I formulated about the SUPD and MMCFs if you think that it could be affecting the textile industry and the recycling of textiles, just because of negative connotation; do you see any ways to eliminate these effects?

Helena:

Well, this is a difficult question to answer, but if the interpretation and the problems arise from the legislation and how that is interfering then I think the legislation should be changed if we want get to rid of the problems, but then if it's like peoples or public thinking that makes the problems that people think that this is plastics and in that way it effects the textile recycling business, then I think more information could help to make people understand what the question actually is, but then it depends on from where these problems arise.

Krisztina:

Yes, I agree. But then I think we kind of went through all the questions, I very much appreciate your contribution! This is a very current topic, so I would not even be expecting to find out much more, because not even the EU parliament could find out yet what to call plastic or what not…

Helena:

Yeah it is a very complex issue if it goes, now as I glanced through these different reports and different definitions, it seems like very strange discussion, and it is bringing a lot of problems if we start defining. But of course we need to define thinks, but well I don't know how this could be solved, but I'm glad if you have any use of my thoughts and they are very confused, but I think this is a confusing issue.

Krisztina:

Yes, it is, and it should be like that, and this is why it is so interesting for me. Thank you for your contribution!

Kaisa Sorsa

(Conducted: 2020.04.29.)

Krisztina:

So my first question would be, if you could tell me about your work, your projects that you are currently working on, and how does it connect to FINIX, or what are your roles in FINIX?

Kaisa:

Okay, well FINIX project is sustainable textile systems cooperating resource wise business for Finland in global textile networks, and Aalto university is the leader of the consortium. I work in the Turku university of applied sciences which is partner in this consortium and our role is to investigate the role of pro-active regulation in the transition towards sustainable textile industry. I also want to see more broadly what is pro-active governance not only regulation but also other governance instruments that help in this transition. There is only I and another college in our university who is working with this, and he is focused on methodological issues. Now we are working on a journal article, but it takes time because we have so small time for it, and we have other tasks as well.

Krisztina:

Can you tell me some examples about this pro-active governance, how should I imagine and what topics are you researching?

Kaisa:

Yes, wait a minute, I will tell you more specifically. I wrote this definition which I have found from other sources as well. so according to researchers the concept pro-active governance is when the citizen is not coming to the state, the state is coming to the citizen, so normally governance is from up to down, so the government makes the laws and regulations and it expects that people comply those rules, but pro-active governance is more open to new ideas so the citizens can also tell to the people who are making those laws that what they want and how it should be like. Pro-active regulation is more user friendly then the typical regulations and laws, and in pro-active governance the governors trust the people who they try to govern. So it goes wiser so it is also enabling so it enables new business models to be created and it leaves quite a lot of space for the people, it is not top-down type of regulation.

Krisztina:

Okay, well my next question was about the EUs multi-level governance and policy-making, how much are you involved, but actually after this discussion about pro-active governance, how much do you think EUs governance is proactive, or how do you feel this happening in the EU.

Kaisa:

Well I have followed the EU regulation, I was very interested in better regulation and smart regulation initiatives, which have taken 10 years or something like that, and in EU they have tried to move towards multi-level governance which means that EU should take the company initiatives and private regulatory initiatives more seriously. And in many regulatory documents they would like to open the road for multi-level governance, but in practice at least in Finland it is not reality, because in Finland our government always only gives laws and regulations so they don't trust the private sector so the companies and citizens would voluntarily do the right things. So multi-level governance at least in Finland is not reality so far, so that's why I'm trying to work with this pro-active governance issue. In 2009 we had a research project on pro-active contracting, and we created a proactive contracting think-tank so people who are interested in the same topic. As an outcome of this work, the European economic and social committee gave an opinion, the name of which is: The pro-active law approach a further step towards better regulation at EU level. So this was one concrete example as an outcome of our think-tank work. And you can find this opinion on internet. If you want, I can send you the link. when you read it you can see what is pro-active law and regulation about, it's quite good opinion I think, but so far it is really slow the way to do policy, and the transition to more multi-level governance is really slow. it is a cultural think.

Krisztina:

Is it because of the many stakeholders which need to have a common ground on the policy-making, or does it have any other reasons?

Kaisa:

Well that's true, but I think the most crucial think is that the people that have the power, they want to keep the power, and they don't want to give other people to start making the rules. So it is the question of trust, so the parliament people think they have the best knowledge and they want to make the decisions, they don't want to give up the power and making regulations and rules is one way in using the power.

Krisztina:

That's interesting what you say, but I was talking to Samuli Patala at one point and I found very interesting for me, that he thinks compared to any other regulatory bodies, like the one in US or north America, compared to that actually EU is actually kind of the best in considering the people and people's opinion in their policy-making. What do you think about this?

Kaisa:

Well, it has improved, for example in Finland we have these digital channels where people can say their opinion about legislative proposals, but how the law-makers are really taking it into account is another thing. there are little steps towards more multi-level governance, but if you read for example OECD evaluation reports, so in 2003, in 2010 and more recently, always is the same problem, that the Finland parliament when they make new laws, they don't consider alternatives to legislation, and one example of that is multi-level governance. You should consider what other measures can be used instead of law and law can also be, there are different kinds of laws. I don't know how much you understand…

Krisztina:

In a way yes, because my study involved that EU has multi-level governance, and then we explained what does it mean, but it's nice to hear an opinion if it's actually happening or not.

Kaisa:

Have you studied private regulation, how do you understand private regulation?

Krisztina:

Not much, at least not in the university, but we had a study project where we encountered the topic, but we didn't go very deeply into private regulation.

Kaisa:

What I mean with private regulations are for example different type of standards, self-regulation initiatives in environmental sector there are plenty of those private-sector initiatives. They are initiated by companies or by civil society associations, or activist and they together they create those rules. This kind of governance has documented especially in the food sector you know all these different kind of labels and behind those labels there are these sustainability schemes and other certification system etc. So in my opinion this is really important part of multi-level governance. In so fast moving society the parliament does not have enough knowledge to make the rules for the economy. So that's why it's important that more people could participate in that.

Krisztina:

Okay but the let's move on with the CE action plan, do you think that the EU policy on CE is effective, and/or it can be improved?

Kaisa:

Well, I read some papers before the interview, in order to find out what is happening. I think it is effective in a way that the action plan has promoted a systemic approach across the entire value chain, so that is very important so in order to make the transition happen, the systemic approach is really important. so the law makers are not only wanting to make laws for single step of the value chain for example, so it is very crucial that the systemic approach is the way. Then in the CE policy, they have principles also for plastic production and consumption and water management food systems and the management of specific waste streams, that is good also. So this show that this is the systemic approach. Then they have energy label measures for several products, and eco-design, then here is one example which relates to private-regulation, or this is co-regulation, the right word is co-regulation because the commission has tasked the European standardization organizations with developing horizontal criteria to measure durability, reusability, reparability, recyclability, and the presence of critical raw materials. So this is called co-regulation. So now the EU commission has given power to the European standardization organization to create more detailed rules for the CE, and that is one example of this multi-level governance. Then one thing which this CE policy also considers, expanding the eco-design policy to non-energy related product groups, which also shows that it is moving on. Then what rule do consumers play in this CE? Well I think, like they say in one report, the transition towards more CE requires an active engagement of citizens in changing consumption patterns, and that's true and therefore we have this all kinds of energy labels and sustainability labels in order to inform the consumers. And then I found out the EU commission is going to start preparing EU textile strategy in 2021.

Krisztina:

I am actually looking forward that one.

Kaisa:

Then you asked the drawbacks in the implementation, so it's one thing that we have the policy but the implementation is the crucial, so what will happen depends how well the implementation is done. From that point of view there are these obstacles, such as taxation and regulation concerning the use of secondary raw materials, and

the lack of harmonization. I think different member states have implemented CE policy on their own way, it can happen that there is a lack of harmonization and integrated recycling plans across the EU. On the local level there are varieties how some countries are interested in implementing those rules properly, and some others don't put enough attention.

Krisztina:

Do you think if there are any ways to rise the power of EU policy-making on the different member states? because it might be that EU has an ambitious action plan for CE, but it very much depends on the states. Do you think there are ways or measures to rise the power from the EU to the state, to have the action plan more implemented?

Kaisa:

Maybe they could use the (not audible), so give some incentives for the member states, so make it like a competition that if you do really well you could get some benefits from the EU. But I don't know, if monetary benefits, or something like that. Because those member states who do the implementation very well, they should be awarded in some way. I don't know how but any way. Those good examples should be spread and shared with others.

Krisztina:

Then let's go back to plastics and textiles, in the CE action plan, in the 2020 action plan they already mention textiles. Do you think there are any contradictions or any opposing plans on the plastics and the textiles?

Kaisa:

Well, this is area which I do not know very well, and I read that okay for plastics, there are new mandatory requirements on recycling content, with a particular focus on microparsecs in addition to bioplastics and biodegradable plastics. I also found out that for example fleece has these micro plastics in the material. So in a way plastics and textile have these kind of connections. And then when EU is preparing policies for plastics they should take into account in the same time the textiles. Now they are creating in silo, they only focus on plastics, while they should also consider textiles with this micro-plastic content.

Krisztina:

Well, actually my research is about another connection about MMCFs, so those are fibers that are biodegradable, but in the new SUPD, they took a role in a way because

these technologies like viscose and lyocell are very commonly used as wet-wipes, and they are claimed to be more sustainable in this single used wet wipe industry. Because of this they are in jeopardy to be classified as plastic or synthetic, which could also affect the textile industry. What do you think about these technologies, about viscose, lyocell and also Ioncell® which is in focus of FINIX.

Kaisa:

Well, I was thinking that the MMCFs is synonym for synthetic fiber technology? Is it? as I heard you it is not.

Krisztina:

Well, it depends, but synthetic fiber technology could be anything like polyester or elastane, those are synthetic and plastic fibers. But MMCF has the term men-made because men had to go through the process, but it is a cellulose material, like biomaterials like wood or any other cellulose is the base, and then the end material will be also cellulose. So that's why it is MMCF, but the first and the end-material is the same and they are both biodegradable, and now they are in the discussion if they should be considered natural or synthetic polymers.

Kaisa:

Okay, so as you explain it now it sounds more sustainable then these synthetic fibers. Yes, my dictionary didn't explain, so it is MMCF and not only man-made fiber, that is the difference. So MMCFs I think are cleaner and more sustainable yes.

Krisztina:

Well, if in a way we look at it, and that's actually my next question, actually Ioncell® which is in the focus of FINIX as new material and which is good technology for cotton recycling and to replace cotton production. That is also a MMCF because it is a Ioncell® technology. So what do you think about Ioncell®, how circular and sustainable it is in the big picture?

Kaisa:

I

Krisztina:

Yes, it seems like, that is why it is in our research. Although with the SUPD, it could be that the perception of these technologies would be bad because if something is plastic or chemically modified, because that is the question in the directive, then it is considered as bad by the people right?

Kaisa:

Yes.

Krisztina:

So what do you think would be the effects on these technologies and overall on circular textile economy, if these materials would be classified as plastic? What effects can you imagine?

Kaisa:

Well, if they are classified as plastic then it is not good for them because then people think that they are not better than the other fibers, so they should not be classified as plastic.

Krisztina:

So you think it is not desirable to have these technologies classified as plastic, right?

Kaisa:

Yeah, because it should be quite clear for the consumer and people that okay these technologies are more sustainable, but if you link them to plastic then it gives the wrong massage. If I understand right, then they are more sustainable technologies, so why then talk about plastics?

Krisztina:

In a way it's understandable, I went through all opposing discussions also, and because of these Single used wet wipes, which are still single used products, and they are quite harmful to the environment regardless, if they are made of viscose lyocell or polyester. So if we don't consider the material, but the consumption behavior of such products, then they are harmful, and they are also should be included in such directive, or in policy-making. That's the reason why many would argue that they deserve to be included in this directive, but I'm not sure that many would consider that it also has a huge effect on the textile industry, where these technologies are actually the more sustainable ones.

Kaisa:

Well, I don't understand so much this technological part, I have to study this more.

Krisztina:

No but don't worry, actually that's good that you said that these regulations are handled in silos, so they don't see the connections between the plastic and textile industries, and actually my research is mainly about that that here there is a connection which would have a big undesirable effect on the technologies in the textile industry, while in the plastic industry with the wet-wipes it's understandable.

Kaisa:

Yes, and I think that in policy-making you should have people who understand these different connections between different technologies and businesses so that you don't see very narrowly when you are making the policies. So that's one problem when you are making new policy instruments.

Krisztina:

Yes, do you see any ways to avoid these problems?

Kaisa:

Well, more networking, more people who know about these things should have possibility to say their opinion, I think in Finland when they are making new legislations it is a quite narrow group of people who are called and discuss. So you should broaden the number of people who can give their opinion.

Krisztina:

wouldn't it slow down the process if there are many people?

Kaisa:

it's true that it slows down, and it is always a problem for policy-makers that it takes so much time, it's too slow, therefore my opinion is that law should be outcome based. The law-maker should only give the target, and then the companies could find the ways how they are achieving those targets. Do you understand what I mean? The law should not be very detailed, it could only be like guidelines or targets, objectives, giving the direction where the technologies or business should go. Because laws and regulations can stop the innovation, and that is not desirable. In very fast moving economy there should be freedom to innovate and it should be incentivized so that those companies who develop new technologies or services etc. They should have freedom to develop their things and law-makers should not dictate what they should do but give the direction.

Krisztina:

Okay, but then my last questions are about yourself as a consumer. Do you think chemical recycling technologies are less circular then mechanical technologies? Here the question is mainly about what do you think about the term chemical recycling, do you think it has a bad connotation for people and for you? if a technology is a chemical recycling technology?

Kaisa:

Yes, it has a bad connotation for me, if you can use some ingredients, more sustainable... those materials which enable the recycling. I don't know how to put it.

Krisztina:

Well, in another way they call it molecular recycling, which is a little smoother, and for the people it's more acceptable. I have seen this in companies, for example there is a company in Netherlands, they are now developing a pair of jeans which would be 100% recycled. For that they need mechanical technologies, but also to mix them with virgin material. So until now they have 40% recycled material and 60% organic cotton in their jeans, because to keep up the quality they need to mix these two. But if the organic cotton would be replaced with MMCFs just as lyocell and Ioncell® then they could say that it's a 100% recycled pair of jeans, so they are using these chemical recycling technologies, but they are calling them molecular recycling technologies.

Kaisa:

Well I think that consumers are very confused with all ways so the communication of these innovations should be very clear, so that what is preferable for the society and the environment point of view.

Krisztina:

And what does it actually mean… which is nice, that this specific company didn't know about these discussion specifically but they also said that they are very sure about their costumers and they are very transparent, they communicate everything, so even if it would be said that it is a chemical recycling technology, they can explain why is it better for the environment then organic cotton, so and they have built this trust between the costumers and themselves.

Okay, and what do you think about plastic and synthetic words also in this way yourself as a consumer, if something is called plastic, it also could be as an example recycled PET in textile industry, but those are plastic materials. So what do you think about these words.

Kaisa:

Well, plastic and synthetic both words make negative connotation. On the other hand, it is good if you can collect those plastic materials from the sea, and recycle them, and make textile from them, but then you must be really sure that it is sustainable. But plastic as a word has a negative connotation and also the synthetic. I don't know.

Krisztina:

So do you think it has a reason for it that it is so bad in the mind of the people?

Kaisa:

I think maybe it's how it is discussed in media plastic, I think the news and everything what you have read and heard make those perceptions and how you understand thinks. But if you try to find more information about them and if you then understand more deeply those things, then your perception will change.

Krisztina:

Okay, actually we went through my questions, and I very much agree with you in many ways. One more thought which I actually probably would like to conclude in this research, is well very much discussing technologies and materials with this SUPD, and with the policies how you said in silo that they are on plastics, on textiles, on different industries. So I think this SUPD could be very much so called Single used product directive, because maybe we should focus more on the consumption behavior or the system how we are producing and consuming of these products than going very deeply into the material of them. What do you think about this?

Kaisa:

Yes, I agree! Then what now came to my mind about multi-level governance, what has been discussed is transparency and accountability are the key words which are very much used when you are talking about multi-level governance, so both on public sector law-making and private sector initiatives they have paid more and more attention to transparency, so that who are participating and interacting in those private sector rules, and how they show their accountability to their stakeholders so in that way if private sector companies and actors can be more transparent, and also improve their accountability then maybe this multi-level governance can become more reality. Because all stakeholders should understand why these roles are made for whom, for what purposes and how they are implemented and monitored and what are the sanctions if they are not applied what happens then, so all the life-cycle of the rules and regulations should be clear and well implemented, well monitored. I don't know if you get the point.

Krisztina:

yes, I understand what you mean and I agree. It might be little difficult and takes time to change things but this is a nice thought.

Kaisa:

okay, lets hope that you got something.

Krisztina:

I think so! this was a really interesting conversation, and you gave a nice input in my research.

Herbert Sixta

(Conducted: 2020.05.05.)

Krisztina:

First of all, I would like you to introduce yourself, and your work, and how does it connect to FINIX?

Herbert:

Yeah, my work is typically as you know I'm professor in Biorefineries, and my industrial background has been as a manager in a company producing pulp fibers and also textile fibers many years back. Then I moved to Aalto, I was pointed as a professor at Biorefineries, and primarily had the focus on novel techniques of pulping of utilization conversion and valorization of either non-cellulosic raw materials from sustainable raw materials like wood or annual plants, so that's what I'm doing in addition to the work that I started in 2009-2010 on MMCFs. At that time Finland was economically in a very difficult position, because the dominance of paper decreased a lot, especially writing papers were under pressure, so the big and also the smaller companies working on this field had to orient themselves to other product, other activities. This is one of the advantages in Finland, is that when they recognize that the economic situation of a big pile of their industry is under pressure, then they open nationwide research projects, and in 2009 they launched a very big, at least for Finland very big national project, where many universities were involved in the south, in the north, in the east, in the west. It was the so-called Shock-program, and within this program all kinds of so-called novel ways to valorize wood, mainly wood, were proposed, and after a critical assessment, certain projects were selected. Among those were also this Ioncell® at that time of course we didn't call it Ioncell® it was a use of a novel class of solvent, Ionic liquids, and I had been working already in my previous job at the company also with different cellulose solvents, also ILs, we had contact whit one of the pioneers of ILs from (?) University, and so we closely watched the activities on the field, until I was convinced to use it also in my own research. So this was a long story, and this FINIX project is just let's say kind of continuation of many other projects in a row, so we

started as I mentioned already 2009, the first experimental activities started in 2011, because it lasted almost two years to invest in this small spinning lab and of course at that time I had zero co-workers, the first one was Michel Hummel, you might know the story.

Krisztina:

But then, can you tell a little more about Ioncell®, how is it now, and well it started in 2009, and what were the evolution of it, and what are the current investigations around it?

Herbert:

When we started with the work on ILs we had different ideas. Not only to use ILs for the manufactory of MMCFs, but also using this as a solvent to separate hemi-celluloses from cellulose-hemi-cellulose substrate, this is still a very important task in the industry, to valorize cellulose, to purify it, and this project was actually the first that was successful, so we successfully could separate the hemi-celluloses, we had a successful Ph.D-s and also collaboration with companies, and this process is so-called Ioncell-P from pulp. Unfortunately the activities stopped around 2015, one company bought one patent, so they wanted to test it, but there was no further interest, so basically we developed it to high level, so the technology is available, but the conversion of the utilization of this technology in the industrial scale is not so simple, because you need to find cheap ways to recycle the ILs also, unfortunately different ILs turned out to be more effective than the one once we later on which you also know have been selected for the spinning. So this is a little bit complicated thing, but it was successful, especially scientifically, we know now how to fractionate polysaccharide according to the molar mass, that's a new application. So we can also fractionate pure cellulose to different molecular weight fractions. So that also has been nicely shown, one of your colleges, she was also from Hungary, Agnes, she was a Ph.D student in (?) and then she moved to Aalto, and she was post-doc for 2-3 years in my group, now she is in California. Okay. She basically wrote two nice publications from what we are doing in this context, also combining Ioncell-P and Ioncell-F by the way. The break-through of Ioncell-F, as we call it Ioncell-F fiber, was in 2013 until 2011-2013 we tested all kinds of different ILs and the attention was to establish the process with one kind of IL, but it turned out that was the worst selection that we could take, there were some papers from eastern Germany which turned out to be fake papers, and we followed them, so it took us too much time until we realized that this system was not working well. So

that is also one reason why we started with Ioncell® not early, but let's say at the end of 2013. The original idea was in a collaboration with Helsinki University that Helsinki University is developing a novel class of IL, and we test them. But as in life many times, this didn't work so well, as the original plan. So we selected ourselves one of those ILs, this [DBNH][OAc], as you know, and this was an issue, and overnight more or less it worked, and the next day we started to write the patent application, and then we published it in ATS conference, so we presented it there, and then we returned back and nothing worked. Nothing. Nothing. So we tried to repeat it, didn't work, until summer, and then Marimekko came and said okay, we would like to have a collaboration with you and so on. And I remember, I was on vacation in France and they reported me that it doesn't work, they didn't have any clue why it doesn't work, but then after a while and with the optimization of the conditions, we then gradually went back to successful spinning operation. But it was a lot of problem, we did not face the influence of humidity, of moisture so outside it was quite humid and so the air-gap was also affected by this humid weather. So that we realized much much later that that was more or less the problem. So this was the story.

Krisztina:

Okay, and then what would you say, are those problems avoided now, is it working well? Because we know that the pilot plan is coming and is it ready to be recognized in the market, and are there any more steps which are still needed?

Herbert:

Yeah, as you know this solvent1 is working without any problems nowadays, so especially from the key people like Yibo, then Sherif, and also Kaniz, they can basically use the system without any problems, so very rarely of course there are still problems, but more or less the conditions now are well known, under which we can have a stable and secure spinning, so that is not my concern. But the problem was with this solvent1 as you might have heard, that it is not very stable. It tends to undergo this hydrolysis reactions that has something to do with this relatively active ring-system of the cation, and the presence of water even at relatively low amount of water, the ring opens, and it forms an (?) and the reaction is theoretically reversible, but then you need to add a catalyst and yeah that's of course nothing what we can do in a commercial way. Then there was almost no literature on this side reactions, so we had to develop also the analytics, so it was not so self-evident, that this was clearly known that these type of molecules tend to undergo this hydrolysis reactions. And then, we

ended up in a very let's say similar IL, but with a decisive difference, we have now two-six membered rings which are much less active, and therefore are more stabilized, they also undergo hydrolysis reaction, but on a much much lower range, and now we know that these rates are low enough to keep acceptable (?) of this hydrolysis products while we do the recycling. Of course the problem if using this solvent2 was and still is the extremely high price, so we are not able to use it instead of solvent1, which is used for the recycling tests, therefor we have not yet the routine to do similar spinning, or to have a similarly stable spinning conditions as with solvent1, but I'm very confident, so there is no reason why it should not work, we need to figure out the optimum conditions, and that will happen as soon as we go back to the lab, because now this crisis have been substantially reduced in the course of this pilot plant activities, and also this bidding process, we have now almost the same prices as solvent1, so it seems that we can start I hope soon, summer or September or something like that. So as a summary, yes, the Ioncell® process is quite stable, I don't see any difference to the classical NMMO based Tencel process, and I'm also confident with the final solvent, with solvent2, we then will be able to spin a similar way, and result the similar properties in the fibers, the only real opened question is, because we have never tested that, in a real continuous closed loop operation, there is of course an accumulation of the degradation products from the solude, from the cellulose as well, and under this small-scale conditions we have never been able to detect those degradation products, so we don't know how do they effect the process, but also for that we are already prepared, we have developed a purification process, so the idea is to take a side-stream of the IL, and to treat it separately so to purify it and then the purified IL will then be recycled back to the process.

Krisztina:

Okay, so it seems like that the loop could be completely closed, and it could be a circular method, that is really nice.

Herbert:

Yeah, so at the moment let's say that we don't know any obstacles or any reasons why to be worried, of course it might still happen, we don't know, that's why we do this pilot thing, that's clear, but yeah we are quite confident as soon as we can start.

Krisztina:

Okay, but then I will ask you, compared to the other MMCF technologies, we talked quite a lot about Ioncell® now, do think that it would be a prominently more circular and more sustainable material then others like viscose and lyocell?

Herbert:

Yeah, Ioncell® is a lyocell process and there is not so big difference to the classical lyocell process. We have a different solvent. The one that we use has some advantages as well over NMMO, so we can do spinning at relatively moderate temperatures, it does not tend to so-called run-away reaction like NMMO, NMMO is a dangerous chemical, it undergoes explosions, of course people know how to stabilize it, but you never know if there are conditions where this cannot be assured, so this is a prominent open thing, thirdly we have the feeling, but this will be shown in a bigger scale only, but we have some evidences, or some indications that our process allows the production of let's say fibers with better properties in the sense of mechanical properties, and also due to the let's say fact, that our solvent is quite inert, it is more suitable for using to recycle textiles. NMMO is an oxidant, and when you have residual contaminants, like in textile waste, then this NMMO also might oxidase those impurities and result in all kinds of other problems, of course to this there are some indications, but no scientific proof yet. On the other side there are also disadvantages, of course one big disadvantage is that the technology is not yet established, so we are behind the Tencel technology, and also we need more energy to remove water, because we have to basically remove all the water, while in NMMO the tolerance is 13 m% of water, so 10% more than in our process. So there are pros and cons, and the biggest pro is and in this industrial environment the biggest obstacle is access to patent. This is for commercial people one of the problems, so Lenzing and those others who has the patent on the field of lyocell, they protect everything as good as they can, and so far they are quite successful. Makes a lot of trouble even if you are allowed to use them, but currently there are a lot of troubles associated, and this way we have no problems, so we have own patent portfolio, so we have no obstacle in commercialization. I think that is the most attractive for companies.

Krisztina:

So then overall you say that Ioncell® would be the most suitable for textile recycling, so the other MMCF processes are actually not necessarily that suitable.

Herbert:

Yeah, of course Tencel they also try to use textile waste, and they also will try everything to do that, but viscose is more or less a dying technology, even in china now more and more, the attractiveness of viscose as it is a very well-known technology, that the products are quite nice, they even have some advantages over the lyocell products in certain niche-applications, also some disadvantages, but at least the textile industry knows the viscose fibers much better, all their machines are adopted to viscose and cotton. So when Tencel was introduced, the textile producers were not very happy because they could not use the same machines in yarn and fabric producing as with viscose so they had to adjust their machines, and this industry is very conservative, they don't want to change anything, so and therefore, it took a long time to accept lyocell. Now it's the opposite, so we benefit the situation that now especially the consumers like H&M and Ikea, they love, and they prefer over viscose more and more.

Krisztina:

So slowly it moves to that direction.

Herbert:

Yeah, so this is the future technology, I'm very sure about that, this lyocell type, and there will be maybe even other solvents, so we have now NMMO-monohydrate, we have ILs, we might have even other ILs in the future. I think this situation will proceed in the future.

Krisztina:

Okay, so then overall in general if you put apart the recycling potential of these technologies, and we think purely about the original idea of using wood, and cellulose materials to make MMCFs, do you think it's a clean and sustainable way of producing fibers and textiles?

Herbert:

Yeah, at the moment, where we are at the moment, with cotton with synthetic polymers with viscose, compared to those technologies, the lyocell technology is a big step towards sustainability, but the time will come, when maybe, I don't know when, when also these technologies will also come under pressure, because not everything is ideal. We have to also have a look at other all kind of raw materials. Raw materials are also like ILs, how they are synthesized, so all those aspects have to also be taken into consideration, but at the moment we feel that even the synthesis of the ILs are not real let's say non-sustainable technology, so it's very simple, and also

relatively safe technology, but also with some factors, which are not so nice, because we are dealing with amine which are critical particles partly, the good thing on the other side, how I see at least, that this technology will only fly if we get recycling rate on the solvent close to 100%, so with this recycling rate, problems associated with the synthesis of the solvent are relatively minor, but of course existing, we have to pay attention to that. The patent and let's say the future aspect we will have to take into consideration is of course the energy consumption. It is always associated with pollution, of course if we make sure that the energy comes directly from the sun, then the process can be considered to be sustainable, if we of course use coal as a raw material, then it will be detrimental, as like with automotive systems, but otherwise I think it's a very simple process, so you have one solvent, you have water, you have three components, and you can compare these three components. In viscose you have many many components, and in synthetic polymers it's a quite complex field of different components, so let's say the basis of this process is quite sustainable.

Krisztina:

But is it very energy intensive? Is the whole process if we see the IL production and also the fiber synthesis at the end, is it very energy intensive?

Herbert:

The production of the IL needs energy, because very very few processes are at room temperature, it has to be heated up to a certain temperature, but also these processes can be optimized. this base or this super-base is nothing new, it's an existing chemical, which is used in catalysis, but in very very small quantities. That was the justification for this high price, so if this process flies, then there will be a lot of effort to optimize the synthesis also in the sense that it should be much more sustainable, then I'm optimistic. So at the moment of course everything is a little bit critical, because it's a very small scale operation at the moment, but I'm confident. The same goes with NMMO, NMMO was also not a mass product that time, now there is a very let's say environmentally friendly process to synthesize it. So of course you always can find problematic steps, I don't want to deny that, energy is one key aspect, of course it has to be shown that the energy is derived from sustainable sources, that's clear, the yield of the reaction is very high, so the threat of the side reactions is very low, so basically all the raw materials can be converted to the final product, so that is also good, so I'm quite confident.

Krisztina:

Okay, but then let's move on with the EU's policy-making, because as you know my project is kind of connecting these technologies with the policy-making now, so how much are you involved in the governance of EU and the policy-making?

Herbert:

Very little. I'm happy not to be involved too much cause its very time-consuming, as you know I was just involved in this discussion around SUPD, of course from time to time I'm also reading the new action plans from the EU, especially now the green deal, of course it's something what concerns us a lot, but EU is just about to prepare the basis, so it's not yet fully available, as you know, so the CE, one of the important part of the Green Deal is just about to be formulated, of course the problem in EU in general is that all those measures are mostly not mandatory, so just recommendations, then of course also its very general, so of course to not to effect the business, to promote business of course in the direction of reduction of GHG-emissions in that I think they do a quite good job, of course you always can say, and maybe the corona crisis will end up in totally different pathway, strategy, this is also something what will come up in the next month, how far the corona crisis will affect the Green Deal , you hear both versions, some of the politicians they say okay Green Deal, we have to get back to the jobs, sustainability is not the first priority in the moment, but you also hear, and I hope those are the more reasonable people, on the contrary now we have to take the opportunity, when we build up the economy again, or when we go back to business again, that we look very careful that we follow the rules of green chemistry, from sustainable chemistry, and these kind of things. So it's not yet clear how this will develop.

Krisztina:

Alright, but them with the current CE action plan which was the green deal, which was in 2020, right?

Herbert:

2021 it think so what I have read recently, that the strategy for textiles will be discussed in 2021, let's see how this develops, or if there is any let's say delays due to the corona crisis, I don't know.

Krisztina:

But the one in 2020. the action plan which just briefly mentioned textiles, that also had separately a paragraph for plastics, and also for textiles, do you think these separated

industries and the policies for these industries are somehow contradicting, or can you find any potential contradiction between them?

Herbert:

I have to say I don't know the details of those let's say action plans, what I have read this EU strategy for textiles, is relatively brief, it is very general, so it means that the materials should be selected as such that they allow better recyclability, and this kind of things, that is quite obvious I would say. plastics of course are very much needed in future of course and EU knows that, so there are many properties that cannot be easily replaced at the moment, but other materials, so that's not possible so we can just ask, or even demand to replace plastic, but whit what? Therefore, the SUPD is the first step, and it makes a lot of sense, because those materials end up immediately in the environment, and then of course there is not so much need to have this in a non-sustainable, to use single-use devices in not environmentally friendly, or biodegradable materials, that I think the first place. Of course as you have also noticed in our discussions, and that sometimes gave feedback to you, the discussion was a bit weird partly, because biodegradability was not the first criteria, it was just if the material is a natural polymer rather than a modified natural product, which might have even better properties, which might still be biodegradable, but still it is then considered to be plastic, so that is a little bit hard discussion, and I'm still not understanding this kind of categorization, but okay, as you know lyocell is now considered to be a natural polymer, viscose is not yet considered to be a natural polymer, but there are also arguments, by let's say the EU consultant companies, like the ECHA, they basically consider viscose also as a natural polymer. Why? Because they say the process which is used to convert pulp to viscose fiber is not relevant in terms of the properties of the end product. So it's just when you compare the end product with the initial product and there is no difference in the chemical composition, then you can say okay, it's still a natural product. Original definition and partly other members still high-lighted is that when there are reactions which are converting cellulose into a modified product, within and intermediate step, this is enough to categorize the end-product as plastic.

Krisztina:

I would like to ask you, maybe this is not in my questions, but came up now. What is your personal opinion in these, because you know the viscose process very well, and

also the lyocell and Ioncell®, how much do you think it should be dismissed the process itself, how the base material is becoming the end material?

Herbert:

Yeah, of course the process if very important as such, but in a different way. Is it a green process? Is it a sustainable process? is it causing GHG-emissions? Does it use toxic chemicals? does it waste any kinds of energy or materials? The process has to be assessed separately, but this directive does not direct towards the processes, just the products as such, and there they distinguish between polymeric material from nature, polymeric material which has been synthetically produced, those are categorized as plastics, even if you combine natural material with chemical modification, and also those materials are considered to be plastic, like cellulose acetate for example, so this is a little bit. I regret these kind of discussion, and it goes back to previous definitions which were set up by the EU commission, namely what is a natural polymer, what is chemical modification, and they want to stick to this previous definitions, and the biodegradability is not in the focus, and their argumentation was that there is no generally accepted method to determine the biodegradability, which is true, but you have to consider different biodegradability, is it in the deep sea, in the shallow sea, in the land? So it depends where this material ends up, and how the conditions are how they affect biodegradability? For me it's not really an argument, it is more an excuse, that they don't want to now combine the definition on biodegradability, with the end use of these products.

Krisztina:

So to what extent does SUPD effect the circular textile economy and these technologies?

Herbert:

Yeah, as we know now, the recommendation of ECHA will be such that lyocell will be defined as a natural polymer, so it doesn't effect, viscose we don't know yet, bet there is a big chance that it will be also classified as a natural polymer and cellulose based materials, either lyocel or viscose are not affected by this SUPD. As viscose is of course considered to be plastic then I'm pretty sure that there will be an acceleration to replace viscose by lyocell, that is a quite clear. Even though viscose has a certain share in these so-called nonwovens, which have single-use applications, and this share will be gradually replaced by for example lyocell or cotton.

Krisztina:

So overall it seems like, that from the policy-maker perspective, and from these directives, this MMCF technologies at the end will not be very much effected, but if we take the other scenario, if we think what would have happened, how do you see what would have happened if these technologies are classified as plastic, and how would it affect them?

Herbert:

I think, and you saw it on the reaction on the company representatives, they were very alert and of course tried everything to avoid this kind of classification, so it already explains that it would have a big impact on their commercial success, because especially nonwovens in the hygiene applications. This is not the primary usage of those materials, but hygiene materials would have been effected substantially, but it would have catalyzed let's say if Lyocell also would have been classified as plastic, that would be a really big draw-back of the development of this kind of materials, because I would assume, that sooner or later this policies would be also applied on textiles, so for the time being its single-use plastic, but that we know, all these regulations will gradually also be used on other materials and products, and that would actually be a big threat. Therefore, this is a good news especially for lyocell now, that it still considered to be a natural polymer. The second thing is if we don't look at lyocell or viscose, but to other natural or sustainable products, there are big efforts to produce polymers by fermentation for example, to replace all kinds of plastic materials. The problem is that due to this existing definition of natural polymers even though these so-called novel polymers has been produced by sustainable products, like fermentation and so forth, and sustainable raw materials like sugar molecules, they are not any more considered to be natural polymer. That is a big obstacle for them, and also for research, some of my colleges in this field to synthetize biopolymers by fermentation, or by other means, where they have to modify the polymer but the final product is not comparable with real plastic or synthetic polymer, because it stays biodegradable. So this segment is really heavily affected by this directive, and I do hope that their lobbying which is still ongoing will be successful in the on or the other way. I would have hoped that the EU commission is thinking on another definition how materials effect the environment, especially the sea, but obviously the test methods are not yet available or accepted, so they avoid to define biodegradability as I mentioned already previously, and that is also then effecting this definition. so it seems that those polymers like this Polyhydroxy alkaloid which is one of the key polymers

produced in ferments, and is about to replace plastic especially for coating material, because they have nice properties avoiding or controlling moisture transport through the surface, so those materials, and the development of those processes have a drawback.

Krisztina:

Yeah because overall they are also classified the same as plastics. There would be no difference in the perception. Well this is very interesting. Then if you think about the people or the public perception, as I mentioned once, I was talking to a company, who were very suspiciously using the term molecular recycling instead of chemical recycling and it turned out that they didn't really know these discussions in the EU, but they purely used another word because they know that chemical recycling already has a big negative effect on the people's perception, they think it will not be sustainable, that is why they thing that if something is mechanically recycled it is a more sustainable process. What do you think what are the reason for this and if there are any possibilities to overcome?

Herbert:

Yeah, of course I don't know this specific case here but in general I think it is a starting point. EU has excellent experts I'm not expecting that they are not so simple minded that they will not see the difference between let's say a real plastic which has no biodegradability at all, but very innovative product which are synthesized by products form nature like sugars or lignin or whatever, and they also turn out to be environmentally friendly processes, and also the final products are biodegradable. So if these properties are attained or convincingly shown by those who produce the products, then I'm pretty sure that there will be a second loop or examination on those products, but of course there is a certain delay. My estimation is that they want to have a quick solution now, to get rid of all these single used plastic devices, which are really polluting all our environment to have first regulation, and then they continue working on let's say on the refinements of this directive, but I don't know.

Krisztina:

Okay, but you are talking about the experts, and of course the experts would know or understand more the processes and would have a better understanding on sustainability and how much different materials are sustainable, but an average consumer, if you tell them that something is chemically recycled, do you think that it

has a negative connotation on the choice of the consumer? Is it something that would make them scared of the material or think that it is unsustainable?

Herbert:

Yeah, of course at the moment when we go back to the textiles, recused or second-hand textiles, they have a certain negative touch, because obviously the quality has also been reduced, but I'm pretty sure that this mindset will change with the observation that we can show with recycled textiles or recycled products which are used in daily life have the same or even have better properties as we also promote Ioncell® that is able to upcycle even certain materials, and that can be shown and then I'm pretty sure that people will gradually accept this. But there will be a segment especially in the hygiene area where this is unacceptable, because of course you cannot recycle these single used products, in textile I think the acceptance will be reached one or the other day. Also with the green movements, I'm pretty sure that in this area, even I had a discussion recently with some of my young relatives, so I think the actual demand, the young generation demand that we have to change the mindset from this fast-fashion and very very waste related technologies. I'm pretty sure. There will be certain segments, especially in hygiene, in medical applications where recycling of course is not possible. But of course we have to show, that the materials used for single-use are biodegradable, the processes and the production are green, sustainable and non-polluting, this of course is needed to show.

Krisztina:

Okay. I have an additional question. What would happen if the focus is not on the material if it is natural or synthetic polymer, or wood for the product, but it is on the consumption behavior, how we buy the products and through them after the first use, would it be possible to create policies focusing on this behavior instead of the materials?

Herbert:

That's my hope also, of course as I mentioned already, there will be materials or applications where you cannot use cellulose, where the benefit of plastic, certain plastic material is so much better then when using cellulose or other biopolymers, so that the user of those products really know the advantage of this material, then the next step would be okay, what happens with this material in the environment? is it persistent, or is there any way degrade it or recycle it, or whatever, yeah? So this is then the task of the plastic industry, and I'm pretty sure that they already have noticed

that of course, and they are heavily working on processes and materials which are more green more sustainable, where the materials can be even biodegraded? it would be difficult, but there are efforts in let's say developing micro-organisms which are capable of degrading plastics, so these directions I'm very sure that human creativity will give some solution of those problems. What we need all those who produce, and who work on new products, we need clear regulations, which are understandable, which are reasonable and which are clear. When we have regulations which are not understood, this is like in corona crisis also, when you get directives from the politicians which are not understood then they are not accepted by the public. So this is very clear and the same applies also to materials, so we need to have clear instructions, what to do, regulations what not to do, then I think the scientists have a clear regulation where to go and then they will find solutions.

Krisztina:

Okay, I think we can close the interview here, I think I got lot of answers which I was hoping for and it was a nice conversation. Thank you!

Herbert:

Thank you for the good work, and your ambitions and motivation!

Dion Vijgeboom & Eske Hurenkamp

(Conducted: 2020.04.16.)

Krisztina:

So if you could briefly introduce yourself, yes, that would be really nice, about your expertise, how did you get connected with the company and what exactly you are doing?

Dion:

Yes, so I actually studied strategic production management in the Amsterdam fashion industry institute, but it was long time ago when it still had another name actually, then I did run a production in a factory in Sri Lanka for four years, and after that I got involved in denim, I worked for G-star for 10 years as head of sourcing and product development of denim, and that is also towards the end of that period that I got more and more intrigued and challenged by finding what ways to do the production and the development of jeans differently. And related to the way how they are doing those things, I decided to leave the company and start as a consultant, I worked for several brands and factories always on the sustainable topics. Then in 2014 I meet with the founder of MUDjeans, and well decided that we could strengthen each other, and my input in term of products could be a good choose, so then at that time I invested also to become a shareholder of the company, and right now in MUDjeans we are a super small team with ten max, so everybody does besides his core activities, which is in my case are the sourcing and the production of the denim but we also do many other things, sometimes related to marketing, finance, organization etc.

Krisztina:

Yeah, I believe that's how it is in start-ups, like in small teams you distribute the responsibilities very freely let's say.

Dion:

Yes, making coffee, watering plants, everything. Then, Eske did her first internship two years ago with us, well you give yourself your introduction.

Eske:

Thanks! I'm Eske, and I'm still studying, I'm student of Fashion and Textile Technologies, in east of Netherlands, and first year of my studies I came across a presentation of Saxcell which is regenerated cellulose fiber, and they were talking about cotton waste

recycling, and I was super, yes I'm interested in sustainability in general, and I was like okay I have to go there, what are they doing, this is interesting! So I started following an owners program next semester for them, and I am getting more and more knowledge about the topic, and then I was thinking where can we actually make a big impact with such a future technology? Where do they use a lot of cotton? And then I was like yeah jeans, so many people wear jeans, almost everyone, and I came across MUDjeans, and this is perfect, and actually they were also looking into using more recycled material, so I did my first internship there 2 years ago, it was super interesting, like you said in a start-up you are getting so many different roles, and learn so much, and I interviewed different organizations like Saxcell in the world, which were there 2 years ago, which are opened also for this, and yeah the topic is really interesting to me and now I am writing my thesis, and from this last research we ended up in this new project together with my university as well, to make the first 100% recycled jeans.

Krisztina:

That is nice that you mentioned that one because that would be part of my question. In one of your webinars you did introduce a little how are you making it, but can you please shortly tell me also that?

Eske:

Yeah, so we are working together with different parties actually with Recover, which is where we normally also get the mechanical recycled fabrics from for MUDjeans, and currently we have a fabric at MUDjeans which has 40% mechanical recycled fibers, and we would like to make this higher, but this is kind of the limit for mechanical recycled fibers, because otherwise it just gets too weak to make good quality products, so there is always 60% new organic cotton added, and we thought maybe it can be interesting the two technologies so mechanically recycled fibers and chemical recycled fibers and actually Saxcell and Re:newcell suggested to work with us, so we are now here in Netherlands spinning yarns with different %-s to see how does this go, the combination of these two fibers and do we get a good quality yarn out of this, can we make jeans from this? We are all at the beginning but…

Krisztina:

Yeah, but do you have like tests comparing the two different fibers, the organic cotton fiber, and then you test also the recycled one via chemical recycling, if it is more or less the same material or it has the same tenacity, and these kind of values?

Eske:

Yeah, we are doing it in yarn-lab right now, because about the fibers, of course from literature you can see it, but it is very different to have a MMCF or to have a cotton fiber of course, but in the industry we could already see that there is like Tencel or lyocell used in jeans, but of course it's going to be very exciting to see how this will end up for tenacity we are testing the yarns so we tested the yarns that MUDjeans is currently using, and then the yarns we are creating right now, but there are still a lot of different factors that play a big role in tenacity actually, not only the strength of the fibers but also how the fibers are together.

Krisztina:

Okay, but you would say that these MMCFs are actually the way to the cleaner and circular production, and the way to make this 100% recycled pair of jeans?

Eske:

yeah, I already went through of your questions super interested, some I even didn't know how to answer, but I think you have mechanical and chemical recycling. Mechanical recycling is a dry process, while chemical recycling or regenerating cellulose fibers is a wet process, and I think dry processes are always better because you don't need any water, and for the mechanical recycling the only input we need is energy. And of course recycling processes always have an environmental impact, we should consider that. Because lot of people are like recycling wow, so good, but they still have an impact of course. In MUDjeans we also did an LCA, to measure all the different processes, and it could be very interesting to measure the LCA of the chemical and mechanical recycling.

Krisztina:

I actually think that there are LCAs about those fibers also, but of course it always depends on the current material that you are using…

Eske:

Yeah, and for mechanical recycling there are so many different ways.

Krisztina:

It depends on the liquid which you are using to dissolve, and other factors, yes. Well I also just got into this topic, and I'm super interested about it, I did an internship last semester in Finland, Aalto university, with one of these MMCFs called Ioncell®, which is only at academic field yet, it is not out in the industry, and that's how got connected

about the whole topic, and now my thesis is also about it because these are good questions.
Okay, so you say that the combination of the mechanical and chemical would be the way to actually close the loop and say, okay this is 100% recycled.
Dion:
I mean there is one technique that we do not know so much about but at somebody introduces with, which is more of a hybrid, well Eske maybe you can tell.
Eske:
Upset
Dion:
Yes, they would like to find a way to make old fabrics softer and weaker and then in a way untangle the yarns back to fiber, so it's more of a mixture between mechanical and chemical recycling.
Krisztina:
It sounds interesting, I haven't heard about them. So are you also collaborating with them?
Dion:
No, we have been in touch with them but it's obvious that those processes are easier when you use for instance bed-linen or any regular materials, and I think so far they only applied it with pre-consumer textiles, but in principle this technique is also interesting.
Krisztina:
Yes, that's true, and of course these experiments and processes are taking a long time until you actually reach the moment that you can use them in the industry. Okay, how much do you think these technologies like lyocell Ioncell® and also which you are about to use that they are capable of post-consumer cotton recycling and they are actually there, and they are capable to jeans recycling let's say?
Eske:
Yes, that is very interesting. The problem is that a lot of post-consumer textiles are blends of course, and they are dyed in so many different ways, but what is really nice, is that if a company applies recycling or takes responsibility for the waste like MUDjeans is doing, like you exactly know already in the design phase what processes are there, what chemicals and materials are there and this makes recycling so much easier if you actually know what has been done to the product, and if you can also

make the design phase for recycling then it's even better, so then the chemical recycling would be easier, I think on a company level it's doable, but if you want to do this as a nation or in a community, or city, it is really difficult. You need good waste collectors, sorters, and then companies like Worn Again, who separate cotton and polyester blends, and maybe even restrictions also for producers, as what can be used, what chemicals materials, can you use like 6 different materials in one piece, or what is allowed.

Krisztina:

Well, the blends are difficult, I actually read that you are taking back jeans and you are also using in your jeans 2-3% of elastane, and that was the beginning of my research that I was testing Ioncell®, how does it work with elastane blends and until what % can we still recycle those materials with elastane, and yeah. So you see and feel that it is possible to recycle and you are actually doing it with this smaller amount of elastane, right?

Eske:

Yes, for mechanical recycling yes, but we don't take back fabrics with more then 4-5% elastane, because if there is a lot of that, it can be problematic. And of course you still see in our new jeans, fibers which have a different color, because dying goes differently for the elastane or polyester, I think it's a really nice characteristic that you can see the recycling.

Krisztina:

Okay, so I would like to ask you how much are you connected to EU policies on CE, and action plans and regulations? How much are you actually effected by these regulations?

Dion:

Not. I mean we have tried to reach out and we have also been approached by some of the, I mean they do surveys by several other companies sometimes CE or other institutes, and we are always happy to give our inputs, but we also noticed, that to be really participating in those discussions and policies, it is not for us, it is too lengthy, too slow, too academic in many cases, and we are just a very tiny player in this field. So we do share our ideas obviously, and we try to give input, but we don't feel that we can really stir them into a certain direction. So far, their objectives are definitely good and work well, but so far not very practical to apply for us.

Krisztina:

What do you mean with that?

Dion:

Because they operate in a much higher level of okay, how should we organize waste collection or can we incentify certain processes and at this stage it is not really happening. I mean we like Eske was saying, if you really want to create a circular system on a really broad scale it is very difficult, because indeed you need to deal with sorting the cotton, wool, whatever composition you have, so that is a challenge and then on a totally different level where we feel quite unheard, I mean we don't get a lot of responses is incentifying, I mean we feel that we are already doing things quite well, and we should get benefits because of that, like you have seen in the car industry, like electrical cars are free of taxes, those kind of things, but big players still have so much power that they would never allow these benefit for companies like ours.

Krisztina:

So it effects the policy-makers and the policies, that EU would not promote these kind of technologies?

Dion:

No no, totally, they do promote these technologies, but we feel that there should be incetives for doing so.

Krisztina:

So they are promoting, but not with real measures.

Dion:

Yes. At least I would say it is still in a too early stage for us to have any benefit from it and to profit from it. But that is also because I mean if you really want to have a voice and be involved in that, we would need one person probably full-time to be dealing with these kind of things, to go these meetings, write our proposals etc. etc. We just don't have the man-power and the funds to do so. So it's more a skill issue I would say. Maybe Eske also has more input on that from her point of view.

Eske:

No. I think maybe for the chemical recycling technologies it is super nice if there is more funding, and I think compared to two years ago there is definitely more intention, but for a producing company I don't think we get a lot, still it is more expensive also to buy the recycled fibers then to buy new raw cotton fibers for example.

Dion:

Totally. Yeah.

Krisztina:

Well, I will change the topic then a little bit, so then when you are talking about these MMCFs and you are talking about them as molecular recycling instead of chemical recycling, what is the reason for that? Why do you think that molecular is a better word to use?

Dion:

It's very simple. I mean people associate with the word chemical with nasty things, whit toxicity, those kind of things, so from that perspective at this stage it makes more sense to create interest, to name it in that way.

Krisztina:

Okay, so it's more like the people's perspective.

Eske:

yeah, communication.

Krisztina:

Okay, and are you aware of the discussions going around these topics in the commission or in the policy making perspective in the EU?

Dion:

Do you mean in the sense how it is named, or?

Krisztina:

Yes, kind of. Because this is the thing: my topic is about actually another directive, the SUPD. This has nothing to do with the textile industry from the first glance. But then if you go deeply into, there are the wet-wipes which are commonly using man-made cellulose fibers to make it more sustainable choice to use these single-use wet-wipes and this discussion is going on about what is plastic, what is chemical modification, what are natural polymers, because both are polymers, and if we are talking about MMCFs, we are going through a kind of chemical process, but the end-result will be the same as at the beginning, a cellulose fiber. So this is the question if these fibers should be classified as plastic, because if they are classified as plastic in SUPD, then they are classified as plastic also in the textile industry, and they will become synthetic, and if we keep in mind the CE perspective, that is really undesirable, and this is a big controversy which is going around these fibers right now, and my research is mainly

about what would be the effect if it really happens, because it is just on-going now, so nothing is sure yet, but yes I would be interested in the effects.

Eske:

I think its super interesting but for me I think, because we are looking from the CE perspective right, and if we are only basically look at the processes from a linear perspective, maybe some processes look like they are the same. But if you look at the end-stage of any product, I think it's very important to ask the question what is the effect if it ends up in the nature, and is it biodegradable, is it fitting in natures closed loop? Because I think there is a big difference between MMCFs and synthetic fibers.

Krisztina:

true, although actually this is also under discussion, that they are having tests on biodegradability, but it is complicated, because it is not something that is very easily measured. So there are still effects, just they probably don't take into account, that the natural fibers like organic cotton textile would have the same effect in those environments. Although I think it is not about the materials which we are using, I think it is about the consumption pattern how we are using things, so if we are talking about single-use plastic directive, we should talk about single-use product directive, and then we don't have a question about plastics...

Eske:

Yeah, exactly, yes.

Krisztina:

Do you think if these materials which you are planning to use for the 100% recycled jeans would be classified as synthetic materials, would it effect the public perception, or how you are perceived as a circular fashion brand?

Dion:

I think that we as a company would still be able to market this as a company and to explain this to our customers. Because we anyhow a very transparent and we have a narrative, we constantly tell what we are doing, so in this case we would also be able to explain it, but it would definitely prevent this technique from having the perception that it deserves on a bigger scale. I already noticed it, because I think two years ago Lenzing launched Lefibra, that was also, well they put the wood pulp of the tree as a base material for their Tencel, they would now use pre-consumer cotton waste as the raw-material. They tried to have that labelled as cotton or as recycled cotton, but they were not allowed, they had to market it as Tencel, even-though the base

material was recycled cotton actually, and that effected the success of that fiber a lot. Many mills and branches even knowing the content was different, they would say okay our customers would not be more interested in it so.

Krisztina:

Actually, Lenzing is also part of these discussion, so it would be interesting to talk to someone there also. Then well, you do have pretty deep knowledge on these materials, and CE within the field, but as consumers yourselves, do you see any effects on your decisions, if someone says that okay this is plastic, or synthetic?

Dion:

Yeah, yeah for sure! I mean already have costumers that refuse to buy our jeans if they contain elastane, so they only want 100% cotton, so it would definitely effect. Like I said I would say that we would be able to communicate it, but it would not help for sure. So it would definitely be a struggle.

Krisztina:

well, I think maybe we didn't go one by one, but I have the impression that I have the answers which I'm very happy with. Thank you!

Dion:

That's good to hear!

ANNEX II.

Questions of Conducted Survey:

Section I.: EU's policy regarding Single Used plastics and Circular Economy in textile industry

1) What comes in your mind when you think about 'sustainability'?
2) Does the concept of sustainability influence you in decisions, like which product to buy? [scale between 1-5; 1- hardly; 5 – much]
3) Give your opinion: To what extend the European Union's environmental legislation considers sustainability issues? [scale between 1-5; 1- less; 5 – great]
4) The EU's Single Used Plastic Directive is aimed to limit certain plastic products leaking to the natural environment. Which one of the following items is not in the focus of the directive?
   a) plastic cutlery
   b) balloons
   c) plastic cups
   d) wet wipes
   e) plastic carrier bags
5) Give your opinion: Which items are the easiest to replace or eliminate from our everyday life? Rate them from 1-5! (1- easiest to eliminate; 5- hardest to eliminate)
   a) Plastic cutlery [scale between 1-5]
   b) balloons [scale between 1-5]
   c) plastic cups [scale between 1-5]
   d) wet wipes [scale between 1-5]
   e) plastic carrier bags [scale between 1-5]

Section II.: Circular Economy in the textile industry

1) How much do you know about Circular Economy?
   a) I am an expert
   b) I am informed
   c) I know a little about it
   d) This is the first time I heard about it
2) Name three ways to promote Circular Economy in the textile industry!

3) How serious do you think the following challenges are regarding textile/fashion industry? (1-less; 5-greatly)
    a) Use of resources [scale between 1-5]
    b) Green-house gas emissions [scale between 1-5]
    c) Toxic chemicals [scale between 1-5]
    d) Human rights abuses [scale between 1-5]
    e) Waste [scale between 1-5]
    f) Usage of water [scale between 1-5]
4) Considering the style, comfort and quality are the same, would you purchase sustainable clothing if it costs more than what you would normally pay?
    a) Yes
    b) No
5) Give your opinion: How sustainable are the following textile materials? Rate them from 1 to 5! (1-least; 5-most)
    a) Organic cotton [scale between 1-5 + I don't know]
    b) Viscose [scale between 1-5 + I don't know]
    c) Polyester [scale between 1-5 + I don't know]
    d) Lyocell [scale between 1-5 + I don't know]
    e) Hemp [scale between 1-5 + I don't know]
6) Which T-shirt would you choose?
    a) 100% organic cotton
    b) 100% recycled cotton via chemical recycling
    c) 100% recycled polyester from PET material
7) If a textile material is considered as 'plastic' or 'synthetic', does it have a negative effect on your choice of sustainable clothing?
    a) Yes
    b) No

Section III.: General information

1) Gender
    a) Female
    b) Male
    c) Prefer not to say
    d) Other
2) Country of residence

3) Location
    a) Big city
    b) Small city/town
    c) Countryside
    d) Prefer not to say
    e) Other
4) Age
    a) 15-25 years
    b) 26-35 years
    c) 36-45 years
    d) 45+ years
    e) Prefer not to say
5) Education:
    a) High school
    b) Bachelor's degree
    c) Master's degree
    d) Ph.D or higher
    e) Prefer not to say