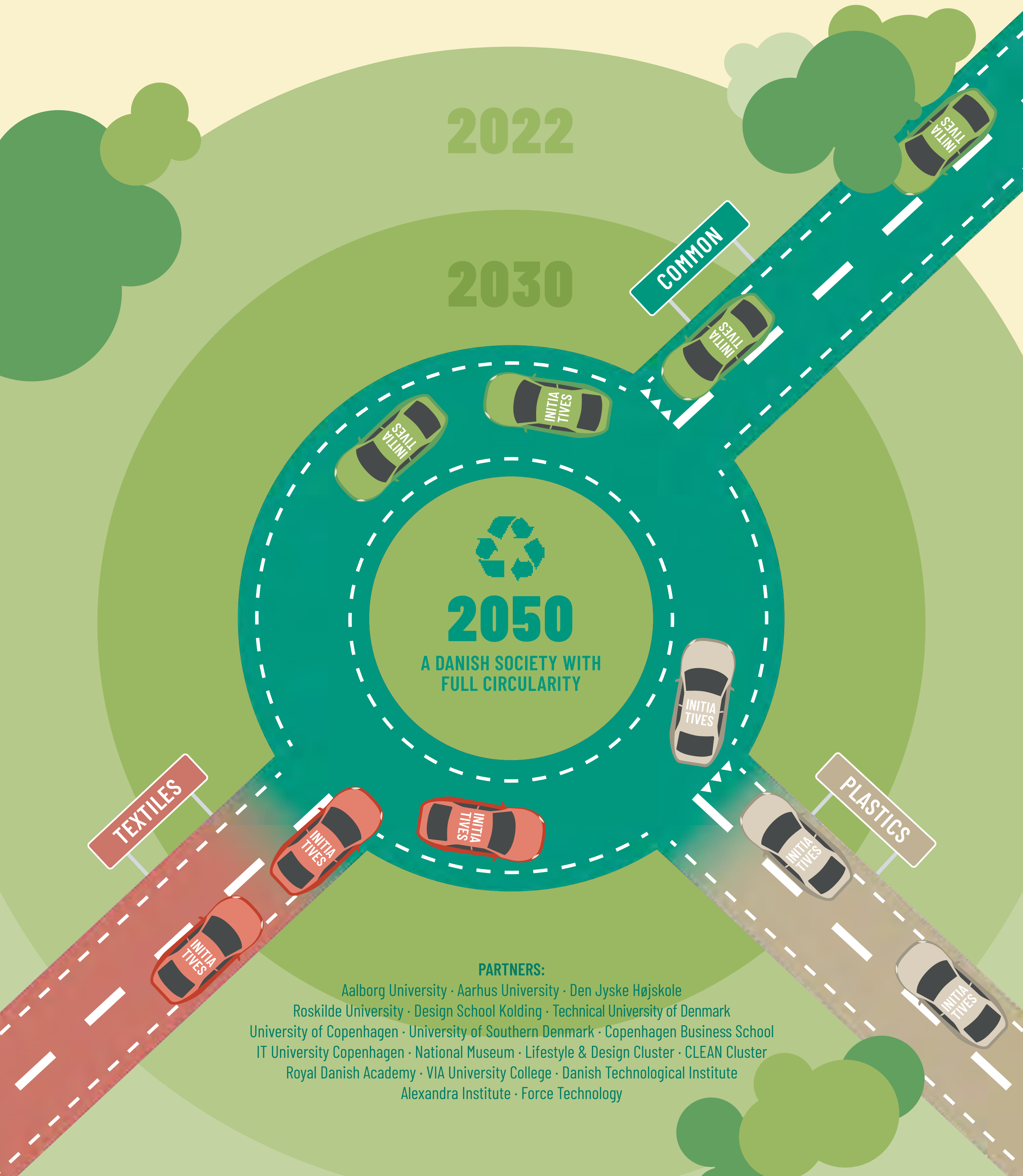
Circular economy with a focus on plastics and textiles

A 2030 & 2050 ROADMAP



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CIRCULAR ECONOMY WITH A FOCUS ON PLASTICS AND TEXTILES - A ROADMAP

INTRODUCTION

Recent decades have witnessed unprecedented growth in the demand for raw materials; current trends in population and economic growth contribute to an unsustainable strain on the Earth's natural resources and the environment (IRP, 2019). This has raised global awareness of resource efficiency, material management policies and circular economy (CE) strategies. Recent assessments reveal that CE practices can contribute to the achievement of several Sustainable Development Goals (SDGs): SDG 6 (Clean Water and Sanitation), SDG 7 (Affordable and Clean Energy), SDG 8 (Decent Work and Economic Growth), SDG 12 (Responsible Consumption and Production), and SDG 15 (Life on Land) are all directly affected by CE (Schroeder et al., 2019).

The European Commission introduced the CE Action Plan (CEAP, March 2020) as the main building block of the European Green Deal. This plan formulates the agenda for sustainable growth whereby CE is the core instrument for reducing the pressure on natural resources, creating sustainable growth and generating jobs. Hence CE is central to achievement of the European 2050 Green House Gas (GHG) emission goals.

In 2019 thirteen Danish climate partnerships recommended initiatives enabling Denmark to achieve a 70% reduction in GHG emissions by 2030. In March 2020 the partnerships revealed that introducing CE (by 2030) in Denmark can reduce global GHG emissions by 7-9 Mt CO_2-eq. and by 12-16 Mt CO_2-eq. in 2050 (Regerings klimpartnerskab, 2020). In April 2021 Innovation Fund Denmark (IFD) launched a call for four roadmaps (IFD, 2021): I) Capture and storage or use of CO_2; II) Green fuels for transportation and industry; III) Climate- and environment-friendly agriculture and food production; and IV) Circular economy with a focus on plastics and textiles. The four roadmaps describe challenges and gaps within the green mission, list strongholds and potentials, sketch key activities, and outline relevant workstream themes for the future Innomission partnerships. The "Circular economy with a focus on plastics and textiles" roadmap is developed by all eight Danish universities, the Danish GTS institutes, The Design School and the Royal Academy and two industrial clusters.

Plastics and textiles involve some partially different value chains in terms of raw material extraction, production, use and disposal. Hence the roadmap presented here was developed with two tracks, one for each of the materials. However, despite being presented as two separate tracks in this roadmap, the two tracks are overlapping in terms of R&D in Denmark. In relation to GHG emission reductions, the two tracks depend on similar sustainability-oriented initiatives and social innovations (European Commission, 2019). Textiles and plastics hence share several opportunities/challenges which are highlighted throughout the roadmap.

GHG emission reductions are of paramount importance to this roadmap and the reader should note that, in line with Regerings klimpartnerskab (2020), GHG emissions are reported in three different ways here: 1) Direct emissions (emissions taking place in Danish-controlled territories); 2) Indirect emissions (emissions induced by Danish activities taking place outside Danish territories); 3) Global emissions (direct + indirect emissions). The reason for using different emission "types" is the lack of relevant emission estimates at the same spatial resolution.

"The entire value chain in the Danish plastics industry is facing groundbreaking changes in these years as the world moves towards a circular economy"
Thomas Drudstrup, CEO, Danish Plastics Federation

"The Danish textile and fashion industry have a potential to be the first mover, when it comes to circular economy"
Thomas Klausen, CEO, Danish Fashion & Textiles Federation

TEXTILES

The current situation and challenges for the textile sector globally and in the EU

The textile sector is particularly challenged with regard to a circular mindset and future due to prevailing linear ideas of fashion as trend- and season-based. Covid-19 has placed the global sector in a state of shock, as unsold deadstock and under-utilized textile waste is piling up worldwide, with vast economic losses and resources as a result.

The textile sector is a significant sector in the global economy (EMF, 2017), with an annual turnover of $2,5T and employing over 75M people globally (UNECE, 2018). The fashion segment leads the textile market and accounted for more than 74% of the global revenue share in 2020. Owing to increasing consumer spending on clothing (fashion), it is likely to drive the global market demand for textiles from 2021 to 2028 (GVR, 2021). Over the last 15 years the global production of textiles has approx. doubled and the demand for textile fibres is projected to increase from 62 Mt in 2017 to 102 Mt in 2030 (GFA, 2017).

The fast-fashion segment (low-quality and low-cost products mainly sold through chains, supermarkets etc.) has pushed for more volume and shorter use-spans with the effect of an estimated 87% of total fibre input being landfilled or incinerated following first use, which is equivalent to a value of more than $100B (EMF, 2017). The global greenhouse gas (GHG) emissions from textiles production totalled 1.2 Gt of CO_2-eq. in 2015 (ibid). GHG emissions are released throughout the lifecycle of textile products, from the extraction of raw materials through production, transport and use and disposal.

4-6% of the EU's environmental footprint is caused by the consumption of textiles, with clothing, footwear and household textiles ranking fourth (EEA, 2014), while 76% of GHG emissions during production of these fractions occur in non-EU countries (Mandshoven et al, 2019). Koehler et al (2021) estimated the overall annual global warming potential of textiles placed on the EU27 market at 198 Mt CO_2-eq. The high ambitions for the environment and climate have resulted in increased regulation of the textile sector. From 2025, all European Member States will have to set up separate collection systems for textile waste. Moreover, Article 11(6) of the revised WFD states that the European Commission must by December 31, 2024, consider setting targets for (preparing for) reuse and recycling of separately collected textiles (ibid). Article 9(1) of the Directive was amended to encourage the reuse of textile products and the setting up of systems that promote repair and reuse activities for textiles.

The role of extended producer responsibility in promoting sustainable textiles and the treatment of textile waste in accordance with the waste hierarchy will also be considered in the coming EU textile strategy (summer 2021) and the implementation of the legal obligation to introduce separate collection of waste textiles by 2025 will be supported.

Hitherto, CE has been widely interpreted to be a silo-based solution within the linear mindset, with minor climate-positive impact as the focus has been mainly on materials innovation and recovery (Greenpeace, 2017). Systemic design approaches to circularity are available but have not been implemented in industry (Kozlowski et al 2019), even though it is estimated that 80% of climate-affecting decisions are made here (EMF, 2017). According to the EEA (2021), there are four main circular business model types, each supporting the shift towards circularity: 1) Ensuring products longevity and durability; 2) Access-based models (renting and leasing); 3) Textile collection and resale; and 4) Recycling and reusing materials. This is in fact the only way a climate-positive sector can be established (Manshoven et al, 2019), and it furthermore holds the promise of new values for the sector and local jobs (Koehler et al, 2021).

> **"Our industry needs a strategy that can mobilize the industry to be at the forefront of current and future regulation from the EU and drive the competitiveness of the industry on sustainability and circularity internationally"**
> *Marie Busk, Head of CSR and Sustainability Head of CSR and Sustainability, Danish Fashion & Textiles Federation*

Danish strength positions, potentials and suggested roadmap initiatives within textiles

Denmark has a long history as an important textile industry, with more than 90% outsourced production during the 1990s. The Danish textiles sector is Denmark's fourth-largest export industry, with an annual turnover of DKK 46B and exports of DKK 31B (DM&T, 2020). The Danish textile and fashion industry employs 47,400 people and consists mainly of a few, large interior textile, fashion and carpet companies and business-led fashion brands, approx. 600 typically design-led SMEs and many small entrepreneurs (LDC, 2018).

> **"It's okay if it costs money. That is something we have decided as a society. We cannot be afraid of letting new fractions be expenditures. The crucial first step is to make good systems, that can drive the volumes up. History tells us, it will turn out being good business - either for availability of resources, economics or both"**
> *Ole Morten Petersen, CEO, DAKOFA*

The Danish government's decision to implement EU regulations on sorting of Danish textile waste early by 2022 (DK Government, 2020) represents both a huge challenge and an opportunity. Denmark face substantial challenges with textile waste at various levels: at the *upstream level* with regard to pre-sale waste, at *consumption level* with regard to over-consumption and limited service lives and at *downstream level* with regard to waste sorting and utilization that is positive for both the climate and the economy.

Firstly, at *upstream level*, 677 t of unsold textile products were discarded in 2020 (Pedersen et al, 2020), deadstock fabrics are estimated to amount to 10-20% of fabric production, and approximately one-third of new garments are never sold (Terkildsen, 2021). Resales and redesign business models are not explored at all although there are plentiful opportunities to use those "deadstock" or "low-value" stocks and turn them into new high-value products. Secondly, at *consumer level*, the annual Danish consumption of new textile products products is approx. 85 kt or 15 kg/capita (Watson et al, 2018) – in the EU it is 12.3 kg/capita (Koehler et al, 2021). Approx. 11% comes from public consumption (Watson et al, 2018). The environmental and climate effects associated with textiles are complicated, as textiles often consist of blended fibres of both natural and synthetic materials. The environmental and climate impact depends on the specific fibre type, the fibre origin and the manufacturing process. It is estimated that the production of 1 t of textiles causes on average climate effects corresponding to emissions of approx. 21 t of CO_2–eq. and consumes approx. 4.5 km^3 of water (Nielsen et al, 2014). In addition, many textiles will have carbon embedded in the materials that is emitted during incineration of the textile waste. The magnitude of the embedded carbon will depend on the type of textile in question. It is also estimated that the recycling process for 1 t of textile waste causes emissions corresponding to approx. 0.6 t of CO_2–eq. (assuming that recycling of textiles entails a global reduction of approx. 20.4 t of CO_2–eq. (Faraca et al, 2019)).

A third of Danes purchase new clothing at least once a month (ECAP, 2019). Danes report an average longevity of 4.4 years for their purchased T-shirts/short-sleeved tops compared to 2.7, 3.4 and 3.5 years in Italy, Netherlands and Germany respectively (ibid). Danes seem also to be more aware of more circular alternatives when purchasing new clothing. 13% of recent purchases were reported as being bought second-hand, while second-hand was considered in with a further 12% of purchases – in our neighbouring EU countries the figure is 5% (ibid). There is, however, a major need for a deeper understanding of consumer behaviour and for work on strategies to reduce consumption and shift to products with higher quality and durability which are therefore an investment, making repair, swapping and reselling more attractive.

Thirdly, at *downstream level*, 46% of new textile products purchased by households are donated to charitable and private collectors for reuse and recycling (Watson et al, 2018). Just over 10 kt of the 36 kt of separately collected textiles are recirculated to secondary users in Denmark. The remaining fraction is currently exported; of this, 70% is reused, 19% downcycled, and 11% landfilled or incinerated (Watson et al, 2018). Export prices of used textiles are dropping and will become a costly affair (DAKOFA, 2019). There is hence considerable interest in finding ways of recycling more collected textiles nationally. Currently, Denmark lags several years behind neighbouring countries such as Sweden, Germany, Finland and Holland when it comes to developing recycling plants and technologies (Watson et al, 2020). With the decision to install household collection and sorting of textiles, there is an opportunity to experiment and pilot innovation and technologies for collection, sorting and recycling plants and to get one step closer to closing the textile loop.

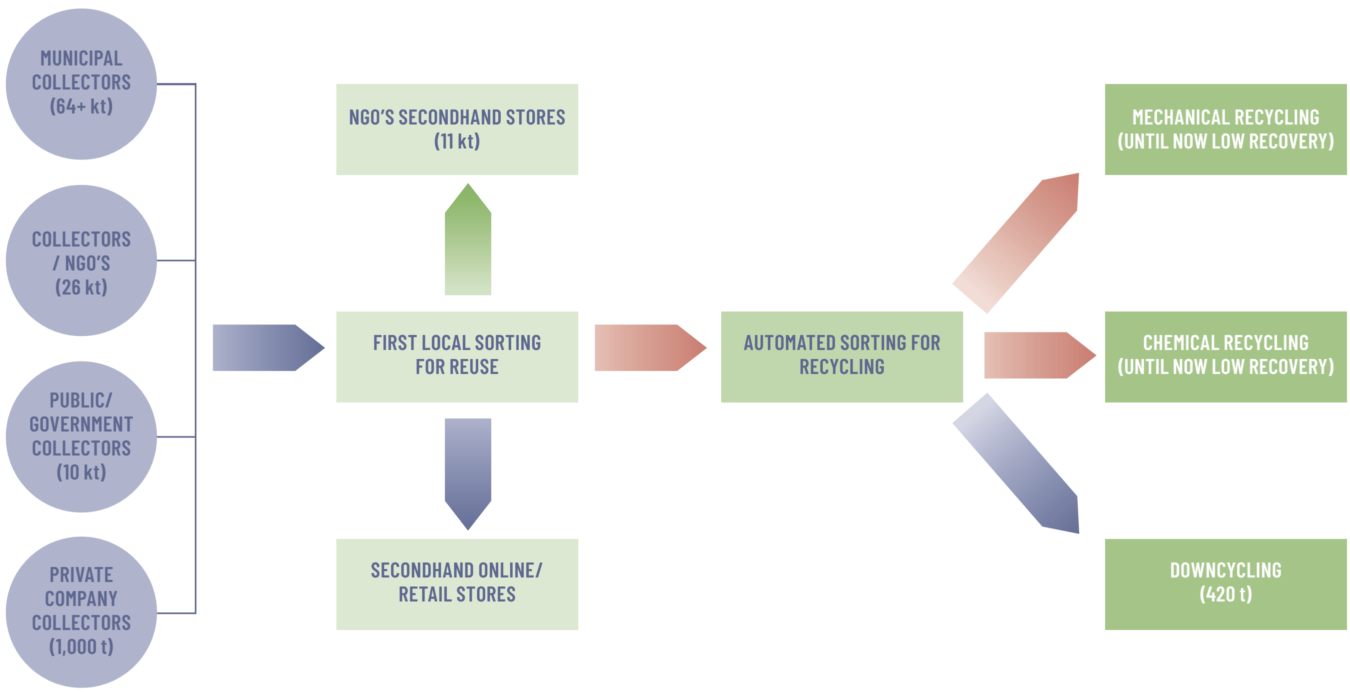


Figure 0: This figure represents estimated amounts of textiles waste in Denmark, and how they are currently handled and dispersed amongst stakeholders. Numbers are low estimates as there is little transparency, overview, estimates and coordination of waste fractions between municipalities, and between the public-private sector. The red arrows indicate areas where research and technology solutions are lacking but all entities marked with blue are currently underdeveloped. These issues are addressed under the suggested roadmap initiatives, particularly in the sections of systems and services and recovery (see figure 3 and textiles initiatives). Source: Danish Environment Proction Agency, 2018, Aabenraa Municipality.

> **There is a need to build research capacity within fashion & textiles.**
> *Thomas Klausen, CEO, Danish Fashion & Textiles Federation*

Even though CE business models are a growing niche, the concept is challenged on several parameters (Elander et al, 2017) such as the absence of reduced VAT on repairs and reuse, barriers to exporting and a lack of data on the use phase in general LCA methodological shortcomings, EPR for optimizing economic gains of CE BMs, and general policy-making on CE (Watson et al, 2017).

The Danish textile sector has the potential to become a key player in the coming transition work. This role is evidence of the fact that at this point in time there is a substantial lack of textile competence and knowhow left in Denmark amongst both consumers and industrialists – be that in relation to material processing facilities, manufacturers, retailers or repurposing initiatives. With typical SME- or entrepreneur-based companies forming the sector, it is not possible to regain this knowhow without close collaboration and knowledge-sharing. Our vision for utilizing the momentum for the sector is to rebuild a new, resilient sector on our proud heritage of collaborative BMs and knowledge-sharing across public-private schemes, coupled with investment in new sorting and recycling technologies, and democratic and user-led design strategies for circular production and consumption – and to build new local jobs through smart production and recovery. Utilizing these options, Denmark can obtain a benchmark position due to our small and agile business environment and world-famous design tradition for including all stakeholders: technology developers, users, industry, NGOs, public organizations and policy makers.

PLASTICS

The current situation and challenges for the Danish plastics sector

Plastics are invaluable materials in our daily lives and our economic activities. Strong, light, and innovative materials in wind turbines produce sustainable energy and cut GHG emissions, while light and functional materials in packaging reduce food waste. These are just two examples out of many. Hence, with their durability and versatility, plastics solve several important societal challenges. Since the 1960s the global production of plastics has increased twenty-fold to 368 Mt in 2019 (PlasticsEurope, 2020), and production is expected to double in the next 20 years (EU Commission, 2018). Denmark is currently using 750 kt of raw material annually for plastics alone. Total Danish plastics imports (including components and products) are 3.1 Mt annually, with the majority (2.5 Mt) being subsequently exported (Pivnenko et al., 2019).

The Danish plastics sector and adjacent industries that utilize plastics generate an annual turnover of DKK 25B, with exports of DKK 15B, and employ 26,000 people (approx. 1% of the Danish workforce) (Plastindustrien, 2018). The use of plastics is not limited to the plastics sector. Plastics as a material are used widely in the production industry, which employs approx. 300,000 people in Denmark and has an annual turnover of DKK 670B (Danmarks Statestik, 2012). In the Danish plastics waste management sector there is a blooming start-up and SME segment. However, these companies are challenged by high Danish labour costs and the low price of virgin plastic.

Figure 1 shows that the segment with the highest demand for plastics is packaging (PlasticsEurope, 2020). Here, single-use plastics, over-packaging and the poor quality of the recycled plastics from this waste stream highlight the major challenge facing plastics as a sustainable material: the prevailing linear approach to plastic consumption – produce, use, and discard. This leads to unmanaged plastic waste in the environment and substantial loss of resources. There is an urgent need for a paradigm shift that moves the invaluable plastics from the linear approach to a CE.

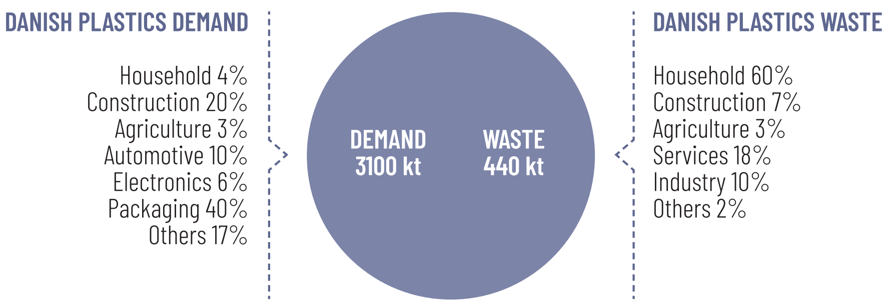


Figure 1: *Shows the demand for plastic in Denmark obtained by assuming EU distribution (PlasticsEurope, 2020). Overall Danish demand and Danish waste generation are based on Pivnenko et al., 2019.*

This is a multifarious and complex challenge that must involve addressing our current plastic waste (e.g. mixed household waste, future plastic waste such as composites from wind turbines, and the introduction of new materials such as bio-based materials) in the resource streams.

Plastics recycling in Denmark leaves a significant potential to be exploited. Today, around a quarter of the total Danish plastic waste is collected for recycling – 110 kt of the total 440 kt annual plastic waste (Pivnenko et.al., 2019).

Overall, Danish industry collects 40-45% of its plastic waste for recycling and Danish companies are at the forefront of minimizing and mechanically recycling production waste. Danish recycling rates for household-collected plastic waste are around 15% (IFD, 2019). Furthermore, Denmark exports approx. half of the plastic waste collected for recycling (Pivnenko et.al., 2019) in addition to the plastic waste exported in combustible waste. Overall Denmark exports 28% of the total waste (IFD, 2019). With overall Danish plastic recycling rates of approx. 25% (Pivnenko et.al., 2019), the potential for improvement is significant. Efficient plastic recycling can eliminate material leakage and ensure efficient use of current fossil-based resources. This is only one part of the picture – a picture which is completed by the transition to renewable feedstocks and long-term decoupling from fossil resources by means of renewable energy, feedstock from waste and renewable resources, and finally exploration of the future opportunities of carbon capture utilization, which will only have an effect after 2030.

Global plastic production and incineration of plastic waste is estimated to give rise to global emissions of approx. 400 Mt CO_2-eq. annually (EU Commission, 2018). For Denmark, incineration of waste plastics emits 1 Mt CO_2-eq. (direct emissions) every year; the use of recycled material holds an additional reduction potential of 0.5 Mt CO_2 -eq. (direct emissions) (Regeringens klimapartnerskab, 2020).

The Danish position of strength, potentials and suggested roadmap initiatives within plastics

To realize the potential of a CE for plastics in Denmark, the Danish positions of strength must be exploited. These positions are driven by the large flagship companies within in sectors such as the food, wind, and medical industries, the innovative start-up environment, a well-developed waste management sector and an internationally renowned knowledge environment. Combining these with the societal focus on sustainability and strong implementation of national incentive instruments, Denmark has a unique opportunity as an incubator for showcasing a CE for plastics.

> **"We believe the Nordic states are setting the scene for the future in Europe. Denmark in particular has frontrunning capabilities in process development, energy conversion and a leading target for waste re-utilization. The existing infrastructure and the stable economy and a positive future oriented mindset combine this and define Denmark as future key actor with global impact"**
> *Dr. René Backes, Business Development Specialist, BASF*

Implementing a CE for plastics in Denmark has the potential to save costs of approx. DKK 1.6B annually via the reduced use of virgin plastics (IFD, 2019). The reduced costs of using virgin material also have the potential to improve the competitiveness of the Danish production industry, in which 51% of production costs are attributed to material expenses (Advisory Board for CE, 2017). However, the price of recycled raw materials for plastics is currently at a level comparable to that of virgin raw materials. Furthermore, a CE for plastics has the potential to create value through innovation and export, for example by creating higher-income jobs in the recycling industry compared to those associated with the incineration of waste, by exporting new technologies and innovations in the areas of plastics recycling, and through new materials and product servicing (IFD, 2019).

Moving plastics from waste to a valuable resource has the potential to decrease CO_2 emissions from plastic in DK by up to 1.5 Mt CO_2-eq. (direct emissions) every year (Regeringens klimapartnerskab, 2020). Furthermore, increased use of recycled plastics can reduce dependence on fossil fuels for plastic production.

A holistic approach to plastics for a product life cycle based on a scientific framework is needed to realize a CE for plastics. To achieve this, R&D needs have been identified across sectors and the entire value chain. These R&D needs have been gathered in the initiative themes of this roadmap covering Materials, Design & Production, Systems & Services and Recovery. In summary the R&D needs point to the indisputable necessities to:

- Develop and exploit current and novel plastics that promote and facilitate longer product service lives, improved reuse and repair, efficient high-quality recycling, and not least the transition to renewable and sustainable raw materials
- Design plastic-containing products for long service lives and highly efficient recycling whilst being efficiently produced from circular materials
- Transform the metabolisms of the public and private sectors, reform legislation and regulation, inform and empower consumers and apply advanced CE initiative performance assessment in relation to CE decision making.
- Innovate advanced sorting and recycling technologies to retrieve maximum value from plastics at end-of-service.

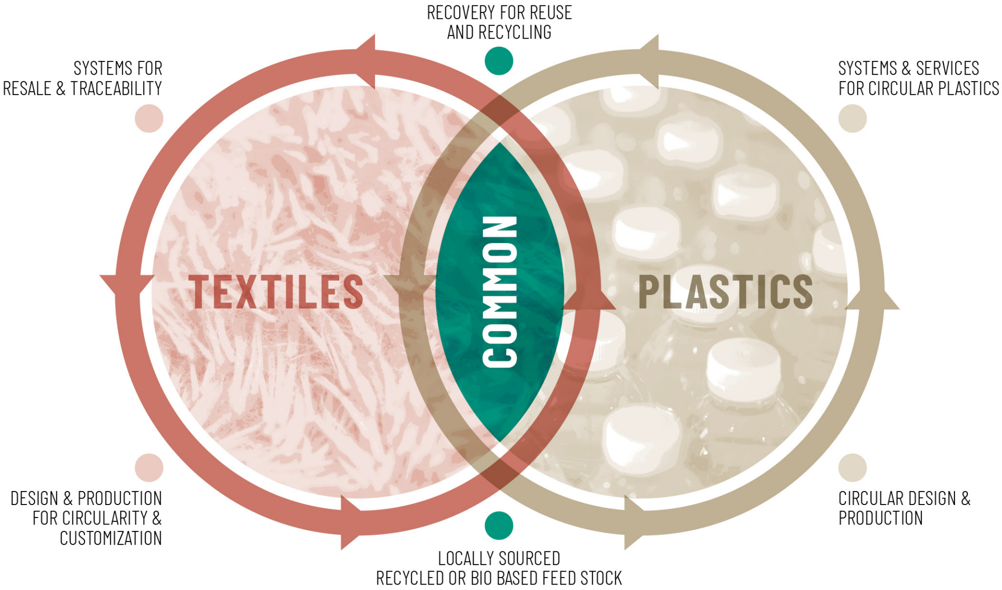


Figure 2: *Illustration of specific themes and common overlaps within the circular economy for plastics and textiles.*

VISION, GOALS, MILESTONES AND SCOPE

Vision

Denmark has by 2050 become a renowned and leading benchmark country in relation to how to develop, drive, and thrive on CE. This is due to the small-scale, entrepreneurial and agile character of both the national and business environments and a well-functioning welfare society with good public-private collaboration and trust. The Danish model of free education and equal opportunities for all have contributed to that and the Danes understand their role as circular consumers. Resource optimization has been enshrined in all parts of the value chains for both plastics and textiles. As a renowned design nation with a proud heritage of resolving great challenges together, Denmark has shown the world that circularity is an exciting paradigm for new and innovative ways of materials extraction and processing, production in consumer dialogue, value creation, design and technology solutions, making CE BMs attractive, convenient and customary. All of this is being studied as best practice and has led to Danish export of products, services and knowhow. However, what attracts most international attention is the Danes' ability to collaborate across the full value chain with clever systemic thinking. Thus, the given initiatives are carefully intertwined and cannot deliver without careful connections between materials, design and production, systems and services, and recovery.

> **"It is important with synergies and learnings across industries – some of our materials are polymer based so there is a great overlap, and we need solutions across materials science"**
> *Dorte Rye Olsen, Head of Sustainability, Bestseller*

In the ideal world - a circular economy to strive for

Denmark is the leading example of a fully circular society in which resource consumption has reached a sustainable level. Resource efficiency in society has increased dramatically to ensure that value creation, economic growth and fulfilment of societal demands are decoupled from resource consumption. Products are designed to have long service lives and to be repairable, materials are used in closed loops and are functionally recycled afterwards. Danish consumers understand their role in the circular economy and have radically changed their consumption patterns. Danish authorities enable sustainable production and consumption by ensuring appropriate incentives, based on a holistic and coordinated approach. The public sector contributes to driving innovation by facilitating development of new green solutions making Denmark a frontrunner in sustainable development, in close collaboration with industry and civil society. Danish products and materials do not contain harmful substances and do not generate environmental impacts on production, use and end-of-service recovery and management. Raw material supply in industry is sustainable and utilizes local resources as much as possible. Danish industry and companies take pride in ensuring that residual and anthropogenic resources are utilized rather than lost. As a society, we base our continuous sustainability improvements on data and informed decision-making.

The starting point for the transformation to a circular economy

Danish resource consumption is significantly higher than what can be considered a sustainable level. Today, resource supply and product manufacturing are "disconnected" from consumers in regional or global value chains with little to no transparency. Raw material costs are too low compared with labour costs to warrant high-quality recovery and recycling of resources. Societal welfare is too linked to continuous economic growth. Consumer happiness is often linked to a fast turnover of goods and products. Circular business models exist, but merely as niche markets with little incentive to grow.

Products are not designed for recyclability, or even prolonged service lives or repairability. The market demand for circular products is insignificant, and even companies that acknowledge the circular challenges often end up maintaining their current BMs with a few modifications to their products. Industry lacks insight and support for strategic decisions to transform products and production towards a circular economy. At societal level, we lack the ability to understand the complex circular value chains and associated mechanisms needed to harvest the environmental, economic and social potential of the circular economy. While we have a wide range of strong industrial and commercial positions, the primary enabler for a leading role within a circular economy is the strong cohesion and trust within Danish society. This provides enormous potential for a circular transition with Denmark as a living lab. There is a high level of trust between societal actors such as authorities and industry, which provides the basis for further utilizing the potential in private-public partnerships, in particular facilitating innovation within the SME landscape.

> **"We are experiencing an increase in demand for sustainable products and it is important for us to have access to steady supply of recyclable plastic packaging of high quality – something we can't get today"**
> *Nikolaj Haulik, Chief Innovation Officer, Nopa Nordic A/S*

The transformation

For DK to move from starting point to vision, this roadmap contains concrete suggestions for research, industry ventures, public-private schemes, technology and necessary education. As a shared starting point, all of these initiatives point towards refinement of production processes to reduce virgin material use (including materials), and implementation of innovative pathways for prolonging use spans of resources, closing the loop for leaks, and capturing full value at environmental, social and economic level.
There are several obvious synergy areas, particularly with regard to materials innovation and recovery. However, there are challenges that are specific to plastics and textiles due to the different material flows, and learning from each other is a proven innovation driver with mutual learning opportunities. Four common key objectives for the transformation have been defined:

Objective 1: Reuse and recycling of all plastics and textiles

Minimization of resource losses further requires that all materials are recycled as efficiently as possible. All plastic and textile products need to be designed and manufactured to ensure full circularity and recyclability. Systems, regulation and market incentives need to support recycling proactively at all steps throughout the value chains. Consumers should favour circular products involving long service lives, repairability, high quality and recyclability.

Objective 2: Recover at the highest possible level

Reuse, repairability, and functional recycling of products, product components and materials requires effective recovery systems and technologies. Recovery and recycling loops should be as short as possible, and materials should be routed to the recovery options that ensure further utilization at the highest possible level of reuse and recycling. Material selection and product design should adjust dynamically towards increasingly circular recovery options and systems.

Objective 3: Decoupling of resource consumption

Consumption has to be reduced at least four-fold to be considered sustainable in absolute terms. This must be achieved through reduction in consumption and a decoupling of resources used in industrial production and provision of societal services from societal growth. This involves a dramatic increase in terms of resource efficiency, in particular within production and manufacturing but also with respect to consumption patterns. Value creation needs to be absolutely decoupled from resource consumption, and the utilization rate of products and infrastructure maximized. Furthermore, reductions in unnecessary consumption of resources are a must.

Objective 4: No surplus production

Waste generation in society and industry needs to be dramatically reduced to minimize the load on resources and the environment. This involves optimization of production processes and avoidance of material loss within industry while also ensuring manufacture of the products that are actually needed by consumers and in society, and ensuring that these products are of good quality, have long service lives and are repairable and recyclable. The focus is on preventing waste generation throughout the entire value chain of products and production.

CATALOGUE OF POTENTIAL ROADMAP INITIATIVES

Several initiatives are suggested covering a variety of topics along the entire value chain. An overview of the initiatives is given in Figure 3, which also highlights significant overlaps between plastics and textiles. The following section introduces the initiatives from the point of view of plastics and textiles respectively. All common initiatives are included in the following plastics and textiles initiatives and only highlighted in Figure 3.

	MATERIALS	DESIGN & PRODUCTION	SYSTEMS & SERVICES	RECOVERY
PLASTICS	**01** Enhance plastics circularity **02** Maintain highest plastics quality (e.g. food-grade) **03** Develop plastics based on bio- resources **04** Enhance bio- plastics properties **05** Research in plastics with novel or enhanced properties	**06** Sustainable design and production within circular economy **07** Develop life cycle assess-ment models for evalua-tion of circular initiatives **08** Inclusion of more recycled materials in production **09** Use digitalization and automation for obtaining CE and CO_2 reduction	**10** Quantitative ranking of plastics based CE initiatives **11** Adjustment of regulation, incentives and public-private interface enabling more plastics recycling enabling reduced plastic consumption and more recycling.	**12** Enhance mechanical recycling for polymer recovery **13** Research in biological, catalytically, and thermal processing for monomer and oil recovery
COMMON	**14** Ensure local recycled or bio-based feedstock for plastics and textiles.	**15** Design and production optimization **16** Adaptation of sustainable materials in production	**17** Citizen's role in the transition to plastics and textile CE **18** Develop knowledge-sharing, take-back, take-further systems in private and public sectors **19** Tracking and qualification of recycled materials	**20** Research in identification, documentation, and sorting **21** Research in mechanical recycling **22** Research in chemical recycling
TEXTILES	**23** Local feedstock and processing of textiles (bast and bio-based) **24** Carbon-capture based materials	**25** User-led design devel-opment **26** Circular design and production strategies **27** Local production and product development	**28** Develop CE BMS for secondary market **29** Tracking + design analysis in use phase **30** Take-back/take-futher in public-private schemes	**31** User & tech driven collection and sorting systems **32** Design- and process technologies for material recovery
OBJECTIVES	REUSE AND RECYCLING OF ALL PLASTICS AND TEXTILE RECOVERY AT THE HIGHEST POSSIBLE LEVEL DECOUPLING OF RESOURCE CONSUMPTION NO SURPLUS PRODUCTION			

Figure 3: *Illustration of core initiatives for the individual tracks and identification of overlaps.*

"We need initiatives that secure a consistent and predictable quality in recycled materials. Both to support the recycling companies and all downstream activities"
Thomas Drustrup, CEO, Danish Plastics Federation

PLASTIC INITIATIVES

Materials

(01, 02, 03, 04, 05, 14 in Figure 3)

There is a need to source materials for plastics from sustainable sources. A scalable solution for substituting virgin fossil-based plastics is increasing the utilization of current recycled plastics. However, bio-based and novel materials, designed for functionality and sustainability, will offer unique opportunities in a range of applications. Upon substitution fossil-based plastics with e.g. a recycled or bio-based plastics, it is important to ensure end-of-service recyclability, manufacturability and performance of the material thus ensuring material transfer to the next product cycle.

Recycled materials

Challenge: Maintain and/or improve plastics properties during use and recycling

As no company can accept poor properties or premature failure of their products due to use of recycled plastics, the challenge is to ensure pure materials with known properties and upgrade recycled materials when feasible.

Initiatives

There is a need for a material certification system, models to predict behaviour, material characterization, methods to upgrade and validate recycled materials so they are trustworthy candidates for new high-value products. This could e.g. be applied to cross-sector collection of specific materials in large volumes (e.g. food packaging), or by industry using its own products by implementing a take-back system. Using recycled materials in new products calls for R&D and in particular a need to minimize costly tests; low-cost methods capable of accurately predicting material long-term properties are therefore key areas.

Technological/Social readiness level

Short-term: high quality recycled materials for products, take back (TRL 4-9)

Medium-term: use recycled materials from upcoming waste streams (e.g. composites) (TRL 3-6)

Bio-based & new plastic materials

Challenge: Develop bio-based and smart plastic materials while ensuring industrial scalability

Producing sufficient bio-based plastics at necessary tonnage from sustainable bio-based resources, ensuring necessary plastic properties of bio-based alternatives and ensuring future recyclability while at the same time not competing with food production for land are the main challenges for bio-based plastics. The challenge of improving the service life of a product, reducing material consumption, easing repair, and ensuring efficient recycling could be answered by developing new smart plastic materials.

"Too little focus on bio-based plastics; this could be relevant to substituting single-use outbound plastic packaging for Danfoss"
Nanna Lundsgaard, Global Head of RAC Engineering Danfoss Climate Solutions

Initiatives

For bio-based alternatives, new processing technologies for bio-based fibre materials, and new technologies, e.g. plasma coating, for functionalizing bio-based materials, are needed. For known plastics with partial biological origin, e.g. bio-PET, development within methods to produce these polymers from a fully biological origin is needed. Furthermore, ways of producing common polymers and ways of producing novel polymers utilizing bio-resources more efficiently are needed.

Development of polymers to improve service life (e.g. by self-healing), polymers that enable use of less material (e.g. by increasing strength or improving barrier properties), and plastic materials that ease repair and recycling (e.g. by responding to external stimuli for controlled disassembly) are needed. In addition to being able to improve the circularity of a plastic material, these polymers could originate from a broad set of bio-based raw materials. Development of new mono-materials with high functionality e.g. with an emphasis on migration related to food safety.

Technological/Social readiness level
Medium term: bio-based polymers in specific applications (TRL 2-6), mono-materials with high functionality (TRL 3-6).
Long term: depolymerization techniques in selected applications (TRL 2-3), integrated production of bio-based polymers from residual resources (TRL 2-5).

Expected impact
Substituting with recycled materials: 50-60% by 2030.
Substituting with recycled, bio and new sustainable alternatives: 40% by 2050.

Design and production
(06, 07, 08, 09, 15, 16 in Figure 3)
Challenges
Design and production play a key role in sustainable resource consumption. Today, product development and design focus primarily on performance and functionality (e.g. barrier properties, appearances, texture) rather than repair and recycling. Material selection and specification and design choices are often not made from a circularity perspective as industry lacks the tools to make sustainable and circular choices in relation to design and production systems. Several new products fail when introduced to the market, resulting in large quantities of non-marketable stock being embedded in the supply chain. Current production systems are designed for low variability and a stable supply of homogenous raw materials. This strategy restricts integration of reused parts and recycled materials. New production systems should support gradual scale-up and be capable of handling larger raw material variability (e.g. enabled by automation and system interoperability).

"We need to design products not only for high performance but also for circularity – for this we need initiatives across sectors"
Peter Rønbøg, Director Engineering and R&D, Logster

Dedicated decision-support tools based on life cycle assessment (LCA) methodologies are needed for guidance of design and material choices, to ensure a holistic view of the full design and production process chain. Today, data on materials, production and product fates across the value chain are under-utilized in the reuse, sharing and recycling of materials in production. As a result, industry is not able to substantiate investment, design, and production changes from a sustainability perspective.

Initiatives
Product design enabling circular economy involves a range of core elements: i) Appropriate models for sustainable product and production innovation supporting the circular use of resources, ii) Informed decisions about critical product aspects (e.g. service life, functionality, repairability, recyclability as well as climate and environmental performance in a full life cycle perspective), iii) Configurable production systems, iv) Interoperability across design, production and materials platforms, v) Relevant material choices and specifications and integration with production platforms, and vi) Implementation of efficient repair and recycling schemes.

Integrated research across a wide range of fields is necessary: i) Implementation of recyclable plastic materials in products and production platforms, ii) Establishment of appropriate indicators supporting circular and sustainable design, and iii) Enabling clarity with regard to take-back/repair/recycling options, i.e. reflecting the entire life cycle of the products. For industry to implement these elements into products, markets and value chains, support systems and enabling technologies need further development across the value chain, e.g. digitalization, material flow transparency, automation, design tools etc.

Circular design and production platforms: Develop industrial processes supporting sustainable and circular product/production designs to enable low waste, long service-life, repairability, reuse and recycling at the highest possible level. Develop circular production systems with the ability to accept recycled materials, higher material variability, and robust production approaches.

Closed-loop and high-value production: Develop technology platforms that can adopt circular waste streams and thereby reduce production waste. Evaluate and implement emerging recycled material in production and design technologies. Introduce circular packaging and transport platforms (e.g. bottles and beer crates).

Data-driven decision tools: Develop LCA-founded decision models and implement tools enabling industry to produce sustainable products in a CE framework. Develop performance assessments of products which enable informed choices of materials, product design, and full product life-cycle impacts.

Technological/Social readiness level
Short term: circular design and production that minimize waste generation throughout the product life cycle (TRL 5-7).
Medium term: integration of new materials (recycled/bio/new properties) in design and production platforms (TRL 4-7).
Long term: quantitative integration of LCA throughout the circular value chain enabling material, design and production optimalization (TRL 4-7).

Expected impact

Enabling design and production capabilities for including recycled and emerging material streams by 2030.
Designing out waste giving a resource productivity increase of 20%; weight reduction of 20%, service-life extension 10%.
Reducing GHG emissions by 10-20% in 2030 and by 50% in 2050.

Systems and services

(10, 11, 17, 18, 19 in Figure 3)

In Denmark, the major stakeholders in the plastic roadmap playing key roles in the transition to a circular society are the public sector, industry and the general public. Both in terms of consumption as well as formulating the legislative frameworks motivating the private sector to undergo similar changes. Subject to regulation, the industry aligns with the legislative intentions while prioritizing the sector's own specific needs and preferences.

> **"Danfoss customers are increasingly requesting data on CO_2 footprint and complete material content for products; further development of standards is needed"**
> *Nanna Lundsgaard, Global Head of RAC Engineering, Danfoss Climate Solutions*

Challenges

CE-oriented research is needed within the public sector with research and experiments on novel regulations, public-private interfaces as well as research focusing on understanding the public sector as a key consumer. The public sector has a special role in terms of consumption, as policy aims can be a driver for consumption and procurement and thus facilitate development that might not be economically feasible.

Within the industry sector, generally applicable and economically viable CE BM/systems/technologies need to be developed and demonstrated. To motivate innovative/improved industrial sector-specific CE development, the establishment and demonstration of profitable circular industry systems and BMs is of paramount importance.

Citizens are also regulated by the public sector and behave according to their individual preferences, information and situation. Effectively engaging citizens in the CE transition necessitates understanding of how information/empowerment affects citizens' behaviour. Impacting citizens' consumption patterns while empowering them CE-wise is challenging but can be achieved through novel research frameworks such as citizen science and thus linking citizen preferences directly with consumption-regulating initiatives.

Quantitative decision support capable of forecasting the climate and environmental potential of initiatives aimed at the industrial and public sectors and at citizens is key to prioritizing the most effective CE initiatives and maintaining momentum. However, this has not yet been developed. Methodologies such as LCA and input-out (IO) analysis are currently static and/or based on retrospective data. Hence ensuring effective CE transition support requires further development of the methodologies, enabling them to provide prospective assessments of CE initiatives through further methodological development incorporating e.g. scenario or equilibrium concepts from related disciplines.

Initiatives

Citizens' role in the transition towards a circular plastic economy: There is a need for research into how citizens' behaviour affects the design, distribution, consumption and disposal of plastics. We need to know how citizens can make more informed decisions when buying, using and disposing of plastic products and to what extent changes in behaviour facilitate transition towards a CE. This could be facilitated through inclusive citizen science projects. Research in behaviour could include e.g. research into citizens' willingness and capabilities to sort plastic waste, effects on consumption of information and shopping/consumption context, and studies enabling citizens to reduce consumption of plastics.

The public sector as a driver of circular transition: The public sector has a dual role in the circular transition as a consumer and as the biggest employer in Denmark. The public sector is a major consumer, which gives green public procurement a unique possibility to drive innovation within the plastics market, not least when the current gains from a market perspective are limited. Reducing consumption within the public sector also has the potential to contribute significantly to climate and other environmental goals. Finally, the public sector is the largest Danish employer and as such has great potential for informing and educating citizens with regard to more sustainable plastics consumption in private households. There is hence a need for research into how the public sector can most effectively be transformed to embrace CE and how the public sector can accelerate the CE transition of the rest of society.

Getting regulation and incentives right for the circular economy: Research is needed to inform how regulations and incentives can be set optimally: how fiscal instruments (e.g. environmental taxes, subsidies) and standards (e.g. ERP) can enhance incentives for reduced resource use, recycling and reuse, how such measures can underpin sustainable BM's and spur innovation along the value chains, including both industry processes and consumer behaviour, and how regulatory standards can enhance the basis for sustainable finance in the CE.

Quantitative decision support on the climate and environmental performance of CE initiatives: Prospective evaluation of CE initiatives must be based on valid and transparent quantitative estimation of climate and environmental performance. This necessitates prediction of how the initiatives will interact with the surrounding society (e.g. via energy, waste flows, and markets), how society will develop and how societal development will affect the societal/CE-initiative interactions. These complex aspects need to be taken into account, since the interactions between a CE initiative and the surrounding society will determine the climate and environmental performance of the CE initiative in focus. The prevailing climate and environmental performance assessment methodologies (e.g. LCA and IO) need to be further developed, e.g. drawing on scenario and equilibrium concepts. Furthermore, industry needs to learn to commercially utilize and interact with these advanced assessment methodologies.

Technological/Social readiness level
Short term: transforming the public sector (SRL 5-7), circular legislation that minimizes waste generation throughout product life cycles (SRL 4-6), involving citizens (SRL 5-8), prospective quantitative decision support (TRL 3-4).
Medium term: transforming the public sector (SRL 7-8), circular legislation that minimizes waste generation throughout product life cycles (SRL 7-8), involving citizens (SRL 6-9), prospective quantitative decision support (TRL 5-7).
Long term: transforming the public sector (SRL 8-9), circular legislation that minimizes waste generation throughout product life cycles (SRL 8-9), involving citizens (SRL 7-9), prospective quantitative decision support (TRL 8-9).

Expected impact

The initiatives presented in systems and services provide impacts in complex interaction with other initiatives, including in relation to reducing GHG emissions, environmental protection and job creation, and thus have significant impacts in combination with the other initiatives.

Recovery

(12, 13, 20, 21, 22 in Figure 3)

This section covers the initiatives that can be employed at the recovery level to enable a circular economy. Inevitably a plastic product will become waste and can then be converted to a material resource for other products. To preserve plastics at the highest possible value level in the waste hierarchy, mechanical recycling is preferred over chemical recycling. However, usage and mechanical recycling will degrade the materials and chemical recycling becomes a necessary step. Hence, interplay among the recycling steps must be developed to realize improved and high-value recycling.

> **"Intensive research and development in detection of plastics contaminants is central for increased plastics recycling"**
> *Hans Axel Kristensen, CEO, Plastix*

Sorting
Challenge: Separate material and post-process critical contaminants. Contamination of plastics suited for recycling could occur via multi-material/composite products, pigments, additives, labels, food residues, etc. The challenges within sorting are to out-sort material and post-process (mechanical or chemical) critical contaminants.

Initiatives
Addressing material identification with sufficient detection limits and processing speed for systems capable of identifying material and product types in waste streams is required. Here, R&D of advanced sensor technology including detectors and algorithms allowing plastics and products to be differentiated based on e.g. chemical composition (and contamination), colour, shape, and emerging tracer systems. This should be combined with R&D in automation and robot-technology to perform the physical sorting of plastic.

Technological/Social readiness level
Short term: Initiatives focused on detection (TRL3-6) and automation (TRL6-8).

Mechanical recycling for polymer recovery
Challenge: Preserve material value.
High-value utilization, minimization of plastics downgrading, and pre-/post-treatment to enable more diverse plastics fractions to be recycled. In addition, mechanical recycling facilities are today highly specialized on a specific product group (e.g. textiles, nets/fibres, foils, EPS, etc.). As little recycling is done today, the number of cycles plastics can undergo before they have inferior properties is unknown.

> **"Recycled plastic should always be in a quality grade that makes it possible to recycle over and over again and it is important to continue this journey through innovation to be even more sustainable in the future way of production"**
> *Gitte Buk Larsen, Chairman/Owner, Aage Vestergaard Larsen*

Initiatives

Minimization or "repair" of degraded polymers (synthetic and biological) during recycling is necessary. The properties can be partly restored through advanced pre-treatment (e.g. extraction), additives, reactive processing, filtering, and chemical chasers. To preserve high plastics and fibre quality during the mechanical recycling processes, R&D targeting these areas is needed, e.g. via method and production optimization, novel additives, and/or novel methods for repolymerizing the thermoplastics, analysis and documentation of plastics. All these areas are not available today.

Technological/Social readiness level

Medium term: initiatives focused on minimizing polymer degradation during extrusion (TRL 5-7).
Long term: initiatives focused on advanced pre-treatment and repolymerization (TRL 2-5).

Chemical and biological recycling for monomer and oil recovery

Challenge: Expand current and develop new technology to recycle waste fractions not recycled today.
Expand current and develop novel technologies to recycle plastics not recyclable today. The challenges within chemical and biological recycling (e.g. solvolysis, catalytically, enzymatically, pyrolysis, HTL) are the plastics complexity and contaminants. Pyrolysis and HTL have a common challenge of varying oil compositions dependent on feedstock requiring expansion of the refinery infrastructure. No process fits all plastic materials and R&D of a variety of chemical and biological recycling processes is necessary.

Initiatives

To recycle plastic and textile waste currently not recycled and recycle plastics waste from mechanical recycling requires tight interplay between a variety of thermal, chemical, catalytically, and enzymatically recycling technologies which need development. Carbon recovery in the form of oil, chemicals or monomers can be obtained from plastics waste – the latter presenting a higher waste hierarchy level. R&D in technologies enabling recovery from highly contaminated thermoplastics, mixed plastics and biomass, thermosets and composites is needed. Challenging plastic waste fractions should be processed for oil recovery by pyrolysis and/or HTL.

Technological/Social readiness level

Short term: initiatives focused on oil recovery (TRL 6-9).
Long term: initiatives focused on monomer recovery (TRL 2-6).

Expected impact

Recycle 42% of currently incinerated plastic waste by 2030.
Reduce direct GHG emissions in Denmark by 360 kt CO_2-eq from increased recycling within households (e.g. plastic packaging) and industrial waste (e.g. production, construction and agriculture) by 2050.

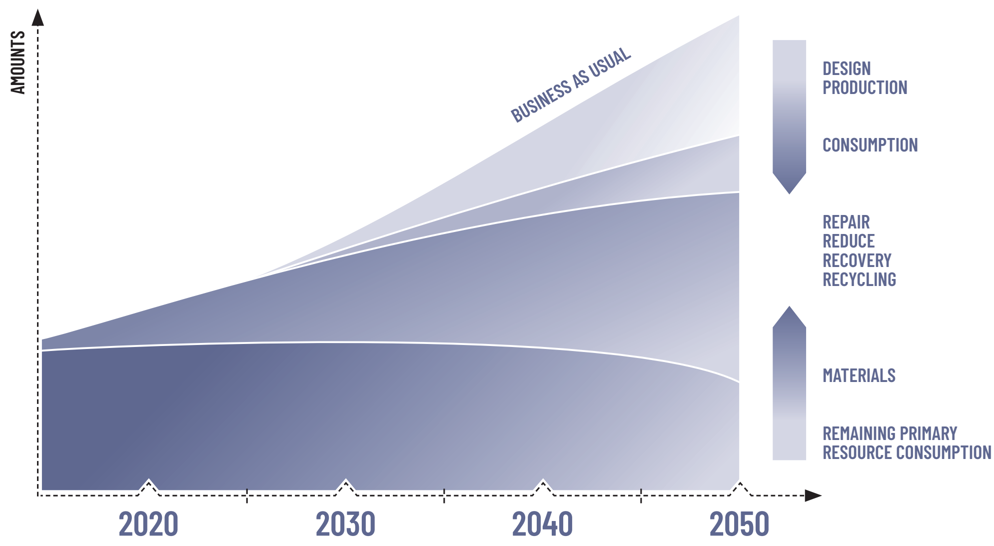


Figure 4: *Scenario-based illustration of how textile and plastic consumption may evolve until 2050 depending on mitigation measures implemented.*

TEXTILES INITIATIVES

Materials

(23,34,14,16 in Figure 3)

This section covers initiatives for climate-reductive fibre cultivation and processing, with a particular focus on bio-based feedstocks, carbon capture effects, and reshoring of industry to Denmark. To ensure climate-positive effects, a massive reduction of new production is needed, and services needs to be introduced to maintain fibres in more long-lasting loops (see design and production, systems and services, and recovery). There is some flax production in the EU, but not in Denmark. Increasing hemp production is taking place in the EU and in Denmark but only limited amounts for textile fibre end use. Most hemp textiles on the EU market are based on Chinese feedstock. By now, more initiatives have started developing value chains for textile hemp from cultivation up to the final fabric stage. There is limited EU production of bio-based fibres, manly PLA, but increasing investment in R&D and pilot productions also in Denmark.

Challenge

Since fibre production and processing accounts for roughly 20-25% of global GHG emissions of textiles production (JRC, 2014), it is worth looking for lower-impact alternatives with fibre qualities suitable for production of yarns and fabrics, in qualities comparable to synthetic fibres and cotton. Globally, the textiles and fashion industry consumes an estimated 79 billion m^3 of fresh water annually (WRAP, 2017). The growing and production of cotton consumes the greatest quantity of water. The production of synthetic fibres is estimated to use 342 M barrels of oil every year (EMF, 2017) The production of cotton accounts for 69% of the water footprint of fibre production for textiles and it is estimated 29 m^3 of irrigated water are required to grow 1 kg of cotton in most cotton areas (SEI, 2005). Cotton production requires 200 kt of pesticides, equal to 16% of world use, and 8 Mt of fertilizers annually (WRAP, 2017). The GHG emissions of synthetic fibres are 20-30% higher than those of natural fibres (JRC, 2014).

Initiatives: Local feedstock and processing of textiles (bast and bio-based)/carbon capture-based materials

1) Research into possible technologies suitable for high-purity polymer synthesis suitable for fibre production (1-3 years). 2) Establishing a knowledge base for quality validation of bast fibres and bio-based polymers usable for textile fibre production (virgin and recycled). 3) Establishment of labs and R&D environments for testing and validation of feedstock materials (1-4 years). 4) Establishment of customer demand through environmental/eco-design labelling and certification of new materials that highlights inherent qualities related to local production, longevity, recyclability, low environmental footprint calculated for the whole value chain (2-5 years). 5). Develop lab-scale HTL technologies for textiles (2-5 years). 6) Develop a Danish feedstock for bast fibres, hemp (next step flax and nettle) from cultivation to fibre extraction. (3-5 years). 7) Develop a Danish value chain for bast fibre processing, spinning of fibres into yarn, fabric production and finishing. 8) Establish a demo plant to optimize technologies to enable reshoring of part of the outsourced production value chain (5-8 years). 9) Growing cultivation of bast crops for textile fibres and reshoring part of the textile value chain, thereby establishing new companies and creating jobs (5-10 years). 10) Develop a Danish feedstock for bio-based fibres based on side streams from agriculture and food production. 11) Develop bio-refining technologies to purify bio-polymers usable for textile e.g. MMCF fibre production (5-10 years). 12) Pilot plants to develop a Danish value chain for bio-based fibres, including spinning of fibres into yarn (5-10 years). 13) Establishing an industry around production of bio-based polymers for textile fibres and reshoring part of the textile value chain, thereby establishing new companies and creating jobs (5-15 years). 14) Bridging knowledge to other sectors looking into possibilities to use new technologies such as power-to-X as a technology for establishing a sustainable feedstock for chemistry and polymers (5-10 years).

Technological/Social readiness level

Short term: lab-scale HTL technologies for textiles (TRL 3-6), Danish feedstock from cultivation to extraction (TRL 4-7).
Medium term: demo plant for reshoring parts of outsourced production (TRL 7-9), develop bio-refining technologies to purify bio polymers (TRL 4-7), pilot plants for bio-based fibre processing for yarn (TRL 5-8).
Long term: reshoring Danish industry around production and job creation (TRL/SRL 7-9).

Expected impact

1000+ jobs in fibre and yarn cultivation, extraction and processing, 10% of all Danish textiles are produced with Danish bio-based fibres by 2030.
A fossil-free textile sector by 2050.

Design and production

(25, 26, 27, 15, 16, 17 in Figure 3)

This section covers initiatives for establishing Denmark as a global benchmark for how to design for multiple inner loop product lives through resale, repair and redesign and for supporting less consumption of resources, increasing the lifespan of products and reducing waste. These initiatives are imperative for changing to a circular textiles industry by increasing and developing knowhow through scaling targeted, new design strategies, user-led and flexible production that is close-to-market, agile and adaptive. Denmark has a very strong tradition of democratic design that can be revisited through building much more resilient production strategies built on actual consumer needs rather than standard fashion logics that build on idealized customers. Such strategies could help Denmark reach both national and international niche markets such as e.g. the modest fashion market of Muslim global populations estimated to reach $402B by 2024 (Lewis, 2020), the plus-size market estimated to reach $697B by 2027 (Allied Market research 2020), or 50+ consumers estimated to reach $15B over the next decades (Bloom, 2019). This is currently hindered by the fact that there is very little research on how textile products perform and create value in the use phase, why companies have lost contact with their actual costumers (Wiedemann et al, 2020). It also means that current production and development strategies are in the dark in terms of new ways for value creation on the secondary market. This is fuelled by linear and far-from-market production that is not compatible with nor flexible in response to actual market needs. To ensure that the suggested initiatives have actual impact and stimulate CE, they need to be combined with better fibres for circularity (see materials), with adjusted value propositions for CE BMs (see systems and services), and for improving technologies for recovery and design for repurposing (see recovery).

> **"The fashion and textiles industry needs more engineers and technical material specialists. If we are to achieve the transition, we must bring together a mix of talent including, clever minds who can go into the important details when it comes to materials science"**
> *Dorte Rye Olsen, Head of Sustainability, Bestseller*

Challenge

Linear thinking has created the perception of customers as a bottleneck in the green transition (GFA, 2019), but it might be the sector itself that is overproducing without investigating who their customers really are and what they need. A 75% reduction in new products is needed to reach climate goals (Fletcher et al, 2019). The use phase has decreased by 36% compared to 15 years ago. (EMF, 2017), but a UK study shows that extending the use of T-shirts by 10% would yield emission savings of approx. 100 kt of CO_2-eq and 2 kt of textile waste per annuum in the UK alone (WRAP, 2012).

> **"One of the large challenges are to separate the different components for reuse"**
> *John Vestergaard, CEO, Ege Carpets*

Textile competences and knowhow have been drained from industry, education and consumers, leading to underdeveloped products and approximately 60% returns in Denmark alone (DFIH, 2019), and the amounts of deadstock being incinerated or landfilled are unknown, with a first estimate of 677 t/year in Denmark alone (Tænk, 2020). Actual figures for deadstock/returned textiles may be higher. A study in the Netherlands (Wijnia 2016) found that 31% of clothing is sold at a reduced price via various outlets, while 4.2% of clothing placed on the market is unsold. The same rate in Denmark would give approx. 3 kt of unsold textiles, of which an unknown share would be incinerated without ever being used. In 2016 Ecotextile News reported that only a third of all imported clothing in the EU is sold at the full retail price, a third is sold at a discounted price and a third is not sold at all.

Moreover, couriers typically use heavily polluting vans to collect returns. A courier emits 181g of CO_2–eq. when making returns (Edwards et al., 2009), but that is assuming a 100% success rate with courier collections, which is far from the case. Looking at three studies on failed deliveries, if we take the median - a 12% failure rate (Logate, 2018) - the total emissions increase from 181g to 203g CO_2. In terms of production, Covid-19 has escalated poor resource optimization and the textile sector is more vulnerable with no incentive to innovate and take responsibility because companies do not possess their own fabrication facilities and time to market is 1-2 years. Long lead times hinder fast feedback from market to the brands and cause overstocking, difficult sale estimates and low flexibility. Long lead time in re-orders and possible delay in delivery time cause increasing amounts to be shipped through air cargo to save time, and the same challenge is the case with online shopping. Large inflexible minimum requirements in the orders are hard to handle for the SMEs as well as the whole industry, as it is troublesome and expensive to produce small production run and offer more customized products and difficult for new labels to be established.

Initiatives: User-led design development/circular design and production strategies/local production and product development

1) Increasing local production with more production on demand, reacting to market trends and possibility for small runs and product development through user-centric design, development of fit and sizing systems, material and product knowledge as well as knowledge within digital technologies; this includes 3D body scanning, 3D virtual prototyping and intelligent production processes – all of which should be combined with automated manufacturing processes driven by robotics technology and AI. 2) Testing and development of niche market-driven design strategies in SMEs is necessary to reduce overproduction of poorly developed products, build up resilience and targeted production, and build customer satisfaction for reduced returns, loyalty, and potentials for CE BMs. 3) Increasing textile citizenship strategies for educating consumers, designers and industry, led by extensive wardrobe audits (quantitative and qualitative) interpolated with production strategies. Learning from historical sources from a time where CE was normal practice in both industry and amongst consumers. Build education schemes for integration through textile skills for hand-held processes of sorting, repairing and re-designing textile products.

Technological/Social readiness level

Short term: the automation of sewing production is validated in the laboratory (TRL 4). A national anthropometric database for seamless integration systems from body scan to product delivery (TRL 8-9). Avatar and 3D model development for less expensive and more compatible formats (TRL 6). User-led production strategies expected (SRL 1-5).

Medium term: automation pilot tested and ready for commercial use in industrial environments (TRL 7). Building up of re-shored industry including CE production strategy implementation (SRL 6-9).

Expected impact

Design for circularity: Every nine months extended active use of a garment provides 16% reduction in GHG emissions (WRAP UK 2017); 1,000+ local jobs (including 200+ integration jobs = DKK 2.7B alone, 20% reduction in Danish consumption of textiles; zero returns from Danish companies.

Systems and services

(28, 29, 30, 15, 17, 18, 19, 20 in Figure 3)

This section covers initiatives for prolonging textile products' performance on the inner loops of the secondary market through scaling resale and services on textile products, redirecting companies' revenue streams into the use phase of products, and getting an overview of product performance at technical, functional, and emotional level. Furthermore, in order to develop and understand how CE BMs actually work and how they create value, a deep dive into past practices is needed, as there was a thriving secondary sector in Denmark for resale, rental, adjustments, maintenance, repairs or re-design up until 4-5 decades ago. These initiatives will create feedback loops for improving product development in the first place, as products that are better developed than they are today are necessary for fully capturing the potential for new revenue streams and climate reduction goals (see materials and design and production).

Currently somewhere in the region of 30 kt of textile products are placed on the Danish market which are transferred to new owners somewhere in the world each year (Watson et al, 2018). We need to specify where they are and how they perform if we are to succeed in transforming the sector from linear to truly circular. This will require both "hard science" software solutions as well as "soft science" qualification of user-product attachment. At global level it is estimated that the establishment of CE BMs on the textile sector's secondary market can lead to a reduction of the country's carbon footprint by 3–7% and a reduction of consumption of selected resources by 5–50%, and an increase in GDP by 0.8–1.4%; between 7,000 and 13,000 additional job equivalents; and last, an increase in net exports by 3–6% (EMF, 2015). But companies are currently not taking a share of the potential revenue as they have not adopted a circular business mindset but are stuck in the linear narrative. Textile and design knowledge in retail for supporting service models for repair, maintenance etc. are lacking, and so are ICT solutions for scaling resale platforms and tracking, locating and validating quality of products. The secondary market is therefore highly under-developed but has huge potential. As an example, according to threadup (2020), resale of garments will exceed fashion by 2029 and generate a value of $64B by 2024.

Challenge

A particularly linear mindset in the textile sector is preventing most Danish companies from adopting CE BMs. The biggest challenge lies in the fashion sector but interior design companies and public-private schemes are also dysfunctional in retrieving resources for take-back or take-further. Newly produced garments in Denmark are currently used on average for six times or 2.3 years before they are discarded by primary users (CONCITO, 2015). If the garments are subsequently discarded in mixed waste for landfill/incineration this leads to an average 90% loss of the technical potential of the products (Watson et al, 2018). There is a small but growing literature on CE BM innovation (Fashion for Good, 2020; Pedersen et al, 2020), but actually CE BMs in fashion have significant potential in Denmark as 9% of new purchases of garments in Denmark are resale against 5% in the EU (ECAP 2019). However, only 3% out of the 30% of resold textile products in Denmark generate high value (40-100+% of new price) in resale and new research shows this has to do mainly with the low level of product development (Larsen, 2015; Skjold et al, 2021). Furthermore, there is currently a barrier for CE in the cross-section between public purchasing, public waste management organizations, and private ventures, which causes resources captured in textile products on the secondary market to be lost or very poorly utilized. With 80% of textiles from the public sector currently being incinerated (Thorin et al, 2020), prolonging the lifetime of textiles through repair and reuse and secondly recycling is expected to lead to environmental benefits (less production of new materials).
According to a recent assessment of the climate benefits of circular procurement criteria, extending the lifetime of products by 15% through repair and better textile management in hospitals, hotels, municipal services would reduce the carbon footprint of procured textiles by 7%. 100% recycling of worn-out textiles would reduce the carbon footprint by around 4% (Watson et al, 2020). There is increasing attention to end-of-service management of textiles in the public sector; however, limited attention is given to this aspect in current procurement practices. Public waste management entities and NGOs are flooded with textile waste and are not currently capable of dealing with the non-reusable textile waste that must be separately collected by Danish municipalities after 2022 (ibid). in Denmark (ibid). In Denmark, Region H, and Copenhagen Municipality are just finalizing a circular textile roadmap, the Partnership for Circular Municipalities (PARCK). The roadmap provides guidelines for collaboration, requirements and circular potentials in PP (POGI, 2020).

> **"Within the public sector, there is a large potential for developing guidelines for high quality and material composition of textiles"**
> *Hanne Juel, Chief Consultant, Central Jutland Region*

Herning Municipality has experimented with a circular leasing model for workwear, trying to integrate repair, reuse and recycling of workwear into public contracts (De Leener, 2021). The current practice of public procurement of textiles is mainly focused on material certifications, which is supported by the recent POGI textile criteria (POGI, 2020). The new procurement law (Udbudsloven, law no. 1564 of 15/12/2015) which entered into force in 2016 furthers the development of circular public procurement in Denmark and several networks are supportive of this theme. The potential and effect of public procurement and policymaking have been shown to be effective in fostering innovation and change and solving major challenges in areas such as the health and energy sector (Kristensen et al, 2021).

Learnings can be transferred to textiles. However, public actors such as laundries (e.g. ELIS and DFD) are tracking their products downstream to a wide degree but learnings and systems are not interpolated between public-private actors and between textile categories such as interior design and fashion. Pilot schemes for product deposits have been initiated in the US as a driver for take-back or take-further.
The biggest challenge for all of this to take place, though, is an urgent need for policy pull for regulation, for example EPR, VAT reduction on repair and reuse and the ECO design directive on textiles. LCA measurement actions are currently not validated by data from the use phase and EU common data. Hence, the following initiatives should also be viewed as research-based validating tools for CE policy making.

> **"Europe needs its own public data collection institute, with verified European data on CO_2 and LCAs. We cannot depend on American systems with unverified data"**
> *Signe Marie Bakka Backhaus, Head of Product Development & Production, Roccamore*

Initiatives: Develop CE BMs for secondary market/tracking + design analysis in use phase/take back + take further in public-private schemes
1) Make use of the Danish tradition of cooperative BMs such as COOP and Kopenhagen Fur for building public-private ventures as well as knowledge-sharing, shared investments in tech or ICT solutions for tracking products and scaling resale and services, and R&D for creating agile and customized markets and platforms for SMEs or larger market players. 2) Historic insights need to be interpolated with quantitative and qualitative studies of textile products on the current secondary market uncovering product performance and value creation at more levels, a) Fibre performance, that is how materials actually perform up to 60 years after they were made, b) Value creation, that is how resale customers get value out of buy-to-sell and sell-to-buy practices and how they operate on the secondary market and c) Design analysis, that is what types of design generate high value (economic and user-related), and what products do not. 3) The following initiatives are suggested for validating and understanding what types of textile products are being circulated on the secondary market and where they end up before they end in the waste sector, which is currently completely unknown: a) ICT solutions based on tracking, Internet of Things (IoT) systems and blockchain for newly produced products latching on to the "design and production" theme is a vital instrument for the sector's new future. b) ICT solutions as vital scalability instruments for documenting one-off products and smaller fractions typical of the secondary market will facilitate cooperation, collaboration and communication across actors, enable alignment of demand and supply, as well as enable traceability and transparency.

Technological/Technical readiness level
Short TERM: ICT solutions and tracking technology (TRL 4-6). Wider implementation and commercialization of CE BMs (SRL 1-4).
Medium term: ICT solutions and tracking technology (TRL 7). Wider implementation and commercialization of CE BMs (SRL 4-6).

Expected impact

30-40% of the revenue stream in Danish SMEs takes place on the secondary market depending on the BM. 1,000+ jobs within sorting and services + CE BM entrepreneurs. The findings from the test areas have been widely implemented in Denmark, use-phase data is the foundation for policy making at global level; most provincial cities have well established resale and services by 2030.
80-90% of the revenue stream in Danish SMEs takes place on the secondary market depending on the BM. 1,500+ jobs within sorting and services + CE BM entrepreneurs. Public procurement in Denmark Is fully circular, full life-cycle regulation measures are being implemented worldwide, resale and services is the general perception of fashion by 2050

> **"We're seeing the rapid development of textile recycling technologies at a global level and a willingness to use them. We need to ensure the business case for these innovations is clear, to enable investment and ultimately scalability"**
> *Nicolai Reffstrup, CEO & Lauren Bartley Head of Sustainability and CSR, Ganni*

Recovery

(31, 32, 16, 17, 18, 19, 20, 21, 22 in Figure 3)

Public waste management entities and NGOs are flooded with approximately 30 kt of textile waste per year and are currently not capable of redirecting it back into use. Collection rates are reasonably high in Denmark with the most recent estimate lying at 44% of textiles put on the market (Watson et al, 2018). Used textile collection has for many years been dominated by charities and private collectors collecting over the desk in second-hand shops and via containers in recycling centres and other public locations. Of the 10 kt collected by these NGOs in 2016, only roughly 30% was separately collected, reused and recycled (Watson et al, 2018). The remaining amount was until recently sold to Eastern European companies. However, the demand for European used clothing has reduced in many markets. The reduction in demand is partly due to strong growth in exports of used textiles from China and other Asian economies but also reflects higher quality demands expressed by customers in these markets (Elander et al, 2017).

"Our products need to be more circular from the start to meet the challenges of the future and we must be more clever at capturing the value of ressources going forward from now"
Nicolaj Reffstrup, CEO, Ganni.

In general Denmark is several years behind other Nordic countries such as Finland and Sweden, where automated sorting and recycling technologies have been supported by public funding since 2016 and are in the process of being upscaled to industry scale. VTT Finland stands behind the technology of, and Aalto University started Ioncell; both work with primarily chemical recycling. Renewcell in Sweden is the only chemical recycling plant in Europe that has achieved a commercial scale and has already produced products with H&M and Bestseller. SIPTex in Sweden is experimenting with automated sorting technology. Denmark must position itself in a way that is either new (like a new way of recycling syntactic fibres and/or a technology-based system for improving the environmental benefits in recycling) or supports the development that has already been going on for the last couple of years in many other countries like Sweden, Holland, Finland and Turkey. However, a local solution is necessary as exporting the used and deadstock textiles will be costly and the highest possible gain of resources and innovation level will disappear out of the market. Impacts are not obtainable without close coordination with systems and services, particularly on public-private collaboration and alignment. For slowly upscaling fibre value towards 2030 and 2050 initiatives from materials and design and production also need to be implemented.

"It is a great problem that the systems cannot certify recycled materials"
Signe Marie Bakka Backhaus, Head of Product Development & Production, Roccamore

Challenge

By January 2022, all Danish municipalities are required to set up curbside or similar systems for collecting household textile waste. There is a need to develop textile-to-textile sorting and recycling infrastructure that 1) Can be upscaled to industrial level to take a large part of the textile waste generated in Denmark and 2) Can provide economic value to collectors and recyclers of textile waste - one key challenge in developing fibre-to fibre recycling is that very little information exists on what the non-reusable textile waste will comprise of in terms of material composition. Furthermore, the quality of the fibre and level of recovery need to be higher in the thermal recycling (similar to plastic recovery used for synthetic fibres). On the mechanical recovery front the benefit is that less energy is needed for the process. and until now the mechanical recovery process requires the textile composition to be mono and preferably without colours. The drawback in mechanical recovery is the shortening of fibre length and the need to add virgin fibres to obtain spinnable yarns of high quality. On the chemical recovery front the challenge is that the quality of the output polymers or monomers much be high to perform in the long chain of fibre to textile processes and end products afterwards. Therefore, it is also essential that textile recovery is coupled with the subsequent production steps, which also represent a challenge, as most production is outsourced. 3) Data is essential for tracking can provide knowledge for future solutions and feedback to the product design phase.

Initiatives: User- and tech-driven collection and sorting systems/design and process technologies for material recovery

1) Research the user behaviour with regard to used and discarded textiles, to inform technology development and circular design decisions. 2) Developing a quality system for textile recyclability and having it running would take an estimated 2-4 years, maybe even less, depending on how much we can rely on adapting existing technologies like image identification and IR. This can help ensure that more textiles are recycled and recycled in the best possible way by implementing a technical quality check. 3) Develop a data-driven technology for separation of waste fractions with textiles integrated, such as fibre composites relevant to the housing sector, the interior design sector and the wind turbine industry. 4) Testing existing recycling technologies for handling textiles. This can be tested at small scale within ½-1 year. Documentation of this technology already exists in studies of micro fibres, of how textile products are made and of examination of fibre waste from tumble driers. 5) Develop market-ready/near recycling technologies for handling textiles (thermomechanical recycling, pyrolysis and HTL). These could preferably be co-developed for textiles and mixed plastics. 6) Develop emerging and biotechnological recycling (enzymatic depolymerisation and microbial upcycling) in existing thermomechanical recycling by targeting those fractions that are currently not (economically) recyclable or at too low quality. More efficient biotech recycling could significantly reduce GHG emissions compared to chemical recycling and avoid the use of harmful chemicals.

"On the road to textile recycling, we are facing some key few key challenges. One is separation of textile blends, where we have a solution. Still, while our technology can process most of the known textile fibers, there are some fabrics, we do not want in our facility. So, pre-sorting of the textile waste is important for us and many other recycling solutions. This also means that we need a common and unified collection and sorting strategy"
Simon Hundahl Rossen, CEO, Textile Change

Technical/Social readiness level
Short term: recycling technologies for handling textile waste (TRL 7). Biotechnical recycling for low-quality/value fibres (TRL 3). Social innovation and integration in public-private schemes (SRL 1-4).
Medium term: biotechnical recycling for low-quality/value fibres (TRL 6). Social innovation and integration in public-private schemes and building up Denmark-based recovery sector (SRL 5-7).

> **"Product design plays a large role in the circular economy of textiles. Better data and increased transparency will support better collaborations across value chains"**
> *Hanne Juel, Chef Consultant, Central Jutland Region*

Expected impact

Realize potential of 50 kt of textile waste incinerated currently per year. Improving existing collection for resource optimization = 172 kt GHG/year. 1,000+ jobs in collecting and sorting (social innovation + integration as potential). 1,000+ jobs in IT sector and new markets for design for repurposing. 75% of all textiles reused or recycled. All fractions are sorted, validated for right purpose and redirected to the best utilization by 2030. Denmark has a closed-loop system for textile recycling, and Denmark is world leading when it comes to textile sorting and utilization by 2050.

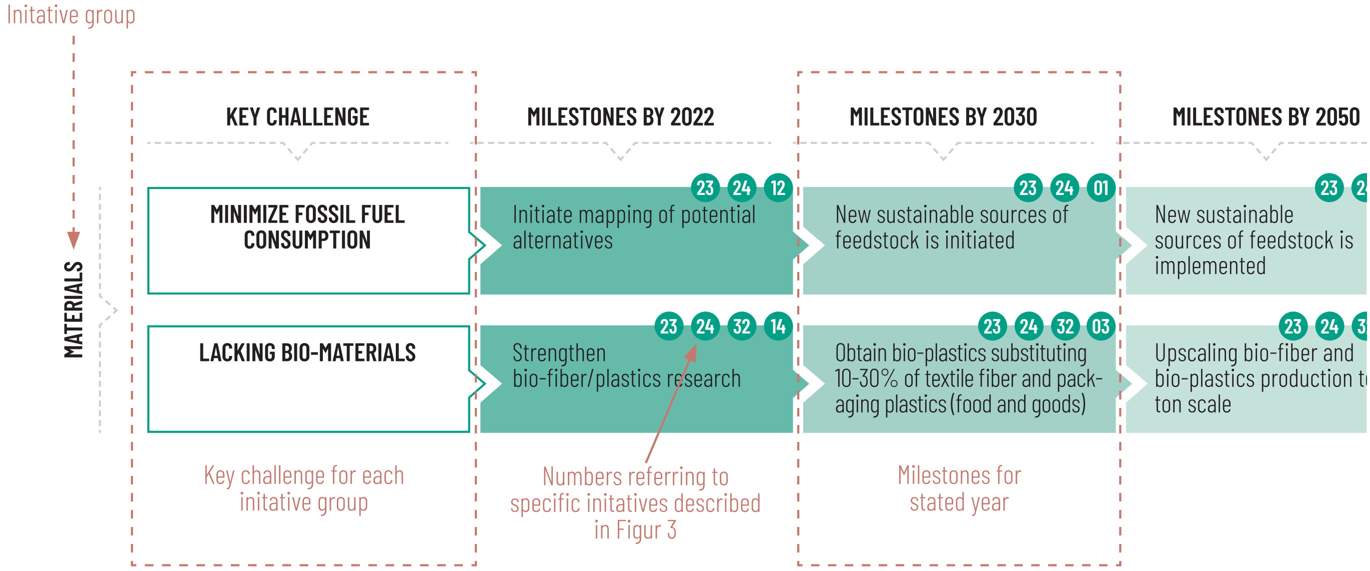
TIMELINE AND SUCCESS CRITERIA FOR GOALS – MAIN INNOMISSION ROADMAP

The actual roadmap is presented in Figure 5A-C and is split into a plastics part (Figure 5A), a common part (Figure 5B) and a textiles part (Figure 5C). The roadmap consists of a visual overview of the specific challenges and milestones for each part of the roadmap with reference to the initiatives leading to these milestones. Figure 6 sums up the expected goals to be achieved in 2030 and 2050 by following the roadmap.

The roadmap is presented below for plastics colour coded grey, textiles colour coded red, and the common part colour coded green, respectively. The individual parts of the roadmap are presented for each initiative group: MATERIALS, DESIGN & PRODUCTION, SYSTEMS & SERVICES, and RECOVERY. Here the KEY CHALLENGES are shown with MILESTONES for the first year (2022), 2030 and 2050. The milestones are presented as goals with inherent success criteria. The numbering (numbers in small circles) on the individual milestones refers to the specific initiatives presented in Figure 3 and described in "Catalogue of potential initiatives".

Numbering:
01-13: Plastic specific initiatives
14-22: Common initiatives
23-32: Textile specific initiatives

Explanation of how to read the roadmap



KEY CHALLENGES AND MILESTONES: PLASTICS

	KEY CHALLENGE	MILESTONES BY 2022	MILESTONES BY 2030	MILESTONES BY 2050
MATERIALS	OBTAIN SUFFICIENT PLASTICS QUALITY/PURITY	01 02 04 Documentation for recycled plastics quality/purity	01 02 40-50% reduction of plastics waste stream	01 02 80-90% reduction of plastics waste stream
MATERIALS	LACK OF BIO-POLYMER PRODUCTION AND THE POOR PROPERTIES OF THESE	03 04 Strengthen bio-polymer/ plastics research	03 04 14 Potential bio-polymer are developed in ton-scale	03 04 14 10% substitution with bio-plastics runs in full production facilities
MATERIALS	INFERIOR MATERIAL PROPERTIES	05 15 12 Strengthen research on novel materials with enhanced properties	05 16 19 Several new food grade mono-materials with enhanced barrier properties	02 10 15 Several new materials are at pilot and industrial scale
DESIGN & PRODUCTION	MAINTAIN PRODUCT VALUE	02 05 19 Focus on dismantling (reversible gluing, minimize multi-materials)	10 16 17 20% of plastics and hybrid products are reparable	16 18 19 50-70% of hybrid products are designed for upgrade and repair
DESIGN & PRODUCTION	DESIGNING OUT WASTE	06 07 15 Development of systemic CE design methodology is initiated	01 12 15 10-20% CO_2 reduction by increased recycling of plastics and extended service life	11 15 19 50% of plastics production with integrated design and production platforms
DESIGN & PRODUCTION	SPECIFIC QUALITY AND FUNCTIONAL REUSE	07 15 18 Initiate models and tests for production systems	02 08 19 50-60% of material are in closed loop production	10 19 70-80% of materials are in closed loop production
DESIGN & PRODUCTION	UPSCALING ALTERNATIVE MATERIALS IN PRODUCTION	06 04 16 Identifying design and production adaptation to include larger material variety	08 15 16 Production platforms are partly implemented	09 15 Production platforms are fully implemented
SYSTEMS & SERVICES	PUBLIC ROLE IN PUSHING CE	17 18 Mapping plastics use, reduction potential, and stakeholders in the public sector	07 11 17 Obtain models for reduction and recyclable plastics in procurement	07 11 17 CE is fully implemented in all public decisions
SYSTEMS & SERVICES	PUBLIC PRIVATE PARTNERSHIPS	06 07 18 Mapping of existing business models and potentials	09 18 Development of strong partnerships, with SME in focus	11 17 18 Partnerships with focused innovation towards CE and plastics reduction
RECOVERY	PLASTICS PURIFICATION	05 12 15 Research in mechanical and chemical purification and upgrading is strengthened	01 13 22 Introduction of several chemical purification solutions	02 12 21 Implementation of several chemical and mechanical purification solutions
RECOVERY	CHEMICAL PROCESSING	13 15 22 Development of chemical recovery of thermosets is initiated	13 19 22 Recycle of composites and thermosets	11 15 22 Several thermosets are in pilot or industrial scale recovery processes

Figure 5A: *Challenges and milestones for the plastics part of the roadmap with indication of fulfilment.*

KEY CHALLENGES AND MILESTONES: COMMON

	KEY CHALLENGE	MILESTONES BY 2022	MILESTONES BY 2030	MILESTONES BY 2050
MATERIALS	MINIMIZE FOSSIL FUEL CONSUMPTION	23 24 12 Initiate mapping of potential alternatives	23 24 01 New sustainable sources of feedstock is initiated	23 24 03 New sustainable sources of feedstock is implemented
MATERIALS	LACKING BIO-MATERIALS	23 24 32 14 Strengthen bio-fiber/plastics research	23 24 32 03 Obtain bio-plastics substituting 10-30% of textile fiber and packaging plastics (food and goods)	23 24 32 16 Upscaling bio-fiber and bio-plastics production to ton scale
DESIGN & PRODUCTION	MINIMIZE PRODUCTION WASTE AND OVERPRODUCTION	25 26 27 15 Adjustment of production strategies and scale	25 26 27 01 20-30% decrease of resource consumption in production	26 16 50% decrease of resource consumption in production
DESIGN & PRODUCTION	DESIGN FOR CIRCULARITY	25 26 27 07 Adjustment of product development	28 31 32 08 25-50% increased recyclability of products	28 31 32 16 60-80% increased recyclability of products
SYSTEMS & SERVICES	LACK OF CITIZEN'S COMPETENCES FOR CE IN DK	25 31 17 Investigate citizen's role in a circular CE economy	25 31 17 50-60% of DK citizen's master skills for CE-based practices	25 31 17 90% of DK citizen's integrate CE-based practises in their daily lives
SYSTEMS & SERVICES	REGULATION FOR PROMOTION OF CE	29 31 11 Research in how to set regulation and incentives right	29 31 11 Implementation of updated regulation on approval of packaging	29 31 11 Implement regulation and approval procedures
SYSTEMS & SERVICES	LCA FORECAST ON CE	29 30 31 06 Initiation of LCA research	29 30 31 07 prelim. methodology and tests developed	29 30 31 07 Methodology and tests developed and implemented
RECOVERY	MATERIAL SORTING	29 31 20 Research in detection systems with improved resolution and detection limits	29 31 21 Sorting systems for textile, fiber, and plastics streams are developed.	29 31 21 Sorting systems for textile, fiber, and plastics streams are operational
RECOVERY	MECHANICAL RECOVERY	31 32 02 Material refining system development is initiated	31 32 12 40-75% of textiles and plastics are recycled	31 32 21 75-90% of all textiles and plastics are recovered
RECOVERY	CHEMICAL RECOVERY	32 14 Research in recovery processes initiated	32 13 1-3 stable processes are implemented (10%)	32 22 90% of material streams can be processed

Figure 5B: *Challenges and milestones for the common part of the roadmap with indication of fulfilment.*

KEY CHALLENGES AND MILESTONES: TEXTILE

	KEY CHALLENGE	MILESTONES BY 2022	MILESTONES BY 2030	MILESTONES BY 2050
MATERIALS	POLUTION FROM TEXTILE FIBER PRODUCTION	[23, 24, 14] Local DK fibers are validated as part of EU Eco-design labeling	[23, 24, 14] New sustainable sources of feedstock is initiated	[23, 24, 14] New sustainable sources of feedstock is implemented
MATERIALS	FOSSIL FUELS IN TEXTILES	[23, 24, 14] 2-3 Danish labs test & validate bio materials	[23, 24, 14] 10% of all Danish textiles are produced with DK bio based fibers	[23, 24, 32, 14] A fossil-free Danish textile sector 40%
DESIGN & PRODUCTION	OVERPRODUCTION & OVERCONSUMPTION	[25, 26, 27, 15] 10% reduction in DK consumption of textiles	[25, 26, 27, 15] 20% reduction in DK consumption of textiles	[25, 26, 27, 15] Consumers actively enage in circular consumption & prefer resale
DESIGN & PRODUCTION	HIGH RETURNS & UNSOLD STOCK	[25, 26, 27, 18] 40% reduction of returns	[25, 26, 27, 18] Zero returns and no deadstock	[25, 26, 27, 18] 60% reduction in production from DK textile companies
DESIGN & PRODUCTION	OUTSOURCES PRODUCTION OF TEXTILES	[27, 14, 15] Local automated production ready to be scaled up	[27, 14, 15] 60% of SME's produce mainly in DK	[27, 14, 15] Most Danish textile companies produces in DK
SYSTEMS & SERVICES	PUBLIC PROCUREMENT IS NOT CIRCULAR	[30, 31, 18] 2-3 micro-system test sites for qualifying textile properties & take-back & tak-further	[30, 31, 18] The findings from the test areas have been widely implemented in DK	[30, 31, 18] Public procurement in DK Is fully circular
SYSTEMS & SERVICES	LCA DATA DOES NOT INCLUDE USE PHASE	[29, 31, 19, 20] DK SME's and legislators starts to impliment use-phase data in their work	[29, 31, 19, 20] Use-phase data is foundament for policy making at global level	[29, 31, 19, 20] Full life-cycle regulation measures are being implemented worldwide
SYSTEMS & SERVICES	CLOTHING IS UNDERUTILIZED	[28, 30, 17, 18] Resale- and service entrepreneurs in DK are scaled up	[28, 30, 17, 18] 30-40% of revenue stream in DK comes from secondary market	[28, 30, 17, 18] 80-90% of revenue stream in DK from secondary market
RECOVERY	TEXTILE SORTING & RECYCLING INFRASTRUCTURE MISSING	[31, 20, 21, 22] 50% of textiles reused or recycled. techs for automated sorting ready to be scaled	[31, 20, 21, 22] 75% of all textiles reused or recycled	[31, 20, 21, 22] World leading when it comes to textile sorting & utilisation
RECOVERY	LOW LEVEL 1:1 FIBER RECOVERY	[31, 32, 20, 21] Experimentation and test of better recovery technologies	[31, 32, 20, 21] All fractions are qualified and redirected to the best utilisation	[31, 32, 20, 21] A closed loop system for textile recycling and 1:1 fiber recovery

Figure 5C: *Challenges and milestones describing the textiles part of the roadmap with indication of fulfilment.*

Expected impacts from roadmap

Full implementation of the above initiatives will result in a reduction of CO_2-eq emissions, fossil fuel and water consumption of 63%, 65% and 50% by 2030 and 97%, 95%, and 60% in 2050 with an additional 7,500 jobs expected by 2030 and 12,600 in 2050.

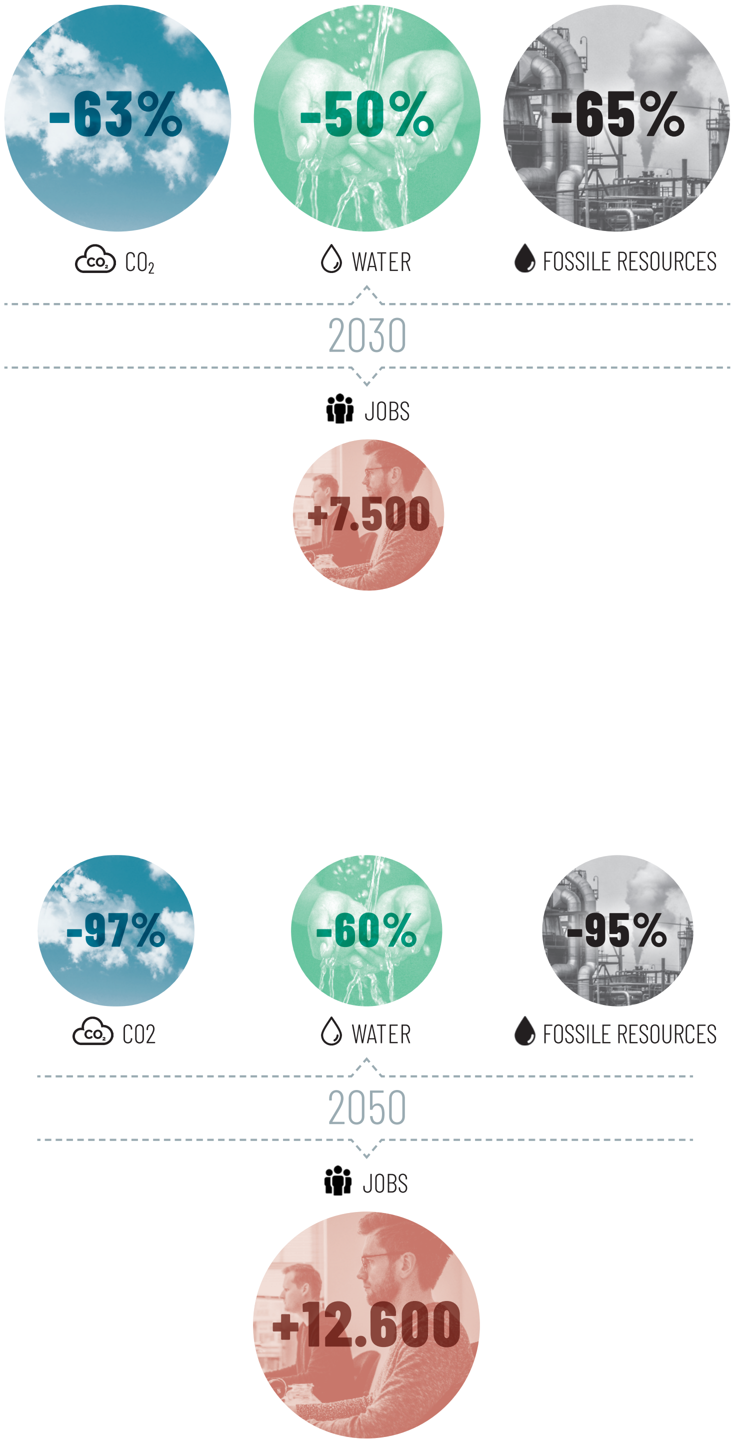


Figure 6: *Expected savings in terms of GHG emissions, water use and use of fossil resources. From 2030 to 2050 will the GHG emissions decrease and the emission and ressource savings increase along with CE related jobs.*

RISK MANAGEMENT AND ALTERNATIVE ROUTES

In order to keep pace with the changing environment there is a need for dynamic identification and prioritization of risks within the partnership of Innomission 4. The risk identification needs to operate with a systematic approach in order to help the partnership decide which risks to take and which to avoid. The partnership's willingness for risk must align with values, strategies, capabilities and the competitive environment at any given point in time. This will dynamically facilitate the delimitation of risk taking, directly translating financial and non-financial principles and metrics into a concrete view based on the overall strategy. Risks identified by the partnership will be dealt with at the most competent level where the complementary expertise of the knowledge and corporate partners will provide the necessary measures to reduce these to a manageable level. Risks identified at an overall initiative level are presented below with associated mitigation measures.

Table 1: *An overview of major risks identified for each of the four themes of the roadmap. A complete overview of risks is presented in Appendix A-II.*

INITIATIVE	POTENTIAL RISK	SEVERITY	LIKELIHOOD	MITIGATION STRATEGY
MATERIALS				
NEW MATERIAL PLATFORMS	Material development is cumbersome and may not be viable for some product groups within the timeframe	High	High	Provide seed funding to kickstart developments across a portfolio of initiatives
DESIGN AND PRODUCTION				
DESIGNING OUT WASTE	Unaligned systems and priorities across value chains	High	High	Develop several routes allowing integration and transparency between market demands, design tools, production technology and materials
SYSTEMS AND SERVICES				
THE PUBLIC SECTOR AS DRIVER FOR CIRCULAR TRANSITION	Miscommunication results in procurement not being conducted based on guidelines	Medium	High	Re-evaluate communication and knowledge sharing tactics between officers responsible for procurement and users of products within organizations
RECOVERY				
MECHANICAL AND CHEMICAL RECYCLING	Low economically feasibility of recycling technologies	High	High	Costs are minimized via limiting process steps, revenue is increased by ensuring high quality of recycled material and/or further valorization of recycled products, and sufficient feedstock supply ensured by combining fractions from multiple companies

INNOMISSION PARTNERSHIP – CREATE FOR TOMORROW, INCUBATE FOR THE FUTURE

The aspiration of the partnership behind the mission is for it to exist well beyond the initial grant period, to build and maintain the necessary momentum needed to address the mission goals by 2030 and beyond. The partnership will initially consist of current key players from all sectors of society, but due to the longevity of the mission the partnership must develop over time. A non-profit association is foreseen as the legal structure for the partnership. This simple and well-known structure will provide a good balance between partner influence, accountability, and the possibility of including new partners over time, and it will enable a cost-effective administrative and support structure. The following describes the proposed partnership of the roadmap.

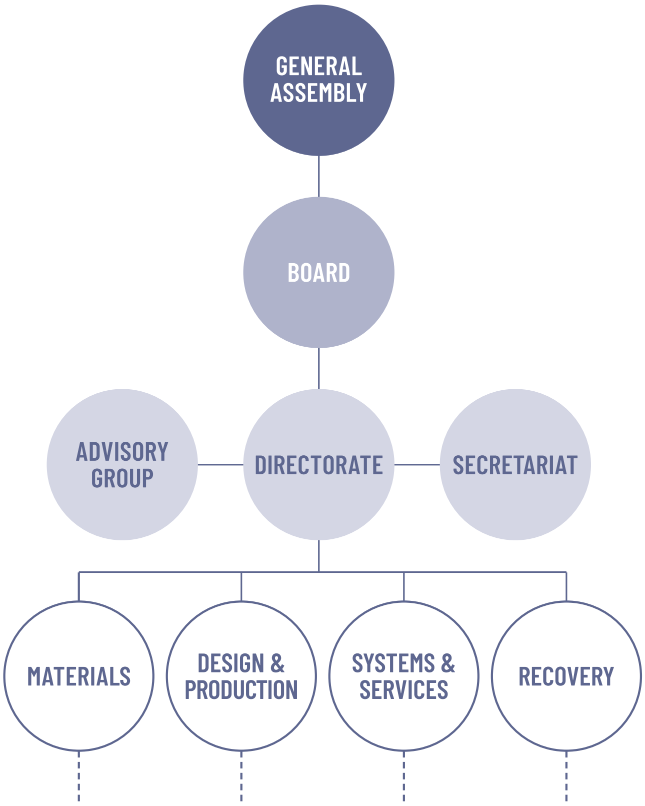


Figure 7: *The proposed governance model for the proposed partnership.*

The partnership is envisioned to be a research and innovation platform comprised of a large consortium of co-financing partners: Universities, RTOs, educational partners and a multitude of large companies and SMEs. The platform will consist of four interlinked thematic workstreams managing partnership initiatives. Each workstream will consist of a team of highly qualified researchers and RTO consultants who will seek to develop innovative solutions to industrial and societal challenges. Organizationally the partnership will be governed by a general assembly, which is the supreme authority of the partnership. All members of the partnership are represented at the general meeting. The board, chaired by a large company, will be comprised of a small group of members (approx. 10) with companies posing the majority, and holds the overall responsibility for the partnership. The management college will be composed of the directorate and the workstream managers. The directorate will consist of one director with a focus on coherence, cross-cutting activities, and financing, as well as two professional directors with a focus on plastics and textiles respectively. Workstream managers will, in collaboration with the directorate, encourage cross-disciplinary collaboration and ensure that important efforts are not overlooked, where efforts cover both tracks in plastic and textiles and cross-cutting joint efforts. The advisory group, comprised of significant stakeholders, including representatives of ministries, NGOs, international organizations, and clusters, as well as trade organizations, will advise the directorate, as well as, where appropriate, the entire management team of workstream managers. The secretariat will facilitate and act on behalf of the director. In addition, the partnership is supported by clusters as an integral part of the partnership that provide through the secretariat the facilitation, networking and bridge building that lies in their mission and that the partnership needs.

To ensure that CE for plastics and textiles is propagated widely throughout Danish society, capacity-building within cross-sector and cross-value chain solutions, and access to knowledge boosts and employees sustaining the CE transformation is needed. This is ensured via e.g. open labs, company visits, innovation conferences and the formation of network groups where inter-sector collaborations are created, specific research and innovation needs identified, and new knowledge and technology is put in play within industry.

Furthermore, within specific research and innovation topics e.g. postgraduate training will be employed simultaneously with education of highly qualified graduates from the knowledge institutions. All activities within this area are defined by industrial and social needs accelerating the CE transition. The specific research and innovation activities aligned with the overall vision and goals of the partnership are beyond the scope of this roadmap. The specific activities are envisioned to be formed in research and innovation partner projects, where multiple knowledge institutions and industrial partners work across sectors and disciplines towards solving the same challenge.

To ensure the partnership reaches beyond its own core focus areas, draws on existing capacities both nationally and internationally, and substantiates Denmark's position internationally, strong ties with networks both nationally and internationally, specifically within the EU, will be formed. Lastly, close collaboration with Innomission partnerships in the three adjacent focus areas will be sought to strengthen the overall research and innovation strategy in Denmark by cultivating activities at the interfaces.

The partnership – Year one

To ensure a swift and agile rollout of the partnership, activities within networking, capacity-building and across the four workstreams will be initiated at the launch of the partnership. These activities are centred on forming the association, building the foundation for the primary R&D activities, and initiating capacity-building and network activities.

To form the association, the governance structure of the partnership will be implemented, and the initial group of industrial members will be expanded. This is of importance as the partnership is based on strong cross-sector and interdisciplinary collaboration. To aid this type of collaboration the partnership must develop and launch a framework which not only ensures strong ties between the knowledge institutions and well-established companies but also ensures the innovative Danish start-up environment is put in to play. To ensure focused R&D initiatives aligned with the overall strategy of the partnership and utilization of synergies across individual activities, sub-workstreams will be developed as well as a framework for educating the current and future workforce. For the specific content of the workstreams see the "Catalogue of potential initiatives in the roadmap" and for the plans for first-year activities see Figure 5. To ensure solutions are industrially implemented, a framework for aiding and matching ideas, innovations and partners with financial opportunities, e.g. public/private growth capital and R&D funds, will be created. Lastly, inter-partnership collaborations will be initiated both nationally and internationally.

STAKEHOLDER AND RESOURCE OVERVIEW – DANISH CURRENT AND POTENTIAL STRONGHOLDS

A circular economy is complex and multidisciplinary, and the mission partnership must include or coordinate with relevant actors from all sectors of society.

AAU: Aalborg University; AU: Aarhus University; DJH: Den Jyske Højskole; DSKD: Design School Kolding; DTU: Technical University of Denmark; UCPH: University of Copenhagen; SDU: University of Southern Denmark, CBS: Copenhagen Business School; ITC: IT University Copenhagen, NATMUS: National Museum; LDC: Lifestyle & Design Cluster; CC: CLEAN Cluster; RDA: Royal Danish Academy; VIA: VIA University College; DTI: Danish Technological Institute; AI: Alexandra Institute; FC: Force Technology; RUC: Roskilde University.

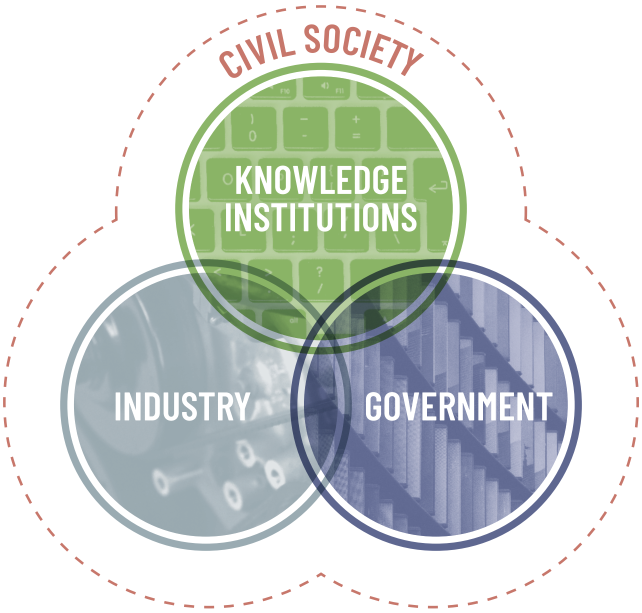


Figure 8: *Overview stakeholder.*

To form the association, the governance structure of the partnership will be implemented, and the initial group of industrial members will be expanded. This is of importance as the partnership is based on strong cross-sector and interdisciplinary collaboration. To aid this type of collaboration the partnership must develop and launch a framework which not only ensures strong ties between the knowledge institutions and well-established companies but also ensures the innovative Danish start-up environment is put in to play.

Knowledge institutions

Materials: Several Danish knowledge institutions have capacities for polymerization, formulation, and analysis of new materials (strongholds: AU, AAU, DTU, UCPH, DTI and FC). RDA, VIA, DSKD, RDS, UCPH, NATMUS and CBS have capacities for fibre analysis and quality validation. For meso- and pilot-scale plastic processing AU, DTU and AAU are strongholds with vast capacities. In full-scale lab processing AAU, DJH and DTU possess the facilities and capacity. AU, DTI, and VIA has the capacity for fibre feedstock and processing. The Marine Plastic research centre (AU, AAU, DTU, RUC and NATMUS) are key within sources, fate, and effects of plastic pollution.

Design and production: DSKD, RDA, and VIA have capacities for consumer-inspired design for circularity and large-scale customization. RUC, CBS and SDU have the capacity for user studies. SDU, AAU, DTU, DTI and AI have the capacity for operations management, robotics, information and communications technology solutions for production automation and optimization.

Systems and services: Within legal aspects AU, DTU, SDU, DTI and UCPH have strong capacities. For analyses of the circular economy and societal development AU, CBS, RDA, SDU, DTU, RUC, UCPH, AAU, DSKD, RDS all have strong research groups. AU, SDU and DTU have capacities within conventional LCA and IO, SDU has strong competences within prospective LCA while DTI, SDU and FC have capacities within system/method development and impact assessments. LDC, CC, FC and DTI are also key players regarding facilitating the circular transition. RUC, SDU and CBS have the capacity for CE BMs. AAU has the capacities for textile retail and the capacities for public procurement strategies, and ICTT for solutions for tracking of textiles together with CBS, AI and SDU.

Recovery: UCPH, DTI, FC, RDA and NATMUS have capacities for validating level of fibre capacity for longevity, past CE BMs, and historical textile design approaches to circularity. RDA, VIA, DTI and DSKD have the capacity for fibre recovery and design for repurposing strategies. AU, AAU, and DTI have facilities and competences for mechanical recovery and AU, AAU, DTI, FC and DTU have strong competences in and facilities for chemical recovery, e.g. HTL, solvolysis, and pyrolysis.

> **"A lot investment plans are in the making among our members in the waste sector these days. To promote the development of a recycling sector for textiles in Denmark, the next step is to set uniform tender criteria for the handling of textile waste. The new organization of the waste sector, where waste is handled on the market, and uniform sorting and collection of waste throughout the country means larger and more uniform amounts of waste and enables investments in sorting and recycling facilities in Denmark. A lot investment plans are in the making among our members in the waste sector these days. To promote the development of a recycling sector for textiles in Denmark, the next step is to set uniform tender criteria for the handling of textile waste"**
> *Iben Sohn Chief, Senior Consultant, Confederation of Danish Industries*

Government and the public sector

The Danish government will play a central role if Denmark is to take a leading role in the CE. Regulations can and should facilitate innovation within all sectors, and the level of ambition when implementing EU legislation such as the single-use plastics directive will not only impact on the consumption of plastic in Denmark but also serve as a societal indication of how ambitious Denmark will be in the transition towards a CE.

The public sector is key in circular transition, especially in three areas: procurement, consumption, collection and end-of-service handling. The healthcare sector is a stronghold within this context since it is responsible for approximately 6% of Danish GHG emissions. Nordic collaborations on public procurement can be a strong driver for the circular transition. The collaboration among the Greater Copenhagen municipalities is an example to follow. In plastics waste processing, Vestforbrænding, RenoNord and ARC are key players. A national collaboration on public health and workwear circularity has been established between the five regions. On the household collection of textiles several municipalities have been piloting and Herning municipality launched a pilot project: Herning Textile Symbioses in a large partnership with NGOs, Dansk Affald, the industry organizations, research institutions and 14 entrepreneurs setting up an eco-system with a vision of no used textiles being incinerated for inspiration and recommendations for other municipalities.

Industry

Several global companies headquartered in Denmark have plastics as a central element in a variety of ways. Within packaging Arla, Carlsberg, Danish Crown and Novo Nordic (and others) are leading in the food and pharmaceutical industries, for plastic products e.g. LEGO and Coloplast and within hybrid products e.g. Vestas, Logstor, Danfoss and Grundfos are on a global scale. Within textiles and fashion e.g. Bestseller, Ganni, DK Company, Ege carpets, Kvadrat, Gabriel and Mascot are global companies. Within packaging e.g. Færch and Pluspack and for plastics components e.g. SP Moulding possess advanced competences. In waste management e.g. Stena Recycling, Marius Pedersen and Ragn-Sells and mechanical plastics and textiles recyclers e.g. Letbek, Plastix, Dansk Afaldsminimering, Aage Vestergaard Larsen, Trasborg and Convert have competences and are involved in national production of recycled plastics and textile materials. In chemical recycling e.g. Quantafuels, Makeen Energy, Textile Change possess advanced competences. In addition, the United Danish Laundries, Berendsen, NGOs (e.g. Red Cross) and Trasborg have strong competences within textiles collection, sorting and utilization. These strong global players possess financial resources and research capabilities that complement the Danish knowledge institutions. Their global influence can introduce and scale CE solutions giving a significant national and international impact. Finally, they would increase the credibility and attractiveness of the partnership and thereby increase the possibility of attracting financing and talent globally.

The above companies and others will be engaged for direct participation in key innovation projects with knowledge institutions with the large companies and others acting as problem-owners.

In addition to the named companies, a vibrant ecosystem of entrepreneurs and SMEs exists within textiles and plastics. They will be engaged in a broad range of smaller-scale innovation activities funded and coordinated by LDC and CC in support of the mission and they will be engaged via collaboration with existing managers of accelerators and incubators (such as InnoFounder, UrbanTech, Sylab etc.).

> **"It is a fantastic opportunity for Denmark that all knowledge institutions and our cluster have got together and are addressing the challenges by working together"**
> *Dorte Rye Olsen, Head of Sustainability, Bestseller*

Civil society

NGOs have played an important role in pushing a development towards less plastic and textile waste/pollution. They have generated massive public awareness about plastics pollution and engaged with both authorities and industry in order to influence developments. The new national plastics action plan and the plastics industries' guideline on sustainable plastics packaging are two examples of areas where NGOs have had significant influence. One of the large drivers in informing on a more circular way of using less and treating and repairing your textiles is the consumer council TÆNK, with campaigns on the textiles waste pyramid. Also repair cafes throughout Denmark, fashion exchange markets, collection of used textiles and many second-hand shops have made it easy to participate in the second-hand part of the circular "movement".

INTERNATIONAL LINKS AND FINANCIAL ASPECTS

The circular economy is a global megatrend attracting attention not only among NGOs and at the grassroots but also in the boardrooms of multinational companies and among SMEs, start-ups and citizens/consumers/end-users worldwide. As a CE hotspot, Denmark will not only deliver on carbon reduction targets but also benefit from increased international collaboration, which holds great prospects for job creation and exports.

The vision is also that a widespread international acceptance of Denmark as a CE hotspot will attract international talent and that the strong public-private CE partnerships will make it attractive to stay in Denmark post-university degree.

Strategic focus areas for internationalization

Foreign direct investments account for thousands of jobs created in Denmark each year, contributing approx. DKK 9B to BNP based on data from Invest in Denmark and Copenhagen Capacity. Being a CE hotspot, Denmark will increase in attractiveness for foreign companies investing in operations abroad.

Export

Denmark is a major exporter of green products and services, and Danish companies are recognized for their innovative solutions, design strategies, technologies, and focus on sustainability and climate according to State of Green. Demonstrating cutting-edge circular solutions at large scale and creating entirely new solutions will be an important driver for future exports, which should be actively pursued.

Bilateral cooperation: Cooperation with strategically important countries is an important driver for pursuing the mission. As proposed by Innovation Center Denmark the aim is to involve countries such as India, Israel, China, South Korea, Germany, and USA.

Focus on cities: Since cities are among the important drivers of the CE and international market opportunities for circular solutions largely relate to cities, the mission should target cities committed to the green transition and implement CE solutions at a large scale, i.e. by working with networks such as C40, ICLEI and Eurocities.

Clusters and ecosystems: Most topics of significance for the circular transition have cluster organizations that convene the ecosystems and support the uptake of innovations. The European Commission gives high priority to developing world-class clusters. Networks such as the International Cleantech Network and European Strategic Cluster Partnerships should be actively utilized for fostering international innovation collaboration that may promote building new markets and strengthening existing ones. The same goes for existing CE networks like Nordic Circular Hotspot and focused cross-border programs like Waste and Resources Action Program (WRAP) and the Circular City weeks of the Danish Business Association.

Financial aspects

Realizing the mission of a CE requires funding at large scale from many different sources. "Soft funding" programs, strategic R&D and infrastructure investments are crucial elements, but private investment via crowdfunding, venture capital and private equity, private bonds etc. are also among the financing vehicles that may be actively utilized.

The partnership should pursue funding following the above approach. The structure of the funding approach as well as relevant funding sources is shown in the table 2 below

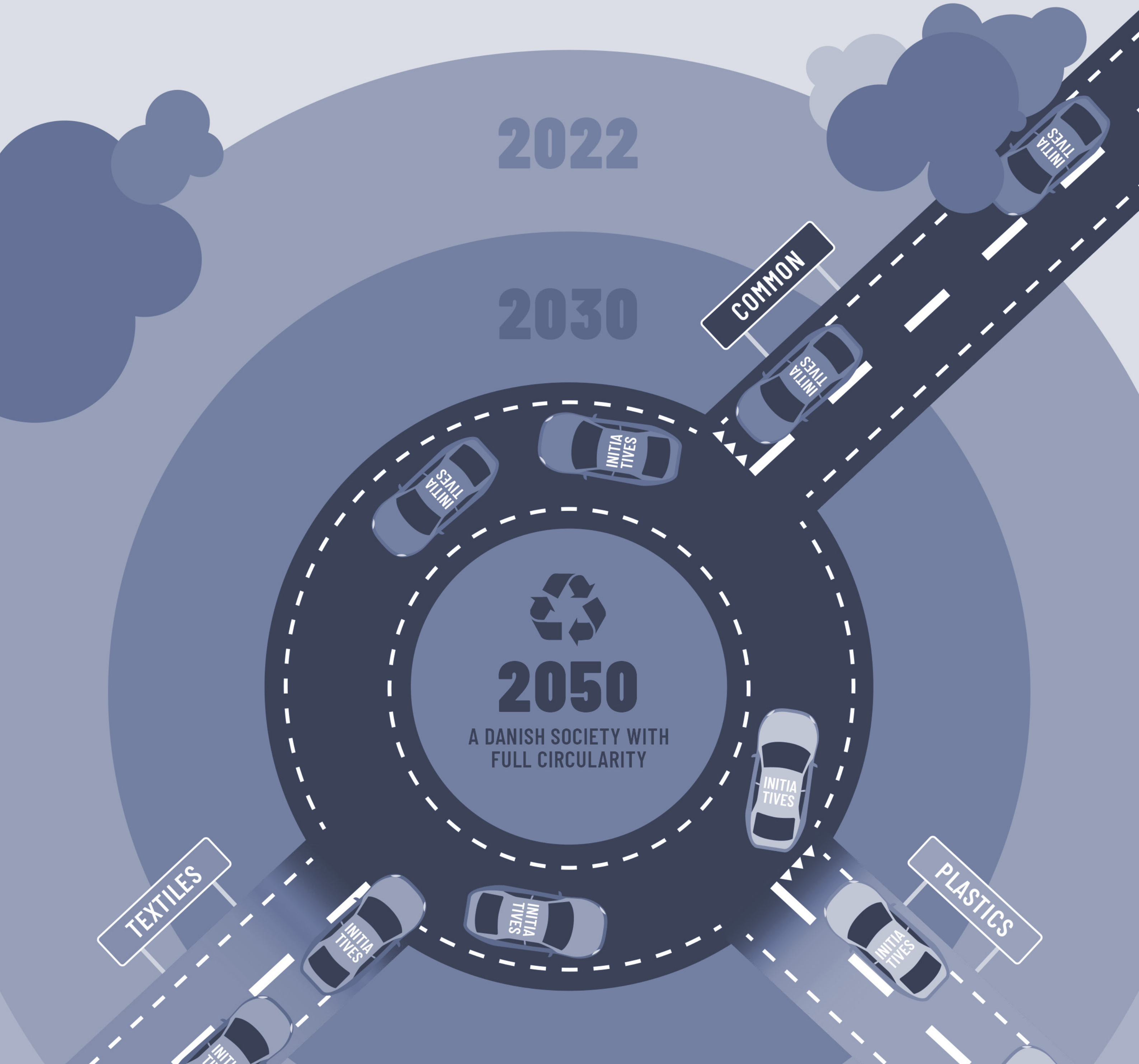
Table 2: An overview of innomission funding approach and sources

IM4 CORE FUNDING Innovation Fund Denmark (year 1-4)	**IM4 SUBSEQUENT GRANTS** Core funding (IFD grant + others): Long term (year 5-10) – creation of value chains, export, new markets, demo projects (MUDP, GUDP)
IM4 CO-FUNDING Project partners in the consortia - SMVs, NGOs, value chain members and other relevant stakeholders, other funding agencies like Horizon Europe (cluster 6), MUDP, GUDP, other funds (a.o. Velux Foundation, Sallingfonden, Novo Nordic fondation, Carlsberg Foundation, NordForsk, RealDania, Industriens Fond, VKR)	
IM4 ADDITIONAL PROJECT FUNDING InnoBooster, InnoFounder, Industrial-PhD, industrial-post docs, Danmarks Erhvervsfremme Bestyrelse, Regionalfondsmidler, MUDP, GUDP, EU Just Transition Fund, Nordic Innovation, EU Horizon Europe, Solar Impulse Foundation, Bloomberg, African Development Bank, World Bank, UN etc.	
Infrastructure investments – DKs Grønne Fremtidsfond, Copenhagen Infrastructure Partners, ATP, PensionDanmark, ELENA, European Investment Bank, Nefco, Nopef, China Investment Corporation, Abu Dhabi Investment Authority, Canada Pension Plan Investment Board, Alliance To End Plastics Waste ***Venture and growth capital*** – Vækstfonden, MAERSK, VKR, byFounders, BNP Paribas, Decalia, BASF, Cornerstone Capital Group, Credit Suisse, BlackRock, Candriam, Danmarks Grønne Investeringsfond	

This roadmap has been developed through input and exchange between 100+ researchers from the respective institutions. Representatives from these institutions, as well as the relevant clusters for plastics and textiles, have been facilitating, conducting and finalizing the roadmap. Furthermore, a large group of stakeholders, incl. companies, have contributed with views and statements related to the roadmap content and visions.

Appendix

CIRCULAR ECONOMY WITH A FOCUS ON PLASTICS AND TEXTILES



PARTNERS:

Aalborg University · Aarhus University · Den Jyske Højskole
Roskilde University · Design School Kolding · Technical University of Denmark
University of Copenhagen · University of Southern Denmark · Copenhagen Business School
IT University Copenhagen · National Museum · Lifestyle & Design Cluster · CLEAN Cluster
Royal Danish Academy · VIA University College · Danish Technological Institute
Alexandra Institute · Force Technology

APPENDIX: CIRCULAR ECONOMY WITH A FOCUS ON PLASTICS AND TEXTILES

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APPENDIX AII – DETAILED OVERVIEW OF RISKS IDENTIFIED FOR THE 4 THEMES.

Table A-II-1: Complete overview of major risks identified for the 4 themes of the roadmap.

INITIATIVE	POTENTIAL RISK	SEVERITY	LIKELIHOOD	MITIGATION STRATEGY
MATERIALS				
RECYCLED CLOSED LOOP MATERIALS (FUNCTIONAL VALUE)	Can recycled materials be accepted as a first choice for high quality purposes	High	Low/ medium	Develop models and tests that accurately describe the properties and quality of recycled materials
RECYCLED OPEN LOOP MATERIALS (MATERIALS VALUE)	Can recycled materials become a viable cost/functionality choice?	High	Medium	Effective sorting, testing, compounding etc. system demonstrated and market platform established
BIO BASED MATERIALS	Can bio based solutions be established as the sustainable choice	High	Medium/ high	LCA will be established to support design-based choices related to scaling the materials platform where it makes sense.
NEW MATERIAL PLATFORM	Material development is cumbersome and may not be viable for some product groups within the timeframe	High	High	Provide seed funding to kickstart developments across a portfolio of initiatives.
DESIGN AND PRODUCTION				
DESIGNING OUT WASTE	Unaligned systems and priorities across value chains	High	High	Develop several routes allowing integration and transparency between market demands, design tools, production technology and materials
CLOSED LOOP HIGH QUALITY AND FUNCTIONAL REUSE	Cost of closed loop exceeds savings	Medium	Medium	Addressed by efficient handling and life cycle transparency.
SCALING UP NEW MATERIAL PLATFORMS IN PRODUCTION	Ability to handle properties and variance that come with the new platforms.	Medium	Medium	Addressed by efficient handling and life cycle transparency. Demonstrate the ability to handle extreme variance
SYSTEMS AND SERVICES				
CITIZEN'S ROLE IN THE TRANSITION TOWARDS A CIRCULAR PLASTIC AND TEXTILE ECONOMY	Lack of willingness to participate from citizens	High	Medium	Development of CS programs should be conducted in an iterative manner, ensuring ownership of participants
THE PUBLIC SECTOR AS DRIVER FOR CIRCULAR TRANSITION	Miscommunication results in procurement not being conducted based on guidelines	Medium	High	Re-evaluate communication and knowledge sharing tactics between officers responsible for procurement and users
GETTING REGULATION AND INCENTIVES RIGHT FOR THE CIRCULAR ECONOMY	Regulations are not agreed upon and legal/ economic incentives will not emerge	High	Medium	If regulations are not agreed upon, customers and industries will have been motivated through other means such as citizen empowerment
QUANTITATIVE DECISION SUPPORT ON THE ENVIRONMENTAL PERFORMANCE OF CE INITIATIVES	Methodologies not further developed	High	Medium	If methodologies for forecasting impacts of CE strategies are not updated CE methodologies will have be assessed with substantial uncertainty, which could stop/decelerate the CE transition

INITIATIVE	POTENTIAL RISK	SEVERITY	LIKELIHOOD	MITIGATION STRATEGY
LCA BASED DECISION-SUPPORT IN INDUSTRY	Inconsistent basis for implementing design changes resulting in no actual sustainability improvements	High	Low/ Medium	Demonstrate and implement process-oriented LCA models that reflect the actual steps throughout the value-chain
RECOVERY				
COLLECTION AND SORTING SCHEMES FOR RESOURCE OPTIMISATION	Lack of alignment between actors	High	High	If public-private policy and technology is not developed to capture full value there will be systemic defaults causing leeks of resources
FULL UTILISATION OF WASTE FRACTIONS	Low quality fractions and lack of design- and business innovation	High	Medium	If quality of fractions continues to be low and if we continue to see larger volumes of waste, fractions are difficult to utilise in a climate-positive way
MECHANICAL AND CHEMICAL RECYCLING	Low economically feasibility of recycling technologies	High	High	Costs are minimized via limiting process steps, revenue is increased by ensuring high quality of recycled material and/or further valorization of recycled product, and sufficient feedstock supply ensured by combining fractions from multiple companies
RECYCLING TECHNOLOGIES	Recycling technologies are not developed synergically and different technologies compete for the same materials streams	High	High	Several routes for developing current and new technologies allowing different materials streams to be used
DOCUMENTATION AND SORTING	Cross contamination and loss of materials due to insufficient detection technologies and sorting methods	Medium	High	Expansion of sensor technologies and enhance digitalization and AI in data processing for ensuring correct sorting and documentation