



**Ministry of Environment
of Denmark**
Environmental
Protection Agency

Insights and outlook from the Circular Industrial Plastic (CIP) partnership: Towards an improved recycling of industrial plastic products in Denmark MUDP-project

MUDP

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Introduction

During the last 3 years, from 2022 to March 2025, a wide range of activities have been conducted in the CIP partnership (Circular Industrial Plastic) to create possibilities for recycling of industrial and technical plastic through collaboration across value-chains.

The CIP partnership involved a range of partners from different industries, with different products, different value chains, and different end-users. The partners include Danfoss, Grundfos, Novo Nordisk, Coloplast, F&H Group, ZIRQ Medical, Trebo, MAKEEN EnviroTech, Geminor, Marius Pedersen, Crossbridge Energy, BASF, Topsoe, as well as Aarhus University, Danish Technological Institute (DTI), and Technological University of Denmark (DTU). The partnership is supported by the Environmental Technology Development and Demonstration Program (MUDP) under the Danish Ministry of Environment and Gender Equality and Managed by DTI. One of the outputs from the partnership is this report, outlining steps taken for a more circular use of industrial and technical plastic across the value chains of the companies.

The purpose of this report is to showcase the experiences of the 3-year-long partnership whose focus was on recycling plastic. The report is based on information gained from numerous meetings, 5 midterm reports, 7 workshops and a number of online meetings, 19 steering group meetings, physical visits and meetings at each partner sites, qualitative in-depth interviews with partners (transcribed and coded in NVivo), a review of comparable partnerships in Europe and report on recycling technologies (Rambøll).

With this report, the partners behind CIP wish to inspire other Danish companies to start and improve the recycling of their industrial plastic and work across their value chain to facilitate the transition towards a more circular society in Denmark. Inspiration from the CIP partnership's experiences and outcomes may encourage companies to take decisive actions improved recycling of industrial plastic products in Denmark. We also wish to encourage political actions that may promote the progress towards an improved recycling of plastic products in Denmark.



Partners in the CIP partnership, November 2023, Hillerød.

1. Executive summary

1.1 Purpose of the Circular Industrial Plastic (CIP) Partnership

The overall purpose of the CIP partnership was to take a holistic approach on how to develop and demonstrate recycling solutions for industrial plastic materials across sectors. The aim was to mature, scale, and implement existing technologies while creating recycling value chains. Notably, the primary focus was on recycling existing products and on exploring if, and how far, new recycling value chains could be established, while at the same time integrating experiences for designing products for tomorrow. These ambitions were only possible through the gathering of partners across the value chain, enabling:

- Matchmaking between products and materials with complementary recycling technologies.
- Technology development and demonstration of recyclability through pilot cases.
- Pilot case scaling supported by LCA screenings to move towards implementation in new value chains.
- Products for tomorrow 'designed-for-recycling'.

Background of the CIP partnership

The motivation for establishing CIP was driven by the different companies' ambitions to take environmental responsibility for their products by reducing the amount of virgin materials, hereby, ideally, reducing the CO₂ footprint, as well as their ambitions to transition towards a circular economy. The transition and creation of new value chains are undeniably complex tasks that require diverse competences and contributions from different partners. Therefore, the Danish Technological Institute built the CIP partnership back in 2021, including companies from different sectors across the value chain as well as knowledge institutions. Key barriers for a circular transition that the partnership faced were:

- a. The lack of commercially viable recycling technologies and waste handling infrastructure for diverse plastic materials.
- b. The complexity of legacy chemicals in collected products aimed for recycling: blended, inseparable or complex plastic products, as well as plastic containing additives and chemicals that are considered problematic today.
- c. The logistical challenges of handling returned products both in the organization, domestically, and internationally: While supply chains have been optimised for production for decades, effective tools for reverse logistics are still limited and organizational challenges of adapting to circular initiatives remain.
- d. Products currently on the market have been designed and optimised for production, function, and costs, not for recycling.

The partnership was executed from 2022 to 2025, funded by the partners and the Environmental Technology Development and Demonstration (MUDP) Programme under the Danish Ministry of Environment and Gender Equality together.

CIP's working definition of 'industrial plastic':

The term 'industrial plastic' refers to plastic products and types that end as residual waste for incineration, whether collected from industry (B2B) or households (B2C).

In CIP we worked with plastic materials (no house-hold waste collected by municipalities) and products suffering from one or more factors currently hindering recycling: 1) lack of separation in the waste collection; 2) contamination of products; 3) problematic additives; 4) high-performing or complex product designs. ; 5) Low volume and problems in scaling.

Value creation for the CIP partners

The CIP partnership provided a solid baseline for the future of industrial plastic recycling in Denmark, highlighting the transformative potential of strategic partnerships and innovative technologies as central elements for change. The value creation gained from participating in CIP was individual for its many different partners, but the three most essential value drivers were as follows:

- **Knowledge Through Network:** The collaborative nature of the CIP partnership demonstrated the immense value of building a robust network of stakeholders across various sectors. Future efforts for a more circular society should focus on expanding partnerships to facilitate the exchange of knowledge and best practices, drive innovation, and overcome shared challenges in recycling.
- **Power of Example:** CIP provided examples of successful recycling initiatives, serving as pilot case studies that were important for accelerating the implementation of strategies among partners and for advancing from theoretical planning to practical application. CIP encourages others to adopt similar practices, fostering an action-oriented culture of sustainability while setting benchmarks for industry standards.
- **Strategic Insights:** CIP gave the partners key strategic insights that each partner could use to inform their own strategies and business development efforts. CIP clarified the significance of integrating recycling technologies and circular economy principles into business operations and strategies. Partners stressed the importance of management support and emphasised that circular business models could benefit from including KPIs with new sustainability targets. Future initiatives should leverage this and develop scalable models for closed or semi-closed loop systems, enhancing economic viability and environmental sustainability.

1.2 Main conclusions and selected pilot cases

While the manufacturing companies in CIP all had a common vision of developing the recycling landscape, they were highly different: Some produced Fast-Moving Consumer Goods (FMCG), some were active primarily on B2C markets, others mainly on B2B. They both operated on entirely different conditions and represented different circularity maturity in their organizations. The partners thus resembled a diversity common to the Danish industry. Despite their differences, all CIP partners referred to the **value of sharing knowledge and**

gaining insight into different companies and their challenges in establishing a more circular production and/or takeback system. While some partners managed to create a complete use case, **others required further time in the organization to transition towards a circular mindset before being able to use recycled materials**. Among both common and individual organisational learnings, the main conclusions of CIP are:

- Recycling of even complex products and materials is often technically possible using available recycling solutions, and the available solutions are best identified through practical testing and demonstration.
- Partnerships and a thorough understanding of your product within the value chain are vital for success.
- Thermomechanical recycling is the most mature, available recycling technology, and sorting methods offer significant potential in many cases. Dissolution and chemical recycling methods, such as pyrolysis and HTL (Hydrothermal Liquefaction), both play a complementary role, especially regarding legacy chemicals, but these methods still need to mature and scale before they can serve as default alternatives.
- Moving forward and accelerating the transition towards a circular economy, there are still barriers that need to be overcome, such as reaching economies of scale, improving the waste handling infrastructure, continued technology development, economic incentives, and legislation.

Enhancement of recyclability

While enhancement of recyclability is often linked to the development of plastic materials or products compatibility to novel and unexplored (chemical) recycling technologies, this in practice turned out to represent a minor, albeit important, part of the CIP product.

The most significant practical impact in CIP was achieved through technical material and product evaluation, and by exploring suitable sorting methods and logistics enablers, still using thermo-mechanical recycling as the workhorse.

Key evaluation parameters have included the mechanical properties of recycle blends, as well as the quality fit in new products.

The general conclusions are based on learnings from more than 20 pilot cases generated by matchmaking between products and potential recycling technologies, progressing through the different phases as illustrated in FIGURE 1.



FIGURE 1. Case overview process for matchmaking between products and technologies: 24 initial cases ending with 6 final use cases (recycled materials used in new products).

Selected cases are shown below.

- **Novo Nordisk** enhanced its Returpen™ (now ReMed) recycling programme through a partnership with **Zirq Medical**, focusing on sorting and decontaminating multi-component medical pens. The collaboration currently prioritises the recovery of two main materials while developing open-loop recycling processes, as a prerequisite to enable expertise for future closed-loop manufacturing integration.
- **Grundfos** partnered with **Trebo** with the goal of achieving closed-loop recycling through obtaining an extremely high degree of purity in several material types recovered from complex materials via fluid-mechanical sorting. Grundfos validated the recyclate in trial productions. In addition, pyrolysis and dissolution methods were explored for fractions not suitable for thermomechanical recycling.
- **Danfoss** successfully tested recyclates from used radiator thermostats, observing no significant property degradation in recyclates several decades old. Prototype thermostat components made from recyclates passed functional tests, validating the mechanical viability of a closed-loop recycling system. A pilot takeback programme was launched to collect used thermostats for recycling of plastics for thermostat component prototypes. Based on the closed-loop validations, it is technically ready for scaling and future implementation.
- **Coloplast** addressed the specific challenges of recycling post-industrial and post-consumer medical devices. In close collaboration with **Trebo** (post-industrial recycling) and **Zirq Medical** (post-consumer recycling), Coloplast conducted several trials and successfully demonstrated the sorting of production scrap into highly pure and usable fractions. Together with Trebo, Coloplast further assessed compatibility

with current recycling lines, resulting in a plan for scaling tests and potential implementation beyond the CIP scope.

- **Chemical Recyclers** (Makeen EnviroTech and Aarhus University (AU running a HTL pilot)) progressed key focus areas in the development of pyrolysis and HTL recycling technologies. Collaborations with **BASF** and **Topsoe** identified commercially interesting fractions from ABS and PA66, though these were not yet viable due to the maturity and complexity of refining processes. Despite technical advancements for the technologies, the readiness and commercial viability of chemical recycling technologies still lagged that of thermomechanical recycling where mass-balance considerations are regarded as a prerequisite for accelerating chemical recycling to commercialisation.

The most mature CIP cases represented by the products in fig. 1 that reached use case level were evaluated on six critical factors to provide a structured framework to assess the value and feasibility of the final use cases. A key insight is that technology development, sustainability impact, and resource investment were central to enabling progress, particularly in advancing recycling solutions and integrating them into the value chain.

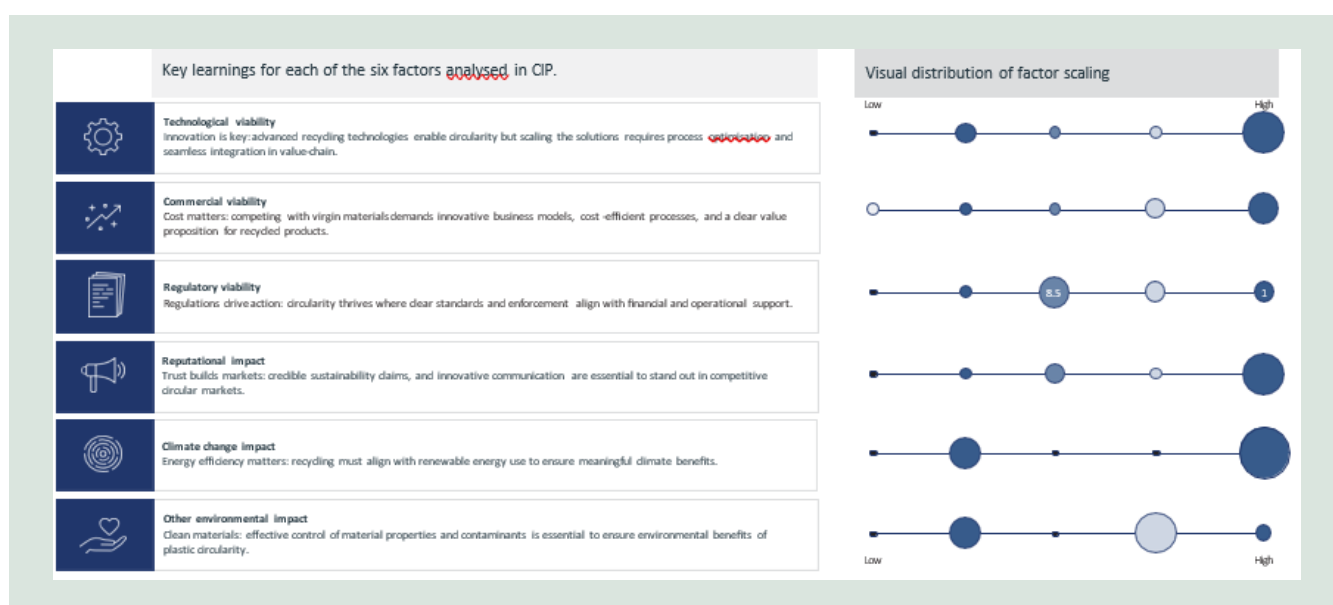


FIGURE 2. Key learnings on six parameters in the most mature CIP cases.

1.3 Recommendations to industry and policy level

Although technical solutions for recycling complex plastic proved possible, there is still a need for both technical and political initiatives:

Improvement of Chemical Recycling Technologies for the industrial plastic fractions.

While progress was made during CIP for the industrial plastic fractions, recycling technologies that complement thermomechanical recycling, such as pyrolysis, HTL, and dissolution, still require continued investment and innovation to unlock their scalability and efficiency.

Enhancement of Product Design for Recyclability with genuine Substitution:

Encouraging product design that prioritizes recyclability will be crucial. This includes designing products with end-of-use considerations in mind. Circular business models should ensure that new products made from recycled materials represent genuine substitution, i.e., that new

products are in demand and substitute otherwise virgin carbon, at best even reflecting radical innovation rather than incremental (where virgin carbon may still be more competitive).

Strengthening Regulatory and Policy Frameworks: Advancing the agenda with policymakers to establish clear regulations and incentives for recycling and sustainability practices will support industry-wide adoption of these initiatives. Long-term political strategies for a circular economy should support the investments necessary across the value chain, making financial incentives clear for all partners. Selected recommendations are listed below.

TABLE 1. Policy level recommendations and drivers.

Policy level recommendation	Driver for policy recommendation
Introduce extended producer responsibility at product level	Ensure producers take responsibility for the lifecycle of their products, including design, material use, and recyclability.
Create incentives for collaboration and novel circular recycling paths	Emphasize fostering partnerships, innovation, and cooperation across industries to develop new recycling pathways and improve circularity.
Subsidize recycled materials and incentivize reentry in similar product quality	Make recycled materials more economically competitive, ensuring they are used in applications equivalent to virgin materials.
Support industry-level efforts for standardization	Encourage uniformity in material types, documentation, and recycling processes to simplify recycling and align industry practices.

1.4 CIP Partnership evolvement

As a result of the CIP partnership, several uncertainties and solution scenarios have been reduced, and the partners now have a more straightforward direction for focusing and continuing to scale the solutions. The future progress will be driven by the partners themselves, in collaboration with their value chain or through innovation initiatives.

The success of the CIP partnership underscores the necessity of collective action in driving recycling and sustainability towards circularity. Stakeholders across the plastic industry are encouraged to:

1. **Engage in Collaborative Partnerships:** Seek partnerships that foster knowledge exchange and provide access to new partners to address challenges in recycling and sustainability.
2. **Invest in Research and Development that Enables Recycling from the Start:** Investment in R&D is crucial for advancing recycling technologies and developing methods to improve material recovery and product design.
3. **Adopt Sustainable Practices:** Businesses are urged to integrate sustainability into their core strategies, including setting Key Performance Sustainability Indicators (KPSIs) focusing on reducing waste, increasing energy efficiency, and using recycled materials, while collaborating closely on these changes with the organisation.
4. **Advocate for Policy Support:** Engage with policymakers to advocate for supportive regulations and incentives that promote recycling and circular economy initiatives.

By leveraging the above and taking the suggested actions based on CIP's way of collaborating, Danish industries may accelerate the transformation towards a more circular future. Support will, in the coming years, be available for different industries, and to SMEs specifically, by several initiatives such as this report and its many recommendations, the conference finalising CIP, and the new partnership initiative "Cirkulær plast – en ressource til fremtidens produktion", funded by the Danish Industry Foundation (Industriens Fond). Ultimately, this may lead to a more sustainable future where industrial plastics are effectively recycled, and resources are used more efficiently. For this, new tools may be required: You can find the free tools developed in CIP - the LCA Product Screening Tool and the Design Tool - in Appendix 1. Partners' experiences and recommendations can be found in Appendix 2.

Reading guide

We will here introduce a reading guide for the rest of the report. As the report progresses, pros and cons for embarking on the circularity journey will be illustrated, for instance what can be recycled or not; barriers and drivers; challenges appearing in the individual partner companies when working with recycled materials, suggestions to other companies who may wish to start with circular initiatives, and for policy level.

For clarification, we include the definitions of sustainability and circularity used in this report:

Sustainability: 'Meeting the needs of the present without compromising the ability of future generations to meet their own needs'. (United Nations Brundtland Commission, 1987).

Consequently, sustainable practices and policies actively promote the longevity of resources for future generations. As a result, circularity aligns with sustainability, being a higher-level goal that encompasses various strategies including Circularity.

Circularity: 'In a circular economy, products and materials are kept in circulation through processes like maintenance, reuse, refurbishment, remanufacture, recycling, and composting' (MacArthur Foundation, 2013). The goal of circularity is to minimize the need for virgin material within manufacturing. This means that products may contain sustainable parts and materials without necessarily being circular.

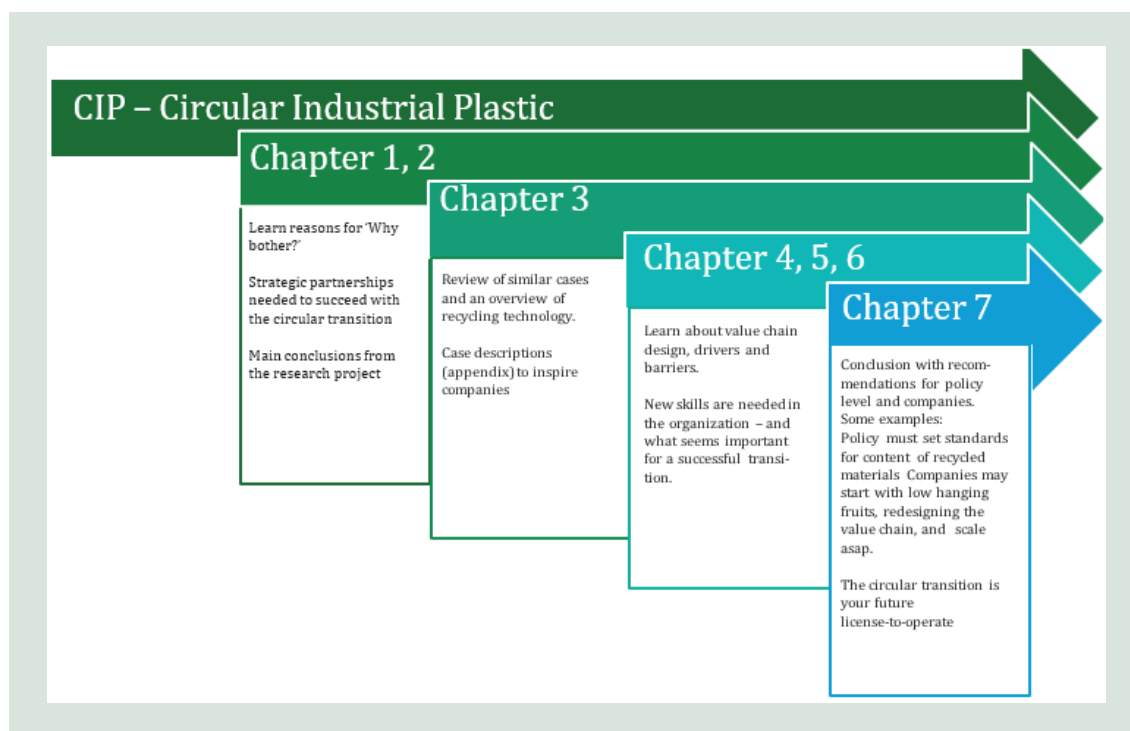


FIGURE 3. Reading guide for report.

Also, we wish to give a brief note on the data and methods behind the report: Our plastic recycling efforts and the value of the chosen recycling technologies have been assessed through LCAs (all LCA screenings went through an internal review at DTU by Professor Thomas Højlund Christensen), we have received a report and review of cases in the EU fairly similar to those in CIP (Rambøll), performed a survey a.o. investigating the circularity maturity of Danish SMVs (Kobra Consulting), a series of videos were made with the partners to showcase the recycled products and recycling processes, and we have made qualitative in-depth interviews with nine partners in the partnership. The report went through an initial external review and all comments from the reviewer were included.

With respect to the qualitative data, we focused on manufacturing companies but also interviewed a waste collector and plastic handler to get the value chain perspective. A semi-structured interview guide was used, all interviews were transcribed in extenso, coded and analyzed in NVivo following topics in the data and those of CIP, a.o. barriers, drivers, challenges, value chain. Word clouds were formed according to frequency of words (signifying the importance attributed to them) and included in the report, not only to show what matters most to those interviewed but also for illustrative purposes. A new topic that turned up in the interviews related to all the social aspects of making a circular transition in a company and we have consequently included this as a chapter in the report to illustrate that while an improved option for recycling plastic may be an option, the whole organization nonetheless needs to be ready for it and what this may entail in practice. We hope you will enjoy reading the report and that our findings and tools may inspire you for further progress **towards an improved recycling of industrial plastic products in Denmark.**

2. Setting the scene of CIP – and reflections on the process

The motivation for establishing CIP was driven by the different companies' ambitions to take environmental responsibility for their products by reducing the amount of virgin materials, hereby, ideally, reducing the CO₂ footprint, as well as their ambitions to transition towards a circular economy.

From the initial partnership discussions, CIP set forth the ambitious task to reshape the landscape of industrial plastic recycling in Denmark. A main challenge for the recycling landscape at the time of inception was the presence of commercially viable recycling technologies that could efficiently process the diverse array of plastic materials used in the industry. Coupled with the fact that many plastic products are not designed for recyclability, this presented significant hurdles within the entire plastic industry.

2.1 The Consortium

Considering these challenges, DTI strategically orchestrated a diverse and robust consortium of partners, forming a comprehensive value chain that extended across multiple sectors of the Danish industry. This collaboration integrated expertise and resources in a unified effort to address these pressing challenges. In this consortium, some of Denmark's leading manufacturing and retail companies were present: Novo Nordisk A/S, Coloplast A/S, Danfoss A/S, Grundfos A/S and F&H group A/S. The partners contributed with their vast expertise in production and distribution, ensuring that the partnership strategies were grounded in practical industry knowledge. To complement this lineup, innovative companies in the recycling industry were included who contributed with technological competence and infrastructural capabilities as depicted in FIGURE 4. Supporting these efforts were three knowledge institutions specializing in circularity and plastic recycling: The Technical University of Denmark (DTU), Aarhus University (AU), and the Danish Technological Institute (DTI), all providing critical research and development support. The partnership was led by DTI.

The financial backbone of this initiative was anchored by partly funding from the Environmental Technology Development and Demonstration Program (MUDP) under the Danish Ministry of Environment. The total partnership budget received a total of 41,9 million DKK, with a requested grant of 18,6 million DKK, while 23,3 million DKK was invested by the partners. This financial structure not only supported but propelled the partnership toward its ambitious targets, ensuring that partners were equipped to meet their commitments and achieve significant milestones in the partnership.

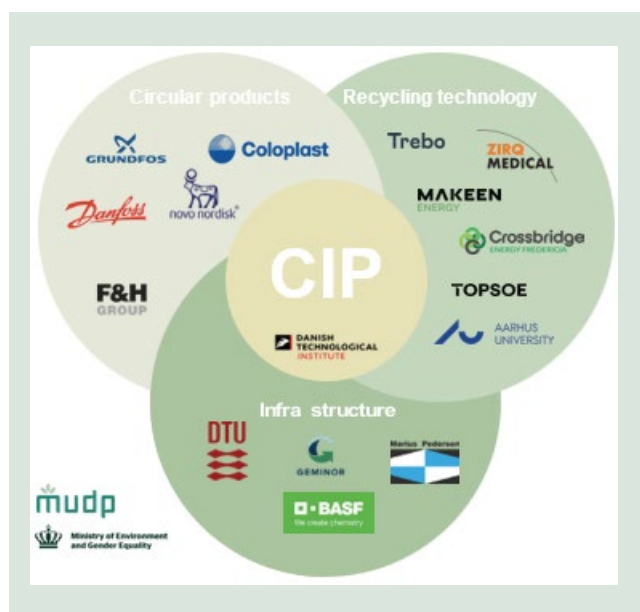


FIGURE 4. The CIP Consortium.

2.2 Partnership execution

The CIP partnership was designed to develop, test, and implement innovative recycling technologies for hard-to-recycle plastic fractions from Danish industry. Importantly, progress was not made in individual company tracks but as a value chain to consult, discover and explore opportunities together. Key to the partnership success was the initial setup of a product-technology matchmaking to identify over 20 potential use case scenarios of hard-to-recycle plastic fractions. This rapid, action-oriented approach leveraged the collective expertise of diverse partners, facilitating both theoretical and practical evaluations. By doing so, the partnership not only advanced the discussion on sustainable value chains and business cases but also provided technical insights into tolerances, grades, and data requirements, demonstrating the power of example and swift learning throughout the partnership and illustrated the transformative power of strategic partnerships. Throughout the partnership key virtues to success were action oriented, collaborative and transparent. According to Kurtz & Snowden (2003), complex problems are characterized by unpredictable cause-and-effect relationships, which can only be understood in hindsight. In such a scenario, an initiative like CIP drive value by adopting a "sense-and-respond" approach, allowing patterns to emerge through collaboration and experimentation.

2.3 Value of partnership

Especially in operations management, supply chain management, and international business studies, value chain collaboration has for the last 10 years been described pivotal in transitioning from traditional linear economic models to future circular frameworks (a.o. McArthur, 2013; Eisenreich et al, 2022). By uniting stakeholders from various sectors and disciplines, the partnership aspired to create a more holistic approach to plastic recycling, moving beyond the classic supplier-to-customer dialogue prevalent in traditional business practices. Emphasizing a partnership-driven methodology, CIP sought to address a larger proportion of the product lifecycle than traditionally done, and to test across industries the recycling efforts. This approach encourages dismantling silos to foster an environment where knowledge sharing becomes the norm rather than the exception.

Platforms, like CIP, is a key recommendation, which facilitate the exchange of knowledge, skills and resources within and between industries is key to advancing circularity (Circularity Gap Report, Denmark, 2023).

Partnerships and circular value chains:

At its core, the CIP partnership sought to illustrate the transformative power of strategic partnerships in driving the development of circular and sustainable value chains.

In a linear reality, partnerships are often deprioritised because it fosters a win-over mentality, as the management team can set a stand-alone direction.

In a circular reality, partnerships are key to success, as one must adopt a win-together mentality in recognition that navigating the value chain alone is no longer feasible.

Partners, ranging from manufacturers and recyclers to academic institutions, brought diverse perspectives and expertise, facilitating a comprehensive understanding of the challenges and opportunities inherent in plastic recycling. The collaborative nature of the CIP partnership was not merely beneficial; it was essential. It allowed for a dynamic exchange of ideas, challenges, and best practices. A synergy that enabled a more nuanced discussion regarding circular industrial solutions, where all parts of the value chain gave input. This model of cooperation serves as a blueprint for other collaborations aiming to transition to circular economies, demonstrating that the whole can indeed be greater than the sum of its parts. Companies involved explored common benefits in greater detail, driving the circular transition through shared impact and values.

By sensing the evolving landscape of plastic recycling and responding through iterative collaboration steps, partners leveraged their collective strengths. This resulted in innovative strategies that matched products to recycling technology and identified new design directions that isolated would have been unattainable.

Additionally, while the material composition of products varied, whether designed to be short-lived or durable, they shared fundamental challenges. These challenges included designs not initially considering the recycling process, highlighting the necessity for technological assistance to navigate and resolve these complex issues. The collaborative partnership structure of the CIP partnership was crucial not only for achieving immediate goals but also for setting the stage for a more sustainable future for the Danish industry and beyond. It contributed to a change in mindset, illustrating how companies can adopt partnership models to foster innovation, drive sustainability, and secure a more circular future for generations.

2.4 Reflections on the process of CIP

As with any pioneering initiative, the path to success was fraught with challenges, presenting both obstacles and opportunities. Technological barriers, particularly in developing new chemical recycling processes for complex plastic materials, and market adoption issues posed significant hurdles. Industries may be reluctant to integrate new recycling technologies into

existing systems. Yet, these challenges presented unique opportunities for innovation. The partnership comprehensive approach allowed for the identification and mitigation of risks through strategic planning and the integration of diverse partner expertise, hereby avoiding the common challenges shown in Fig. 5. This strategy aimed not only to develop practical solutions but also to create a framework replicable on an international scale, amplifying its impact on global sustainability efforts.



FIGURE 5. Common challenges in achieving circular plastic recycling goals, DTI 2025.

It is important to state that circular transition in an organization is inherently a change management within the sustainability domain and should be rooted in the executive leadership team. It is crucial for leadership to decide whether sustainability is merely an appendix to the business or a core part of its value. This decision shapes how effectively a company may drive the circular transition. Once sustainability is embedded in the core business strategy, it promotes not only a culture of innovation but a kind of resilience towards future sustainability requirements, preparing companies for the future circular society.

In sum, the legacy of the CIP partnership exemplifies how product circular readiness is accelerated through knowledge-driven innovation fueled by partnerships that cover the value chain. It shows that the path toward a future where industrial plastic recycling is integral to modern industry is through collaboration rather than isolated developments. Strategic partnerships, innovative technologies, and a steadfast commitment to sustainability positioned CIP to tackle possibilities within circular economies of industrial plastic, setting a precedent for others to follow.

3. From CIP to the European world: Initiatives in Europe for increased plastic recycling

To contextualize the CIP partnership and in line with the ambition of this report – inspiring other companies interested in becoming more circular through recycling of plastic – a review was made to investigate similar partnerships and partnerships and their results, including potential policy recommendations from the identified partnerships. The review focused on EU and EU conditions and involved publicly available information about industry and company cases with relevance for value-chains involving product manufacturers, recyclers, feedstock providers and users of recycled feedstock, with focus on circularity and circular value-chains for industrial plastic. While the ambition was to capture robust learnings from available sources, the included literature is not to be considered exhaustive, and the included cases must be seen as selected key examples. While repairability and business models involving shared use of products and assets are not excluded, the primary focus of the review was on value-chains managing plastic material loops and thus on pathways involving mechanical or chemical re-processing of plastic. Out of 37 initial plastic cases, 19 were identified as particularly relevant, and from here a further selection was made, ending with 13 industry cases chosen for inspiration. These cases are included in detail and accessible through its own link, but below we present an overview of types categorized into four case types, followed by impact descriptions:

1. Initiatives aiming at closed-loop plastic recycling
2. Initiatives focusing on increasing recycled content in products
3. Initiatives creating material feedstock from plastic waste
4. Initiatives promoting new products from plastic waste streams

3.1 Introduction

3.1.1 Four archetype plastic circularity cases included in the business review

The below four types of cases emerged after reviewing the 13 appropriate cases.

1. Full circle	2. Recycle upgrade	3. Feedstock futures	4. Next cycle
Closed-loop initiatives	Increasing the recycled content in existing product portfolio	Creating material feedstock from plastic waste	Designing and selling a new product from plastic waste streams
The aim of these cases <u>address</u> the full value chain. They aim to design existing products to improve recyclability, improve collection through take-back schemes, and then increase the recycled content in new products. These initiatives often include collaborations with several partners across the value chain.	In these initiatives, manufacturing companies aim to increase the amount of recycled content in their product. These initiatives require companies to procure recycled plastic that fits with their existing production processes and thus tend to focus on a single plastic type and not on mixed plastic waste.	These cases center on a plastic recycler, that then sells recycled plastic feedstock to a manufacturer. The aim in these cases is techno-logical innovation within mechanical and chemical recycling.	In this category, the aim is to create new products using recycled plastic. What distinguishes these cases from those focused on increasing recycled content is that they tend to be innovative start-ups making use of mixed plastic waste streams to design consumer products.
- Case 1 - Recycling plastic pipes for construction sector (FI/AT) - Case 2 - Circular Foam (DE) - Case 3 - FAERCH Group Tray 2 Tray (DK) - Case 4 - <u>Bewindo</u> (DE)	- Case 5 - Philips (EU) - Case 6 - Whirlpool (EU) - Case 7 - Recycled ABS plastic (AT/FR)	- Case 8 - Partnership for production of 100% circular plastic (NL) - Case 9 - <u>Cirplus</u> (DE) - Case 10 - <u>Igus</u> (DE)	- Case 11 - Transportation <u>packaging products</u> (DE) - Case 12 - ReMix Blender (DE) - Case 13 - <u>Gomi</u> (UK)

Ramboll

FIGURE 6. Overview of 13 industry cases from EU identified in review (for a detailed description: See Appendix 3).

Based on an analysis of the 13 selected cases, some similarities with CIP appeared despite some of the cases representing manufacturing start-ups. At least 5 similar aspects were found:

1. The need for staying updated on the ideal recycling technology for the specific product and having access to it;
2. Since recycled materials are still a relatively new field to most, CIP partners found it difficult to build a positive business case;
3. Difficult to find the right partners for the circular value chain;
4. Standards were mentioned as highly required in the area; and
5. A need for a new type of trust appeared, one where the partners could trust the quality of recycled materials and the data behind it. Also, the review showed that having the right energy mix would benefit the LCAs, as was the case with one of the use cases in CIP, when e.g. production took place in a country with less green energy types.

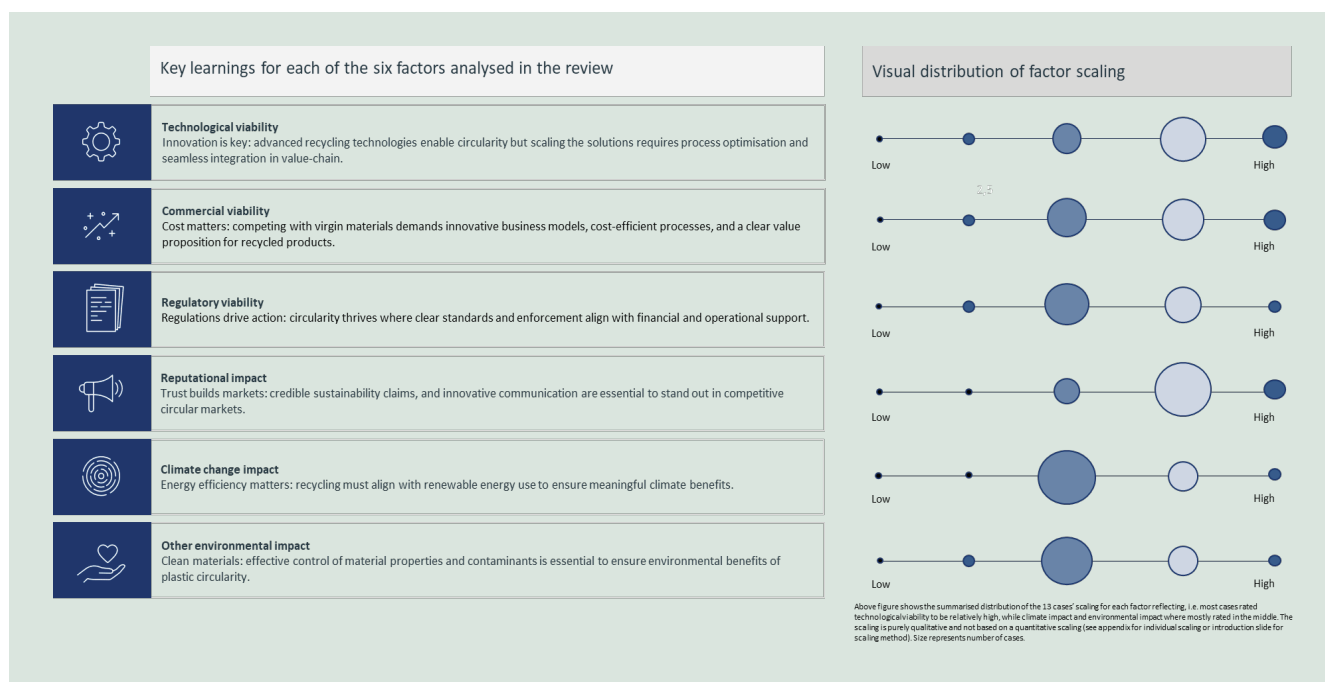


FIGURE 7. Key learnings on 6 parameters in 13 industry cases (review).

To keep businesses updated on the essential recycling technologies for a circular transition, the following section provides an overview specifically on this topic.

3.2 Common and new Recycling Technologies

Today, plastic waste recycling is based primarily on thermomechanical recycling, where the plastic waste is sorted into fractions with similar material properties (e.g. polymer type, color, etc.). Then each sorted fraction is cleaned, mixed, and re-extruded into recyclate for manufacturing of new plastic products. However, other recycling technologies are maturing. As it is important for companies to be aware of the recycling technologies available and their pros and cons, the next section describes these in more detail.

3.3 The existing challenge in recycling technology: Maintaining a high quality

Recyclates inherently suffer from transparency of input material and as a result the recyclate properties represent a mixture of the material properties of the original plastic in the sorted fractions. As the secondary plastic risks to contain impurities, malsorting of polymer types and polymer degradation, the quality of recyclates in many cases are inferior to the original virgin plastic with respect to mechanical properties, processability, odour, colour, durability, etc. Potentially this limits the applicability – and thereby functionality – of recycled plastic. This may also affect the marketability of the recyclates for use in new products. Hence it is key to understand the recycling input in relation to the required material quality, by internal testing or by supplier datasheets. For European conditions, a typical recycling rate for mixed plastic is around 20%, which in a 'closed system' means that plastic on average is recycled about 1.25 times before leaving the system. The recycling rate may be improved by coordinated improvements throughout the entire recycling value-chain: design-for-recycling, collection, sorting, design-from-recycling, etc.

While no recycling value-chain can ensure 100% circularity of plastic, mechanical recycling can be an efficient pathway for recovery of suitable plastic fractions. Yet, in most cases mechanical recycling involves some loss of quality throughout the recycling value-chain. Several new pathways based on novel chemical recycling technologies are under development. While these technologies have different feedstock requirements and different performance, chemical recycling may have the potential for 'recovery' of providing 'virgin-like' raw material for new plastic production. Some of these technologies are already implemented, albeit on a very limited scale, while others are still early in development.

In fig. 8 we provide an overview of key plastic recycling technologies and compare strengths and weaknesses as well as the expected performance. On this basis, the potential impacts from these technologies on plastic recycling at system level is evaluated.

TABLE 2. Archetypes of recycling technologies (Rambøll, 2025, adapted by authors, 2025).

Technology	Process	Energy consumption	Mature feedstock	Recycling output	Level and examples of use
Mechanical	Clean, melt and regranulate	Low Sorting operations and re-melting	Clean, homogenous purity essential	Polymer. Recyclate ready for product moulding.	Widespread. Almost all current plastic recycling (Examples: Zirq, Aage Vestergaard, ...)
Dissolution (Mechanical category)	Dissolve polymers, rinse, regranulate	Medium Distillation of solvent	PP, PE, PS, (separately)	Polymer. Recyclate ready for compounding then product moulding.	PureCycle - PP APK (Lyondell Basell) - LDPE Creasolve (Fraunhofer) - Multiple plastics Trinseo (PC and ABS) Polystyvert (PS and ABS)
Solvolysis	React into monomers, reprocess polymers	High Distillation and repolymerization	Mature: PET and PUR Development: PC, PA, epoxy	Monomer. Clean monomers ready for polymer production	Few specific cases: PUR: DOW, Covestro, BASF, Evonik PET: Eastman, Gr3n, Loop Industries, Jeplan
Pyrolysis	Break down thermally to crude oil. Re-refine.	High Heating the plastic, hydro-treating and refining pyrolysis oil, distillation, repolymerization	PP, PE (mixed) or PS separately or PMMA separately	Crude oil. Refining in several steps to provide building blocks to new plastics. Steps include purification and hydroprocessing.	Novel industry. ~50 small development and demonstration plants. (Examples: MAKEEN EnviroTech, WPU, Quantafuel, ReCraft Energy, Ineos; Hydroprocessing: Topsoe)
HTL	Break down thermally to crude oil slurry. Separate and re-refine.	High Heating the water, water separation, hydrotreating and refining pyrolysis oil, distillation, repolymerization	PP, PE (mixed) Or PET Separately	Crude oil. Refining in several steps to provide building blocks to new plastics (PET: Monomers)	R&D (Examples: Aalborg Universitet, Aarhus Univsersitet, Licella/Mura)
Gasification	Convert thermally to syngas, catalytic synthesis	High Heating the water, water separation, hydrotreating and refining pyrolysis oil, distillation, repolymerization	All but PVC	Syngas. Many synthetic steps required to achieve new plastics.	Novel industry - technology proven. One operating in Japan. Two waste-fed under erection/ commissioning (ABSL, Enerkem)

A homogenous feedstock with high 'traceability' is preferable for most plastic recycling technologies, i.e. well-defined properties and composition. Much of the current examples of high-quality recycling is based on pre-consumer recycling of production cut-offs, products with manufacturing faults, etc. – mainly because this stream can precisely offer high traceability, homogeneity, and useful properties for the manufacture of the same product. Closed-loop recycling can potentially provide some of the same technical benefits by returning a known end-of-life plastic product to the manufacturer of the same (or similar) product. These advantages must, however, more than counterbalance the logistic burdens of selectively collecting end-of-life products and making a dedicated processing system available.

While the above table and its technologies shows an overview of recycling technologies, it does not include the time frame of the technologies, for instance gasification may not be a realistic choice for the next many years. The point, however, is to show that a mixture may be the optimal choice for a company depending on the plastic type. While partners tested out different recycling techniques, a central aim of CIP was to bring value chain members together and foster learning across the value chain. The following sector will focus on value chain aspects.

4. Designing 'value-chains-for-recycling'

Value chains reflect the activity of organizations engaged in delivering a product or service, from conception to end use, covering raw material sourcing, production, distribution, and customer support. To transition from a linear 'take-make-dispose' model to a circular setup, a value chain must prioritize resource efficiency, waste reduction, and the reuse or recycling of materials. In line with systematic literature reviews on value chains (Sudusinghe & Seuring, 2022), the CIP partnership recognized this need for transformation and was launched to change the recycling landscape of industrial plastic in Denmark through a comprehensive value chain approach. The CIP partnership enabled collaboration across the value chain, integrating diverse stakeholders to address complex issues related to recyclability and material recovery. However, the shift from a traditional linear to a new circular value chain requires innovative partnerships and collaborations, and this transition has not been easy for the partners in CIP. All partners had to reconsider the value chain and partners needed for recycling and/or takeback system. They referred to their organizations being in a somewhat new role and the necessity to find new partners, as illustrated in the following quote:

"Frankly, none of us knows a circular value chain, since we simply don't have it yet".

Grundfos

All partners were aware of the challenges of introducing new stakeholders in the value chain but also acknowledged the need for them. Concerns related to getting accurate and correct data, issues of building trust and preferably quickly, but also cost-benefit concerns and thoughts about if customers would eventually welcome (buy) the products.

- **Win-Together Mentality:** Creating a win-together situation aligns interests and incentives within the value chain. The CIP partnership emphasized collaboration so that success was mutually beneficial, encouraging active participation and commitment.
- **Collaboration and Co-Creation:** Successful value chain redesign requires cross-sector collaboration. The CIP partnership fostered co-creation among manufacturers, recyclers, academic institutions, and policymakers to develop innovative solutions tailored to specific challenges. However, new partners in the redesigned value chains were needed and while some were suggested by CIP partners, much work was required to find the right ones for each manufacturer.
- **Technology and Innovation:** Embracing cutting-edge technologies and encouraging innovation are vital for enhancing recycling processes and improving resource efficiency. The CIP partnership used technology matchmaking to identify product and technology fits and integrate suitable innovations into the value chain.

Redesigning an organization's value chain towards increased recycling is very time consuming and a highly individual process that CIP partners referred to as 'essential, but really hard'. Despite the difficulties, the CIP partnership shows successful cases that illuminate the core elements of effective value chain design, demonstrating how collaboration, technology, and strategic alignment can transition industries from linear to circular models.

4.2 Case Studies and Practical Insights for value chain design

Successful Implementations:

One standout collaboration was between Novo Nordisk and Zirq Medical, which focused on recycling medical devices by processing polypropylene (PP) and polyoxymethylene (POM) from multi-component pens. This partnership exemplified upstream collaboration, where understanding supplier capabilities led to innovative recycling solutions that retain material value and enhance efficiency.

Similarly, Grundfos's partnership with Trebo highlighted the critical role of technological enablers. By implementing fluid-based sorting technology to isolate clean polycarbonate (PC) and thermoplastic polyurethane (TPU) fractions, they demonstrated how digital platforms and automation can streamline operations and increase transparency. This technological integration supported the shift to a circular model by ensuring materials can be effectively reused and recycled.

Danfoss' take-back initiative for used radiator thermostats showcased the importance of building trust through transparent communication and mutual respect. This effort created a win-together mentality by aligning interests and incentives, encouraging active participation and mutual success among stakeholders.

Coloplast's collaboration with Trebo underscored the significance of cross-sector collaboration in enabling innovative solutions tailored to specific recycling challenges.

Finally, Makeen EnviroTech's involvement in technology matchmaking demonstrated the critical role of embracing innovation to enhance and understand fit of recycling processes. Using pyrolysis, the output and process effect of introducing ABS and PA66 was successfully evaluated with Topsoe and BASF to identify potential valuable fractions for future scale and market potential.

These examples from the CIP partnership illustrate how trust, collaboration, inclusion of new partners, technological integration, and strategic alignment are vital components of effective value chain design. Together, they ensure a successful transition to a more sustainable and efficient recycling landscape, providing a blueprint for future initiatives in the plastics industry.

Key Takeaways:

1. Effective value chain-for-recycling design involves collaboration, technology integration, and strategic circularity considerations.
2. Value chains-for-recycling place companies in a new role and new stakeholders in the value chain may be required – a time-consuming process, but essential.
3. Closed loops may be referred to as the ideal but often require a tight value chain and a solid takeback system, so consider using semi-closed, open, or entirely open market trading of recycled plastic if there are valuable economies of scale and clear advantages of open loop.
4. Successful implementation of a value chain-for-recycling provides a blueprint for future initiatives.
5. Continuous improvement and adaptation, a.o. inviting new stakeholders on board, are necessary to address challenges and leverage new trends.

The above cases show the differences in the products, but what seemed common were the drivers behind as will be described in the following chapter.

5. Main drivers behind circular transition

Understanding these drivers and barriers is crucial for companies aiming to successfully transition to a circular economy. By leveraging drivers and addressing barriers, businesses can develop strategies that promote sustainability and long-term profitability. CIP partners expressed different drivers for participating, yet appeared more aligned when it came to barriers, reflecting, though, their different role in the value chains and different markets. Some hoped for new customers, others to gain knowledge, yet others felt obliged (but would have done it anyway). While companies investing in the circular transition may see it as a way to differentiate their company, take responsibility, grow their business and gain more specialist knowledge, consumers may be interested in products better aligned with their values, and governments may wish to increase innovation and resilience of society.

At its core, circular economy refers to the recirculation of goods and materials via reuse at product level (such as repair and refurbishment), reuse at component level (like manufacturing), and reuse at material level (recycling). However, while targets for an increased circularity may be pursued at societal level and incentives made to facilitate progression, the real change will be realized at micro level, with firms and individuals producing, distributing, and utilizing products in a more 'resource-effective way' - and this has to be learned, for instance through marketing or communication models, for a shift in consumption to happen (White & Hardisty, 2019).

TABLE 3. Overview with examples of common drivers from two systematic literature reviews (Govindan & Hasanagic, 2018; Tan, Tan & Ramakrishna, 2022) – and those identified in CIP as marked by .

Common company drivers	CIP	Societal drivers	Consumer drivers
Resource efficiency and cost savings		Environmental protection and reduction of impacts	Cost savings
Supply chain resilience		Economic resilience	Product quality and value
Regulatory compliance and benefit from incentives		Job creation and innovation	Ethical concerns, ethical consumption
Market differentiation and competitive advantages		Public health improvements	Health and safety improvements
Brand reputation and customer loyalty	We expected 'yes', but it was not mentioned. Focus was plastic	Sustainable growth	Innovation and customization
Innovation opportunities		Meeting EU & intl targets	
Access to financing	(1 partner)		
Risk minimisation by anticipation of future trends and policies			
Mitigation of climate change and environmental impacts			

A key to successful investment and implementation of circular initiatives in companies is clarity of the goals with the initiatives, understanding of enablers and barriers for reaching these goals, and transparency in documentation of the effects. In CIP, there was a clear focus on development, quality, and documentation, but also a common perception that CIP should provide early data and learnings on recyclability of tangible cases. With the CIP partnership evaluations and discussions were based on in-depth testing of the recycled plastic combined with LCAs documenting potential feasibility based on materials and the chosen End-of-Life recycling technology. All partners aimed at the highest possible quality of recycled plastic, preferably in a closed loop, but as described, one of the learnings in CIP was precisely that closed loops are difficult and, in most cases, not yet economically feasible. The only exception was when a takeback system was implemented and material were validated performance tested, to reintroduce recycled plastic in parts.

But how do we in general know if plastic circularity works? From a material perspective, circularity involves

i) recovery of materials that would otherwise be wasted, ii) potential processing of the materials, and iii) subsequently returning these materials as secondary raw materials in production of new products. The bottom line is that *material consumption is displaced because of the circularity*, hence also includes reuse and repair initiatives. Recycled material thereby substitutes other (virgin) raw material. For this to be efficient, the recycled material should have high substitutability, and the functionality of the displaced materials should be equivalent to the functionality of the recovered materials. However, this may not always be the case. Recovered plastic may not have the desired grade or worse, contain legacy chemicals, additives, or other materials making unpredictable batch to batch variation or even contaminating the plastic. This challenge causes several limitations for the technical properties and use in the production of high-quality products. As a result, plastic that is recycled without transparency might only be possible to be used in specific applications to safeguard consumer health and ensure production reliability. This underscores the importance of the quality of plastic used in the recycling loop in driving circularity forward. Ensuring a sufficiently high quality of recycled plastic was the primary concern among all partners, making it the most frequently mentioned issue in qualitative interviews on the topic of "challenges."

From a mass balance perspective, there is generally an inverse relationship between the quality of a mixed plastic stream and the quantity of recycled material: focusing on high quality in recovery often results in lower quantities. Products made of recycled plastic may have a different price point as well as a different perceived value in the market, relative to the traditional products. This means that products from recycled plastic may not necessarily displace virgin plastic products at a 1:1 ratio. This was also evident from all the CIP use cases but one (chair made entirely of recycled plastic). Another concern, which works entirely against the circular transition, is that low-cost products made from low-quality recycled plastic could potentially drive higher demand, ultimately increasing resource consumption at the system level.

From a resource perspective: While plastic circularity aims to reduce the overall resource consumption at the system level, the product and material levels are critical to document and understand to ensure the intended effects. This was of much concern among CIP partners, worrying that adequate and correct data sheets were not available from suppliers of recycled materials.

From a circularity perspective, it is important to make sure that the substitution, i.e. the recycled product, reflects a genuine market demand or meets a new need. While some use cases in CIP fulfilled this, others were a result of the company not yet being able (or allowed) to substitute part of their products with recyclable materials. One learning from this is that

deciding which products to make from recycled materials should be initiated early and tested for its substitution value to the market. Having an internal process that facilitates such early recycled product ideations or a value chain partner doing this - a product substitution analysis - can be useful and save time once it is established that recycling of the company's plastic material is possible.

So, from an environmental and material/resource perspective, the above may facilitate the circular transition – and the drivers mentioned in fig. 10 were evident in CIP too. But is this enough? How about social and organizational perspectives? Which are the main points of learning in the CIP partnership on these aspects? Unexpected benefits from taking the circular path in the organization appeared. From a research perspective, CIP has increased our knowledge on practical issues related to the transition, illustrating how knowledge sharing and collaboration are vital elements in the organizational progress towards circularity. This was highlighted in a review (Eisenreich et al, 2022), showing that these two aspects were little researched: “Particular foci might be set on knowledge sharing, collaboration mechanisms, contracts, or supply chain integration aiming e.g. to secure secondary raw materials or to establish cross-value chain standards for carbon accounting” (ibid, 8).

The following chapter will describe how knowledge was built in the organizations, since it became clear that a technical solution made no change on its own.

6. Social aspects of a circular transition in the organization: Building competence

To embark on the circularity journey, most manufacturing companies in CIP needed to take immediate actions to address challenges (including those with an elevated level of circularity maturity). These were often of a practical nature, but they also reflected a social aspect: Building circularity skills in an organization and the need for new skills for communicating, solving value chain problems, and working together in new ways. In this chapter, comments from companies illustrate precisely that:

"In our organization, we are uncertain about the drivers. We need to know the coming regulatory demands and how they impact us. We need to be able to explain the complexity of recycling to our suppliers, but also internally".

F&H

"We have had a takeback line for some years now and we still need to know more about circular economy. CIP has given us more knowledge on the importance of value chain aspects."

Grundfos

"We still have problems with handling the waste we receive. If it's not labelled or in a line or has impurities, then we sometimes say: 'We can't use it'. But we can. It's behavioural, I think [...]. We must find solutions together across our organizations for how to use this plastic"".

Letbek (Zirq owned company)

6.1 Building new skills & competencies

Inspired by CIP, new methods were introduced and new skills appeared in the wake - not only the result of a deeper knowledge of recycled materials, but skills that reflected a new way of looking at the internal production waste. For a number of years, Coloplast has had an internal Waste Competence Centre at their major production site in Hungary, running different recycling activities. Being part of CIP inspired the Centre to organize production scrap into four categories based on the recycling technologies best suited to handle them.

Most partners described the significance of having people on board the circularity journey, listening to them and learning about the new practical problems, as illustrated in the following quote:

"Like all other partnerships that start their lives in top management, the top manager must be very good to make it drip downwards. Involving those on the ground is highly recommended".

F&H

"We had to find out, 'how do we do this', so that people also feel that they are seen and heard. The guy processing the material through the machine, it doesn't work if he has to change a filter because it gets clotted all the time. These types of talks are needed to understand what we work with. We need to face our colleagues and learn about their challenges, how we can solve them".

Letbek

Even a company highly knowledgeable and mature in terms of adopting circular principles since long stressed that the right skills in relevant staff was crucial:

"It has been a tough journey the last 3-4 years. The demands from medical and pharma are higher than any other customer group when it comes to waste and recycling. Safety, documentation, procedures, reporting on many parameters. We didn't know this when we started. We had to learn it the hard way, had to hire people to handle this that we didn't plan. We have a safety regime here like no other place. When our new employees go through training, we need to make sure that they have these skills. It's important everyone knows and feels a part of it".

Zirq medical

During CIP, new roles of staff members appeared in some of the partner companies. This new role reflected the need for staff members with a new type of knowledge. A knowledge that covered many aspects of the organization and its manufacturing process, unrelated to the previously mentioned need for the organization to redefine its role within the value chain. Being able to navigate between multiple functions and provide help across the organization was useful for progressing circular ambitions and practical problem-solving:

”Because these roles are not directly related to operations, they seem to be transdisciplinary and also used in different places in the company to facilitate collaboration”.

Letbek

The circularity process towards increased EPR and closed loops requires new skills for a new market:

”We need to be in control of traceability and tag exactly where it comes from and where it’s going. How to do that practically is a new learning and one step up the waste hierarchy. We must be ready and able to say, ‘now we can do this too”.

[collecting/handling separate waste streams for takeback]

Marius Pedersen

6.2 Building a circular mindset means building resilient companies

The risk of staff not understanding or engaging in the circular journey is that they may choose to leave the company. Losing skilled employees who could be assets in the organization's move towards circularity may derail and postpone the entire process and cause loss of competitive edge. It is worthwhile to remember that competences are the most developed and experienced capabilities that become the sources of competitive advantage (Zott, 2003). In short, competences are the organization's differential: Since they are deeply embodied, they are exceedingly difficult to imitate. Competencies also reflect values and beliefs, making them of strategic value. This implies the need to update them continually (Teece, 2014). Competences can be seen as underlying dynamic attributes in staff members and the organization that enable difficult things to be done reliably and economically, and once an organization possesses competence, it may progress in ways not possible previously (Francis et al., 2003).

Circularity-based competences are seen as a set of combined knowledge, skills, and attitudes that enable successful task performances and problem solving. Like adjusting the machines to the new type of recycled materials, setting up a new part of the internal logistics, and dealing with acute problems in the takeback transportation of products. All done in accordance with circularity principles.

However, what seems required is not only agile logistics and a more open-minded staff, but an organizational culture that builds on, supports, and acts according to circular principles from the outset. Organizational changes towards circularity require values modification and alignment with circular economy principles and strategies. This transformation must come from the top:

"Focusing on sustainability is 100% a change management task".

F&H

"There seems to be a focus on carbon emissions, a 'carbon tunnel vision' you could say, but KPIs on circular initiatives might be better. Employee-driven initiatives are great and can showcase potential, but to become an integral part of your business you need support all the way up".

Grundfos

The organizational culture can be understood as a combination of soft and hard assets that together build skills and, over time, competence. Soft assets are based on our individual experiences as well as all those symbols, stories, relations, and values that shape an organizational identity. When enacted, they constitute the collective human behavior in the organization. Hard assets represent all technical aspects that comprise the organization, such as the infrastructure, shared knowledge, technologies, and ability to implement strategies and adapt.

While hard assets are those we can observe, map, and change and thus useful to work with when changes are needed, soft assets are mostly hidden and non-measurable. However, soft assets in a company, being shaped by beliefs, attitudes, and how management behave and enact strategies, may precisely be the glue that makes an organization run smoothly and what motives people to stay in the specific company. One reason being is that soft assets may make people feel personally aligned with strategic values, and thus important for the circularity journey. This alignment may happen through systematic inclusion and dialogue. Circularity maturity is built over time and seems to correlate with building competence.

To support circular behaviors and allow changes in the organization, capabilities and competences need to be built (Christensen & Overdorf, 2000). Competences are translated into results to the organization and reinforce the organizations' values, mindsets, and behaviors. Once acquired circular capabilities and competences meet existing ones, not only will a more circular mindset in the organization be the result, but a mindset that is exploitative and exploratory towards circularity in general.

Company managements that succeed in making the complex match between company core values, strategies, and the circularity agenda will profit from gaining increased competence across their organizations. The company becomes more resilient towards future changes and barriers that would previously have been considered challenging. The word cloud (fig. 10) highlights the topics believed by partners to be the biggest barriers for a circular progression, and these challenges should be addressed openly by management.

Challenges, now converted into recommendations, reflect the following:

- Make sure to have access to the right plastic materials that can be recycled.
- Make sure to deliver high quality of your solution/product.
- Small volumes can be a problem, so consider joining forces with others interested in similar recycled material.

- A negative business case can be the situation, but it is presumed not to be so in the long run, and for this reason, partners found a short-term money focus from management problematic.
- Get your experience – consider takeback solutions, new markets, new roles, identify the right partners.
- Ensure that the organization is ready and mature enough to proceed with the initiative.
- Know your legislation.
- Always avoid green washing in your communication, an obvious point but it reflects that the organization must obtain deep knowledge of recycled content



FIGURE 9. Highest word frequency in qualitative interviews on topic 'challenges'.

Naturally, a negative business case is a major obstacle to gaining the required management support and may be the situation for an initial circular initiative. And it may demotivate staff as well. In the spirit of transparency, CIP wishes to stress that the first initiatives toward recycling plastic/recycled plastic products may indeed be unfeasible and involve a negative business case in the short term, when demand and markets may still be immature. This is of course a problem common to all, but especially problematic to companies selling fast moving consumer goods, where the market is exceptionally price sensitive and dynamic and end customers have specific requirements for colors of their plastic products at home. It is also highly problematic for companies operating in markets dominated by tenders and products for the public sector. Likewise, the significance of scaling should not be underestimated:

”Young companies that enter the circularity area tend to underestimate the basic challenge: logistics. To us it’s essential to get scale. If there is no scale, you will not get impact, and you will not get the economics right”.

The above comments reflect a fundamental problem in all areas that are novel. Being first movers comes at a cost. While scale may not yet be achievable, it should nonetheless be pursued. This is where CIP wishes to advocate for supportive policies and for companies facing similar challenges to collaborate in scaling recycled plastic. Open markets selling high quality recycled plastics with solid documentation for content may become strong stakeholders in the circular future.

Key takeaways:

- Deep knowledge on recyclability in materials and recycling technologies is not enough: Know soft and hard skills in the company and which people who possess knowledge across the organization to promote the circularity journey
- Include the whole organization in the journey, with specific targets and easy cases to get the experiences and successes from low-hanging fruits
- Identify staff members respected and known by many that may serve as ambassadors for promoting the circularity agenda
- Any circular initiative should be discussed in-depth with those staff members that will be involved, and a contact person should be designated for acute problem discussions
- Set ambitious targets, but start with the easy recycling initiatives
- To improve a negative business case, consider costs, how to scale, and value chain partners for reducing costs in the process and gain scalability as soon as possible

7. How can we increase plastic recycling in Denmark? Here are CIP's suggestions

With considerable focus on plastic circularity from policy makers, industry stakeholders, and consumers, a wide range of 'circularity initiatives' have been put forward in recent years; some are sector initiatives claiming more 'circularity by design', others have been manufacturers promoting 'new recyclable products', and yet others may be local authorities implementing new waste-sorting practices. Common for all such initiatives, including a partnership like CIP, are the dependency of a value chain and other stakeholders for success rather than standalone evolutions. For example, 'designing for recyclability' is not enough to ensure circularity of materials in the product. Also required are appropriate take-back systems, recycling technologies, recycling capacities, and market drivers. A review of over 50 initiatives aiming at increasing plastic circularity (H/S: (Lisiecki et al, 2023) has shown that most of these aspects critically depend on other stakeholders for implementing new recycling capacity, new regulation, new economic incentives, etc. to realize the claimed effects on plastic circularity. Some initiatives did not even adhere to basic circular economy principles, such as reducing waste or virgin resource consumption, yet claimed considerable effects on circularity. The bottom line is that *claiming plastic circularity is not enough – real effects should be demonstrated, and pursued, from the beginning.*

This highlights the need for 1: management active in setting both circularity goals and key performance sustainability indicators (KPSIs), 2: the right cultural mindset and people who can address the circularity in agile ways, 3: a detailed understanding of the full value-chain to achieve real-life impact and desired effects – and 4: supportive legislation.

We end this report with some suggestions that may facilitate and speed up the use of recycled plastic in Denmark. And we clarify which ones that need to be addressed by policy level (highlighted in BLUE).



FIGURE 10. Highest word frequency in qualitative interviews on topic 'suggested actions'.

7.1 Embracing Circularity: Suggested Actions from the CIP partnership Learnings

Embedding sustainability and circular economy practices within the plastics industry into company strategies and company value chains is not trivial. Throughout CIP, it has become clear that strategically implemented actions not only enhance recycling, but also *promote responsible plastic use, foster collaboration across intricate value chains, improve organizational competence, and drive legislative support* for circularity. This has been instrumental for a circular progression, and the strategies behind present a way for businesses eager to integrate circular principles into their operations, reshaping the future of plastic use.

7.2 Responsible Use of Plastics

Responsible Use of Plastic requires knowledge of the legacy chemicals in products intended for recycling - a challenge for some partners whose products have a lifetime for several decades. Furthermore, Responsible Use of Plastics necessitates a strategic approach to waste reduction and value preservation. Employing spare parts instead of replacing entire products extends product life, conserves resources, and minimizes waste generation. This strategy is both economically and environmentally beneficial and potentially fosters new business areas. Moreover, it is vital to retain the value of recycled materials throughout their lifecycle, ensuring that recycling processes do not degrade material quality unnecessarily. This retention is crucial for maintaining the integrity and usability of recycled materials.

Critically assessing the necessity of additives is also paramount. Companies should investigate how additives may impact recyclability negatively and strive to minimize their use where possible and avoid creating highly company specific grades if possible. This critical evaluation improves recycling and the overall environmental performance of products. Additionally, reducing the number of industry-available materials can simplify recycling processes and improve material compatibility, further supporting circular economy goals.

Summary of Key Suggestions and [policy level \(PL\) recommendations: \(count/total count\)](#)

- If legacy chemicals, additives, or other included materials can be identified in your old products, exclude them from recycling efforts for now - take the low hanging fruits first and get experiences.
[PL: Introduce extended producer responsibility at product level. \(1/8\)](#)
- Use spare parts to extend product lifespan.
[PL: Incentivize repairability and spare part availability. \(1/1\)](#)
- Preserve the value of recycled materials.
[PL: Subsidize recycled materials and incentivize reentry in similar product quality. \(1/3\)](#)
- Minimize the use of unnecessary additives.
[PL: Introduce extended producer responsibility at product level. \(2/8\)](#)
- Reduce the number of industry-available plastic materials.
[PL: Support industry-level efforts for standardization. \(1/3\)](#)

7.3 Use of Recycled Plastics

The adoption of recycled plastics stands as a pivotal element in the journey toward sustainability. Proactive engagement with waste handlers and suppliers from initial product development stages is crucial to understand the landscape of recycled materials. Such proactive dialogues ensure that recycling initiatives are both strategically aligned and practically feasible. An emerging solution in this area is the development of digital marketplaces, like the 'Cirplus platform' (see link with industry cases identified in review, case no. 9) which facilitates the trade and integration of recycled plastics into supply chains. While such a platform has the potential to completely rethink material sourcing, challenges such as inconsistent material quality due to limited standardization and material remain main barriers.

Simultaneously, it is imperative to minimize the diversity of materials used within products. By doing so, companies can streamline recycling operations, facilitating easier sorting and repurposing of materials. This approach significantly reduces complexity and enhances the potential for producing new recycled plastic.

Designers, as key decision-makers, must collaborate closely with material specialists early in the product development process to ensure that sustainability is embedded from the outset. However, achieving a more circular production system is not just a design challenge — it is fundamentally a management issue. While management often focuses on CO₂ reduction targets, sustainability goals should be broadened to also prioritize circularity. This approach also prepares organizations for upcoming regulatory requirements, such as the EU taxonomy, CSRD, and other emerging frameworks. By setting clear key performance sustainability indicators (KPSIs) and gates on par with already existing KPIs for cost and performance, companies may steer the creation of products that are both innovative and environmentally conscious. Additionally, the implementation of product passports can enhance traceability and transparency, allowing for better tracking of recycled content and facilitating more effective recycling strategies.

Summary of Key Suggestions and [policy level \(PL\) recommendations:](#)

- Understand your own specifications.
[PL: Introduce extended producer responsibility at product level. \(3/8\)](#)
- Prioritize and utilize recyclable materials.
[PL: Subsidize recycled materials and incentivize reentry in similar product quality. \(2/3\)](#)
- Engage waste handlers early in the process.
[PL: Create incentives for collaboration and novel circular recycling paths. \(1/8\)](#)
- Simplify designs and minimize material diversity.

- [PL: Introduce extended producer responsibility at product level. \(4/8\)](#)
- Ensure management support for setting circular goals.
[PL: Require companies to establish circular economy targets for new products. \(1/1\)](#)
- Implement product passports for enhanced traceability.
[PL: Mandate digital product passports to track materials. \(1/1\)](#)

7.4 Design for Reusability and Recyclability

Designing for reusability and recyclability of products containing plastic involves establishing rigorous documentation standards for recycled plastics. This ensures transparency and consistency in recycling efforts, allowing for better tracking and validation of recycled content. Advocating for legislative support to reduce barriers can accelerate the adoption of recycled content in products, creating a more favorable environment for circular practices. Legislation that mandates circular requirements and provides subsidies can incentivize businesses to adopt sustainable practices more readily.

It is essential for businesses to prioritize materials that are inherently recyclable, thereby simplifying recycling processes and enhancing material recovery efficiency. This prioritization not only conserves resources but also aligns with broader environmental goals. An active engagement ensures they remain at the forefront of industry advancements but can be difficult for smaller companies.

Setting requirements for minimum recyclable content in products encourages the use of recycled materials, driving demand and supporting circular economy goals. Businesses should also embrace ambitious and innovative approaches to product design. By challenging conventional norms and exploring new possibilities, they can drive considerable progress in sustainability and circular design. Integrating design-for-disassembly principles may enhance product recyclability, making it easier to recover valuable materials at the end of a product's life. Also, when combined with an instructive end-user guide on the disassembly, it will provide a good outset for communicating with targeted consumers about the need for circularity.

Summary of Key Suggestions and [policy level \(PL\) recommendations](#):

- Establish documentation standards for recycled plastics.
[PL: Support industry-level efforts for standardization. \(2/3\)](#)
- Advocate for legislation that supports circularity.
[PL: Subsidize recycled materials and incentivize reentry in similar product quality. \(3/3\)](#)
- Set minimum recyclable content requirements.
[PL: Introduce extended producer responsibility at product level. \(6/8\)](#)
- Integrate design-for-disassembly to enhance recyclability.
[PL: Introduce extended producer responsibility at product level. \(7/8\)](#)
- Use design-for-disassembly to communicate with consumers.
[PL: Require products to clearly state intended waste handling method. \(1/1\)](#)
- Challenge all plastic materials used in terms of properties and number.
[PL: Introduce extended producer responsibility at product level. \(8/8\)](#)
- Evaluate plastics and targeted waste handling to fit infrastructure.
[PL: Create incentives for collaboration and novel circular recycling paths. \(3/8\)](#)

7.5 Partnerships and Value Chains

Scaling recycling efforts requires robust partnerships across the value chain and may also be useful when companies need new partners to be integrated in the circular value chain. By fostering collaboration with suppliers, waste handlers, and other stakeholders of relevance, businesses can leverage collective expertise to enhance recycling processes and help promote a circular mindset in the organization. Understanding

the intricacies of materials and end-of-life streams is essential for identifying recycling challenges and opportunities. This understanding enables businesses to develop more effective and efficient recycling strategies and will aid the transition of the organization towards a more circular business mindset.

Promoting transparency and open communication is also vital. By being transparent about challenges and engaging openly with other companies, businesses can foster collaboration and mutual problem-solving.

This approach not only strengthens the value chain but also enhances the overall effectiveness of recycling initiatives, paving the way for more sustainable practices. Cross-industry initiatives can further bolster these efforts, encouraging standardization and shared goals that transcend individual sectors.

Summary of Key Suggestions and [policy level \(PL\) recommendations](#):

- Foster robust partnerships for recycling efforts.
[PL: Create incentives for collaboration and novel circular recycling paths. \(4/8\)](#)
- Be prepared for the need to find new partners for the circular value-chain.
[PL: Create incentives for collaboration and novel circular recycling paths. \(5/8\)](#)
- Understand materials and end-of-life streams thoroughly
[PL: Create incentives for collaboration and novel circular recycling paths. \(6/8\)](#)
- Help other companies: Promote transparency about challenges and collaboration.
[PL: Create incentives for collaboration and novel circular recycling paths. \(7/8\)](#)
- Engage in cross-industry initiatives for standardization.
[PL: Support industry-level efforts for standardization. \(3/7\)](#)
- Change of mindset: From winning over each other to winning together.
[PL: Create incentives for collaboration and novel circular recycling paths. \(8/8\)](#)

7.6 Strengthening Political Action for Denmark's Plastic Recycling Transition

While many companies aim to increase the use of recycled materials in their products, several key suggestions outlined above remain hindered by the lack of robust legislation or drivers needed to accelerate a broader transition toward circularity. A recurring request from frontrunner companies is the creation of a level-playing field supported by strong economic incentives. This is because the current emphasis on the "soft values" of sustainability and recycling, such as brand reputation or corporate responsibility, often proves difficult to quantify or valorize in a competitive market. Without tangible incentives or stricter policies, these efforts struggle to gain the traction needed for meaningful change.

A significant step forward would be the implementation of **extended producer responsibility (EPR) at the product level**. Such policies would ensure that producers are held accountable for the lifecycle of their products, incentivizing them to prioritize recyclability, reduce unnecessary additives, and promote material transparency. These measures would not only encourage better design practices but also help create a market where recycled materials are prioritized over virgin plastics.

Additionally, Danish legislation, while aligned with broader EU benchmarks, is mature for further ambition. By setting higher national standards and leading by example, Denmark could foster innovation and establish itself as a global leader in plastic recycling and circular economy practices. For instance, the introduction of **subsidies for recycled materials**—making them more competitive with virgin materials—would address one of the key economic barriers identified by industry stakeholders. Subsidizing recycled materials and incentivizing their use in equivalent applications could move market dynamics to circularity.

Furthermore, fostering collaboration and partnerships across industries is essential. Many companies emphasize the need for **incentives that encourage cooperation between producers, waste handlers, and recyclers** to develop novel recycling pathways and circular value chains. These partnerships would be **strengthened by policies that standardize materials**, recycling processes, and documentation, simplifying the recycling infrastructure and ensuring efficiency. In conclusion, while Danish legislation has been effective in some areas, there is room for improvement to accelerate and truly drive a larger transition. To accelerate the shift toward a circular economy and establish a leadership role in plastic recycling innovation as frontrunners require the legislative and economic framework to turn ambitions into measurable impact.

TABLE 4. Summary of top 4 policy level recommendations.

Policy Level Recommendation (PL)	Repeats	Intended driver for policy recommendation
Introduce extended producer responsibility at product level	8	Focuses on ensuring producers take responsibility for the lifecycle of their products, including design, material use, and recyclability.
Create incentives for collaboration and novel circular recycling paths	8	Emphasizes fostering partnerships, innovation, and cooperation across industries to develop new recycling pathways and improve circularity is needed.
Subsidize recycled materials and incentivize reentry in similar product quality	3	Aims to make recycled materials more economically competitive, ensuring they are used in applications equivalent to virgin materials.
Support industry-level efforts for standardization	3	Encourages uniformity in material types, documentation, and recycling processes to simplify recycling and align industry practices.

7.7 The circular transition: Your future *license-to-operate*

One final comment will conclude this report: Companies that understand the need for collaborative progress towards a circular transition, a.o. by increasing recycled contents of their products and scaling as soon as possible, not only **become resilient and prepared for regulatory changes** with respect to the materials in their products; they basically **maintain their license-to-operate** in a future with fewer resources and higher demands for sustainability. Let's speed up this process together.

As a result of the CIP learnings, DTI together with Plastindustrien has intensified efforts to address the growing challenge of plastic waste in Danish industry. Recognizing that reducing material consumption and increasing recycling are critical steps forward, the Danish Technological Institute is leading the partnership "Cirkulær plast – en ressource til fremtidens produktion". This initiative is part of the larger effort "Cirkulær Produktion" grant pool funded by Danish Industry Foundation (Industriens Fond).

The partnership is directly tailored to the needs of small and medium-sized enterprises (SMEs) and aims to develop practical solutions, equipping them with the necessary tools and knowledge to embed circular processes into their plastic production. As the CIP partnership has been a stepping stone in building this partnership the reference group consists of several CIP partners as well.

By doing so, the initiative not only strengthens the competitiveness of these companies but also supports their transition to sustainable production practices, ensuring they are well-positioned for the demands of a greener future.

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Appendix 1. Free tools from CIP to all interested – the LCA Product Screening Tool and a Design Tool



FIGURE 11. This QR code will bring you directly to LCA Product Screening and its user manual (<https://sustain.dtu.dk/en/forskning/waste-climate-og-monitoring/lca-product-screening-tool>).

Appendix 1.1 LCA Screening Tool for Sustainable Plastics

Introduction and Background

The LCA Screening Tool was developed by DTU Sustain with the intention of providing partners with a quick way of making an estimate of the environmental impacts from waste management. The tool facilitates an overview of the plastic materials and end-of-life recycling technology chosen. The user may define up to three scenarios per product. The scenario definition worksheet allows users to assess environmental impact of different recycling pathways for plastic waste and a 'one pager' combining and comparing the scenarios is part of the tool. The modelling is done according to the consequential method. The tool thus includes large-scale consequences of the decision-making.

Relevance and Purpose

The LCA Screening Tool is exclusively intended for use in the early product design stage and for internal discussions. It can help companies identify different waste management strategies for their products.

The tool is intended to provide an early estimate of the potential environmental impacts of different waste treatment methods for the handling of plastic waste. It is not intended to replace a full LCA for the handling of plastic waste. The tool is exclusively intended for use in

the early product design stage and for internal discussions. It should not be used for reporting of results to the public.

The tool allows for the comparison of up to three scenarios. The different scenarios could be used to test different technologies, assumptions, lifetime impacts etc. The scenarios should not be used to compare different products, materials, or technologies as the uncertainties associated with the results are expected to be too large. The tool uses generic estimates of energy inputs for waste treatment technologies covered in the CIP partnership. Material and technological compatibility cannot be guaranteed.

Design for Recycling: Materials and Processes

Of the 16 impact categories evaluated with the EF3.1 life cycle impact assessment method, a sub-set of five are selected to highlight the key findings of the study, Climate Change, Particulate Matter, Acidification and Fossil Resource Use, which typically are the most relevant when focusing on plastic waste management, based on previous studies (JRC 2023).

In the Waste treatment section, there are 5 subsections (Main waste treatment type; Treatment of residues, Sorting; Shredding/grinding; Extrusion). In the Product definition, there are 2 subsections: Materials (you may choose between up to 10 different plastic materials – user defined can be included) and ‘% of product weight’.

Scenario 1		[Enter product name]					
Waste treatment definition		Product definition					
Main waste treatment type		Materials	Share of product weight [%]				
Treatment of residues							
Sorting of waste							
Shredding/grinding of sorted waste							
Extrusion/pelletisation/chemical upgrading							
Energy composition							
Electricity inputs							
Heat composition							
Clear data from Scenario 1		Transportation					
		Transport type	Distance [km]	Comment			

FIGURE 12. Overview of the scenario definition as seen in the excel tool. White cells indicate required input, while yellow indicate optional input. Depending on the selected waste treatment type, different inputs are required.

Features and Parameters

The main worksheet in this tool is the Scenario Definition (#1) worksheet, where the frame for the screening is set up. The product composition worksheet (#2) is an optional sheet to help in defining the share of the different materials of the included product. The efficiency worksheet (#3) is an optional sheet used for thorough definition of the treatment efficiencies across all included recycling processes.

The workflow in the tool is as follows:

1. **Select Waste Treatment Technology**
 - a. Mechanical Recycling, Incineration or Landfilling (chemical recycling not implemented in the current version of the tool)
2. **Define Optional Processes** (if applicable)
 - a. Sorting
 - b. Shredding or grinding of waste
 - c. Extrusion.
3. **Handle Recycling Residues** (if recycling is chosen)
 - a. Select a treatment method for generated residues.
4. **Define Product Composition**
 - a. Specify polymer type(s) and weight percentage.
5. **Input Treatment-Specific Data**
 - a. Recycling efficiency (if applicable).
 - b. Optional: Define substituted material and substitution factors for virgin plastic displacement.
6. **Additional Considerations**
 - a. Energy composition (used for recycling or energy recovery from incineration).
 - b. Transportation impacts.

The tool is based on handling of 1 kg of material. All inputs should consider that 1 kg of input is required. The tool provides emissions for the treatment of 1 kg of waste input.

Example Scenarios

Scenario 1							
Efficiency of	Sorting	Shredding	Recycling	Extrusion	Pelletisation	Treatment efficiency per plastic fraction	Total treatment efficiency
PP	90.0%	98.0%	95.0%			83.8%	
POM	85.0%	98.0%	92.0%			76.6%	
Silicone	0.0%	0.0%	0.0%			0.0%	

FIGURE 13. Example of efficiency definition targeting different materials.

User Engagement and Validation

The LCA Product Screening Tool was developed in an iterative process between partners and tool developer, allowing for several processes of comments and tool updates. Whenever possible, user feedback on the technical part of the Excel tool was integrated to improve usability.

Target Users

Potential users of the LCA Screening Tool can be product designers and sustainability officers. For ease of use, results are presented in four worksheets: Worksheet #4 presents the characterised and normalised results of the screening. It provides visualisations of the impacts and highlights the ranking of the scenarios, if several are selected. Worksheets #5 to #7 provide a summary of the results and allow for inputs and interpretation from the user highlighting the key results. The 'one pagers' are provided for three scenarios (sheet #5), two scenarios (sheet #6) and a single scenario (sheet #7).

Limitations

As with any tool, having reliable data is vital, preferably from acknowledged sources like LCA databases, Ecoinvent, Easetech, etc. The screening tool is inherently constrained due to it being simplistic. The main limiting factors are the following.

- The tool does not guarantee that the recycling technologies comply with the waste input. In this regard, the tool requires a high knowledge level of the user to provide a robust estimate of the impacts.
- The recycling technologies are limited to small-scale tests and thus full-scale operation, material and resource requirements, and efficiencies are uncertain. The available operational data was limited and expected to be uncertain, being a major limiting factor. To mitigate this, the user can adjust the technologies (energy and material inputs), if more information becomes available.
- Direct emissions are currently not included for the recycling technologies due to a lack of data. This is a simplification and will lead to a potential underestimation of actual impacts.
- Chemical recycling had to be omitted from the tool, due to a lack of data.

The tool includes data regarding the production of a range of materials used for substitution. Substitution in this tool is defined as the avoided production of virgin materials by provision of recycled materials to the market. The materials included are collected in TABLE 4. The materials mainly include plastics and plastic precursors, while a few glass materials are included as well. Metals have not been included, as the tool and the CIP partnership have a focus on plastics. However, the user has the possibility to include their own materials, such as a plastic type not included. Other materials can also be included, however compatibility with recycling technologies might be an issue.

Production data is exclusively from the Ecoinvent data, version 3.10 consequential datasets. The Ecoinvent database covers many plastic types, but not all. It has been decided to exclusively use the Ecoinvent database to keep the data consistent. A different database can yield different results and inconsistencies when mixed.

Outlook and Gains

The LCA Screening Tool can be a steppingstone for companies towards a more circular mindset in the organization, helping them with an overview of their intended products that may foster a more critical approach to material composition and end-of-life choices.



FIGURE 14. The template and user manual for Design Tool for Circular Plastics is available here: This QR code will bring you directly to the tool and its user manual.

Appendix 1.2 Design Tool for Circular Plastics

Introduction and Background

The Design Tool was developed by DTI to facilitate the design of plastic products optimized for circularity, focusing on how the material composition effect product end of life and recycling. This tool is part of the CIP partnership's broader initiative to transition from linear to circular economies in the plastics industry and aims to include CIP learnings. It enables users to enter information about product material composition, assess circular readiness, and explore material alternatives, thereby enhancing the sustainability of product designs.

Relevance and Purpose

Designing for circularity is crucial in tackling the pervasive issues of plastic waste. The tool supports designers and engineers in making informed decisions that align with circular economy principles, by conveying recycling consequences from the design and material choices. Its primary purpose is to guide the development of products that are inherently more fit for recycling, facilitating their integration into a recycling solution. By looping over designs, users can build knowledge and optimize product circularity designs iteratively. The tool provides a simple comparison between initial scenarios and those incorporating recycled materials, offering insights into potential improvements.

Design for Recycling: Materials and Processes

The tool provides a database for selecting the most common materials used in the plastic manufacturing industry. It aims to highlight the importance of choosing materials that can be easily separated and recycled, thereby enhancing the product's circularity. Users begin by entering product information and material composition on Page 2, where they receive preliminary CO₂ estimations and recycling scenarios to get an initial idea of the design consequences. For a more precise assessment, users are encouraged to obtain exact material data from suppliers, which can be entered in Tab #7, Custom Material Data, for direct use in the tool.

Features and Parameters

Key features of the tool include a user-friendly interface that allows designers to input various design parameters and receive feedback on recyclability and material compatibility without specialist knowledge. The tool evaluates parameters such as material type, ease of disassembly, and potential environmental impacts. On Page 3, users can evaluate a product's circular readiness, scoring how circular a product is based on empirically derived questions regarding recyclability design considerations. setups for easy access and future reference,

facilitating iterative improvements. The "Save this configuration" feature requires macros to be enabled.

Target Users and Limitations

This tool is aimed at product designers, R&D teams, and sustainability professionals across various sectors, including consumer goods and packaging. In depth technical knowledge is not required since the focus for the tool is to mature an initial understanding of how design affects recyclability. While the tool offers a built-in database of most types of used plastics, new or specific materials can be introduced by custom input into the database prepared to be directly useable in the tool.

Outlook and Gains

The Design Tool is poised to assist product design by unlocking recycling consequences. By facilitating the creation of products that are easier to recycle and reuse, the tool contributes to reduced waste and improved resource efficiency. This not only supports environmental goals but also enhances the competitiveness and innovation of companies adopting circular design principles.

Appendix 2. Partner descriptions: Differences in maturity

CIP partners not only represented different markets, products, and customers (hence different value chains); they also referred to being on different levels of the organizational 'maturity scale for circular economy' (Acerbi et al, 2021; Uhrenholdt et al, 2022), a scale that ranks companies from 1-5 (1 lowest, 5 highest).

Originally, the circularity maturity scale has 6 levels (ibid), but in the survey and during interviews level 5 and 6 were combined into one, making the scale less complicated. The levels reflect:

1. NO maturity: Company has no circular mindset or elements of a circular economy (CE) in strategies or activities. Only regulations, like waste management or environmental safety measures, are in place.
2. BASIC maturity: The company has started to identify the need for circular economy and discusses how and where to start.
3. EXPLORATIVE maturity: The company has initiated demo and pilot partnerships across different functions to prove the value of circular economy and the capacity of the organization.
4. SYSTEMATIC maturity: The company has taken actions to pursue CE as part of the organizational structure. Successful pilot partnerships are implemented, and steps for scaling taken.
5. INTEGRATED/REGENERATIVE maturity: Circular initiatives are made and synchronized across the whole organization and with critical members of the value chain. Fully engaged and focused on CE, ensuring regeneration (recirculation/recycling/reuse) of materials in all operations.

While most CIP partners placed themselves at level 3, some felt closer to level 2 (one felt level 1), explaining that their organization needed a change of mindset. To progress, further training of staff was required, but naturally increased training was also required for companies higher on the maturity scale when introducing a new waste handling process (medical waste).

The above picture is not uncommon. A report on the status of circularity among Danish SMVs (Hauge et al, 2022) identified the problem of companies lacking the right knowledge in the organization for making the transition. While most had organized environmental assessments, companies felt they were still not mature enough to work strategically with CE. Also, a recent survey (forthcoming, 2025) on the use of recycled plastic in Danish SMVs illustrated that organizations may not be ready yet, as it showed that the highest maturity level also has the highest % stating 'there are no significant barriers related to organization and competences.' The lower the maturity level, the more they felt the organization was not ready to make the necessary move to recycled plastic. These were the results of a much larger number of respondents, of course, but CIP partners were quite open about their need to progress further in the circularity field. The partners referred to learning from each other, and an increased collaboration may have a positive effect on actions initiated and the maturity level of each.

The following individual partner presentations describe reasons for joining CIP, challenges met during the partnership, the main impact from participating, and their recommendations for other companies interested in pursuing a circular path.



FIGURE 15. Grundfos logo.

1. Company presentation

Grundfos is a global leading pump manufacturer with around 20,000 employees, operating within 4 business divisions: Commercial Building Services, Domestic Building Services, industry and Water Utility. Our official company purpose is stated as: We pioneer solutions to the world's water and climate challenges and improve quality of life for people. To this end, sustainability has always been at the core of our business and a pivotal element in our success in delivering innovative, high-efficiency, energy-saving pumps and water solutions to a wide range of applications and customers. Within our sustainability framework, circular business is a key pillar, and we focus on both the elimination of waste as well as the continual use of resources. For a number of years, we have operated a takeback system that has provided us with valuable insights into end-of-life (EoL) products and materials. These efforts, in combination with material expertise and our testing and manufacturing capabilities, are the main drivers for how we pursue recirculation of the plastic types we use.

2. Why we participated in CIP

In Grundfos we recognize that no one company can succeed in isolation with circularity; this will always require collaborative efforts across the whole value chain. And this is particularly true when it comes to industrial plastics, as both recycling technologies and infrastructure are not very mature. We have participated in CIP to both learn about relevant recycling technologies for our specific plastic usage, but also to discover and connect with partners that can help in closing the loops – an exercise requiring both a local insight and a global outlook. As a desired outcome, we wanted to establish a decision basis, connecting our plastic types to an optimal recovery route.

3. Our main activities in CIP

Within CIP we have looked at polyesters, polycarbonates and polyamides – all being engineering thermoplastics with fiber-reinforcement and additive packages. These materials are key in our products and are used for encapsulations, internally in motors and for fluid contact. Some cases have focused on mechanical recycling, e.g. where we have collaborated with partnership partners in terms of preparing waste for new production as well as separation of mixed plastic waste. These efforts have demonstrated the technical feasibility, and we have succeeded with utilizing polyester production waste into the production of a new component. Furthermore, it has demonstrated the necessity to sort waste into clean fractions. On physical/chemical recycling we have explored both pyrolysis, hydrothermal liquefaction and dissolution. Although we only perform at lab/pilot scale, we have learned which technologies are best suited for the plastics we use in Grundfos. A noteworthy case has been the collaboration with Trinseo regarding dissolution of EoL polycarbonate waste. This is of particular interest to Grundfos, as this dissolution technology not only can yield virgin-like material from waste but also holds the potential of purification wrt legacy substances of concern.

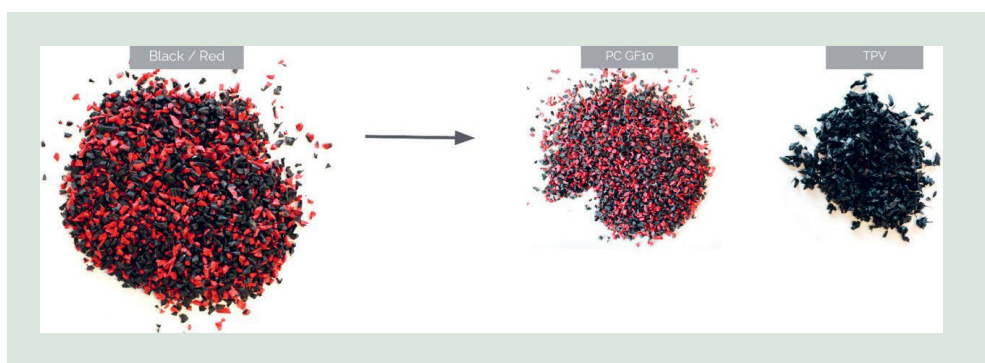


FIGURE 16. Example of sorting results of mixed plastic fraction into PC and TPV.

4. Main outputs and challenges

A major output from the partnership has been a deeper technical understanding of what recycling technology is most suitable for a given plastic type. Selecting the right technology is paramount to ensure that plastic recycling is both profitable and environmentally sound.

Another key output has been connecting with other partnership partners and learning how they can contribute and what is important from their perspective when scaling solutions.

It remains a challenge that many recycling technologies have not matured to the point where they can support a viable business case. Remaining technical challenges, uncertainties regarding scalability, and a lack to properly document environmental impact (via LCA) are key barriers.

Another challenge is an uncertain regulatory landscape around industrial plastics. We know that regulations will come into effect (EcoDesign, Digital Product Passport etc.), but we do not have exact details on how and when this will impact our products.

Grundfos delivers durable, high-quality products, and ensuring compliance and not compromising quality are non-negotiable. Here EoL plastics present a challenge that must be addressed. How can we ensure traceability and properly document that EoL plastics do not contain harmful legacy chemicals and have a technical quality that allows for recirculation. To this latter point, lack of rapid, non-destructive testing of remaining useful lifetime is a technical challenge across industries.

5. Our role in the value chain

Grundfos might have multiple roles in the value chain for recycling of industrial plastics, and it remains to be seen if the true closed loop opportunities are going to be open, semi-closed, or fully closed, either driven by demand, resiliency or regulation. However, recognizing that we are not a material recycler, the main role of Grundfos could be that of a “material provider” to either recyclers or directly back to suppliers. This could be collected post-industrial waste (from own production) and also post-consumer waste (from EoL and takeback). For Grundfos to be able to use such plastic waste into new components, it would require that the recycled material could be supplied with proper documentation regarding material safety and performance.

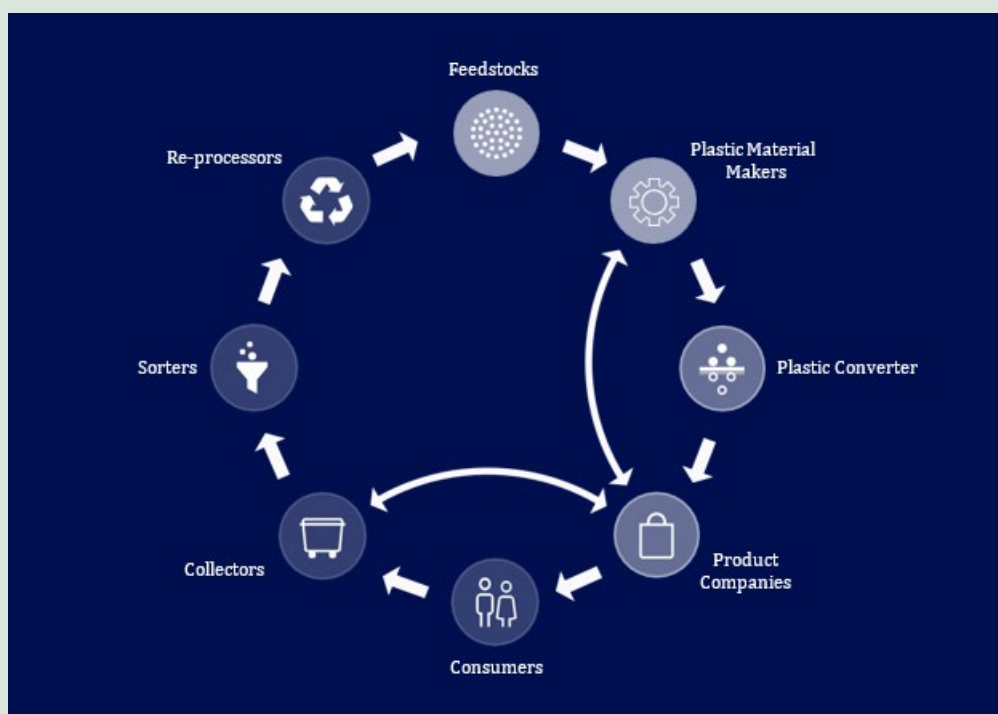


FIGURE 17. Overview of Grundfos value chain.

6. Our main recommendations to other companies

Ensure organizational support from top management. Employee-driven bottom-up initiatives are great and can showcase potential, but to become an integral part of your business you need support all the way up.

Identify where you fit into the value chain and act. Accept your responsibility and role in achieving circularity, but also where other partners are better at solving a task. Find and engage with these partners by proactively reaching out.

Match recycling technology with your exact needs. Many new technologies are developing, and there is no “one size fits all”. Find the recycling technology provider that can facilitate recycling of your specific plastic with the highest economic value and lowest environmental impact.

Appendix 2.2 Danfoss



FIGURE 18. Danfoss logo.

1. Company presentation

Danfoss is a global leader in engineering solutions, focusing on climate and energy-efficient technologies. The company designs and manufactures products for cooling, heating, motor control, and industrial automation.

Committed to sustainability, Danfoss drives the green transition and enhances energy efficiency worldwide. Founded in 1933, it operates in over 100 countries with more than 41,000 employees dedicated to innovation and excellence in technology for a better future.

At Danfoss, we engineer tomorrow by emphasizing energy efficiency, crucial for achieving the Paris Agreement goals. Our 2030 ESG ambition is to be the preferred decarbonization partner for customers, targeting carbon neutrality in our operations and reducing emissions across the value chain. We are committed to designing products for a circular economy, addressing resource demand and waste reduction. Our Rethink-Reduce-Recirculate (RRR) approach fosters innovation by transforming business models, minimizing material and energy consumption, and maximizing product reuse. We pursue recycling and circular economy strategies by applying the RRR approach in product design, collaborating on new recycling technologies, and engaging in circular business models such as take-back and remanufacturing. Our goal is to enhance resource efficiency and reduce environmental impact while achieving our sustainability targets. The Danfoss Circularity Framework and Sustainable Design Guide supports our engineers in developing sustainable solutions.

2. Why we participated in CIP

Participation in the CIP partnership allows Danfoss to collaborate with relevant partners, as achieving circularity requires working within and creating new value chains for reverse logistics and recycling used plastics. This partnership presents a strategic opportunity to enhance our circularity focus, strengthen initiatives for sustainable products, and stay ahead of regulatory requirements through knowledge exchange with like-minded partners. By engaging in this collaboration, Danfoss can significantly advance recycling of industrial plastics, reduce environmental impact, and reinforce our commitment to sustainability.

3. Our main activities in CIP

In the CIP partnership, Danfoss has established a take-back pilot with a customer to return used radiator thermostats to recycle plastic components. On the technical side, plastics recycling has been explored with closed loop mechanical recycling for PBT and ABS in the thermostats, with pyrolysis for ABS, and with HtL technology for PBT. Further, dissolution technology is being tested for polycarbonate materials for removal of legacy chemicals, with results still pending.

Mechanical recycling: Preliminary results of mechanical recycling demonstrated that mechanical properties of the recycled materials were within specifications of those required for same virgin materials for radiator thermostats. Prototypes of the new thermostats with recycled

content in relevant components also passed all tests for final products, leaving aesthetics a final issue to evaluate.

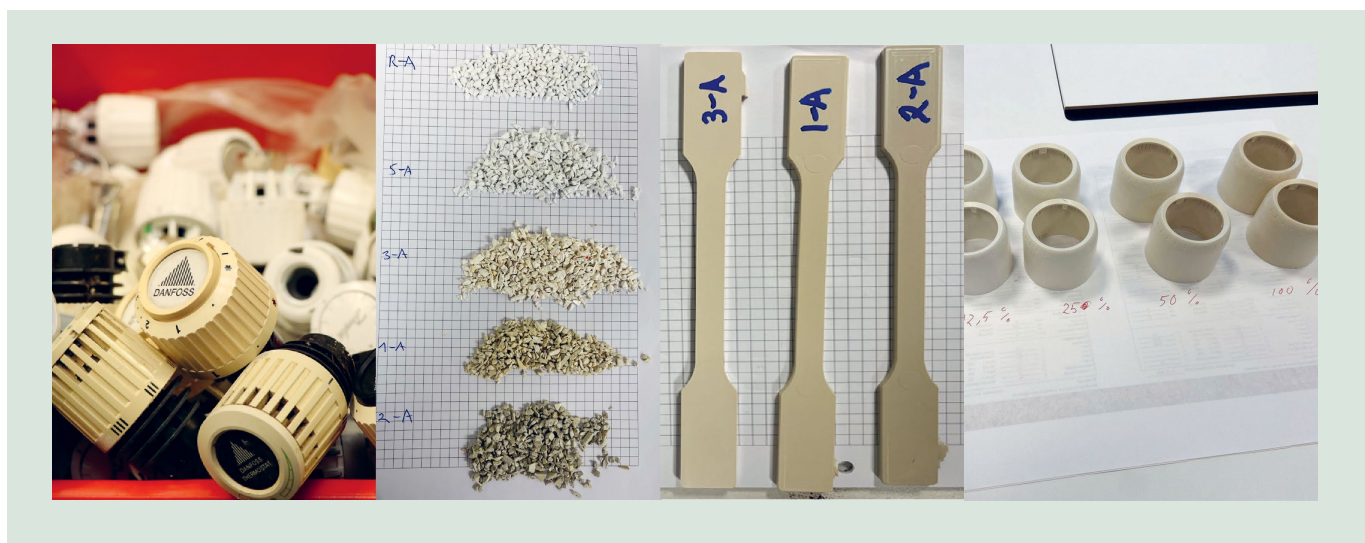


FIGURE 19. The exploratory journey from used thermostat to grinded material, tensile bars for mechanical testing, and to prototype thermostats.

Disassembly and sorting: Disassembly of end-of-life products and sorting of materials were further basic steps required to be addressed to make any recycling of end-of-life thermostats possible. Internal investigations of processes and partnerships for disassembly were investigated and a prototype disassembly tool developed. Sorting of mixed plastic materials was demonstrated with Trebo, proving that it was possible to sort materials in high quality, i.e., purity above 99.95 % and yield above 90 % for ABS and slightly lower for PBT.



FIGURE 20. Plastics from end-of-life thermostats and resulting materials after test sorting at Trebo.

Chemical recycling: Other technologies for chemical recycling of relevant plastic materials from thermostat were also explored; however, with less success.

A chemical recycling investigation of ABS via pyrolysis showed that the produced pyrolysis oil properties were not ideal for either steam cracker feedstock or for purification into chemicals. The process is mainly designed for post-consumer plastics like PE and PP and did not demonstrate potential for ABS.

A study on hydrothermal liquefaction (HTL) was conducted for PBT reinforced with 30% glass fibers. HTL breaks down polymer chains into basic monomers, allowing for the creation of new materials like those from fossil feedstock. Although high depolymerization rates can be achieved with materials like PET, PBT, and PC, we encountered process challenges with the glass fibers and found no clear potential for recycling glass fiber-reinforced PBT using this method.

Related activities: While making the practical tasks of establishing a takeback pilot and conducting technical recycling and material tests, we carried out numerous investigations, calculations, and considerations related to sustainability, partner identification, logistics, and regulations for takeback solutions. We have also explored how to scale these initiatives and the associated technology and logistics. This work has provided valuable insights and raised additional questions that will require further investigation and discussion with partnership partners.

4. Main outputs and challenges

As a partner in the CIP partnership, Danfoss has successfully driven a pilot take-back initiative by collaborating with a customer, arranging reverse logistics, and testing materials for recycled content in new prototype products. This partnership has been instrumental in overcoming obstacles, as partners have shared knowledge and identified key collaborators. The collaborative approach has effectively addressed challenges that could have delayed or halted progress, ensuring a continuous internal focus on advancing circular products and providing a platform for this important ambition.

Some major challenges encountered include the immature market for reverse logistics, which lacks the necessary systems to efficiently manage product returns. Without a robust reverse logistics network, closing the loop becomes difficult. Another challenge is the demand for volume from waste handlers. Waste management companies often require large quantities of materials to make recycling economically viable.

Circular products may not yet be produced or returned in sufficient volumes, reducing economic incentives for waste handlers to participate in circular systems.

Addressing these challenges requires the development of reverse logistics systems and economic models that support handling smaller volumes of circular products. Further collaboration among manufacturers, waste handlers, policymakers, and consumers are essential to create a more mature and efficient market for circular economy practices.

5. Our role in the value chain

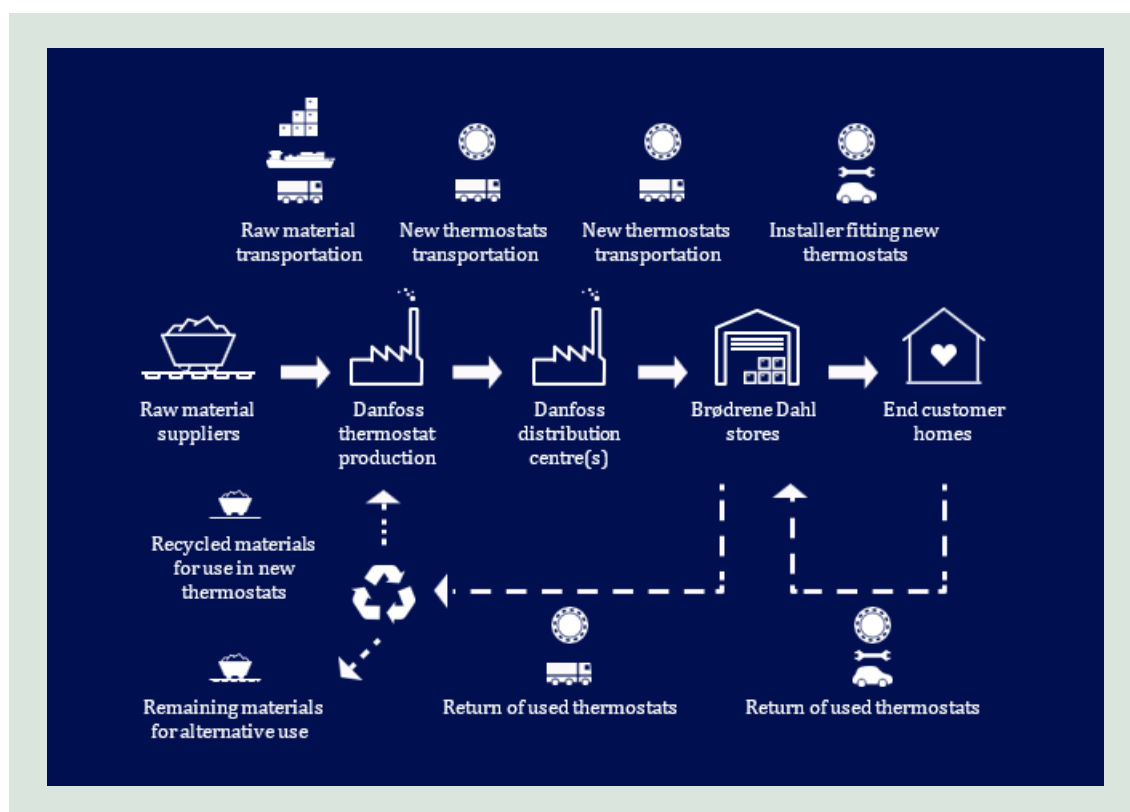


FIGURE 21. Danfoss value chain for thermostats.

6. Our main recommendations to other companies

- **Design your products for Circularity & Disassembly:** Prioritize designing products that allow for easy disassembly and recycling. Use compatible materials, avoid mixed materials, and enable straightforward component separation to boost reuse and recycling efforts, driving your company towards a sustainable circular economy.
- **Try it out, make pilots, be brave:** Embrace experimentation by launching pilot partnerships and taking bold steps in your recycling initiatives. Testing new ideas will help you learn, innovate, and pave the way for effective solutions in your sustainability efforts.
- **Enter partnerships:** Forge new collaborations with partners you previously didn't have access to, such as waste management companies. These partnerships can provide valuable resources and insights, enhancing your recycling efforts and driving greater sustainability.
- **Map the reversed value chain:** Ensure you understand the end-of-life (EOL) of your products by mapping the reversed value chain. Treat your waste partner as a supplier, leveraging their expertise to optimize recycling and recovery processes for your materials.



FIGURE 22. F&H Group logo.

1. Company presentation

F&H Group A/S is a brand house within the kitchen, living and dining categories. The company was founded in 1945 and has since developed into a global player with 340 employees with offices in Denmark, Norway, Sweden, Germany, France, the USA, and a sourcing office in China.

Our mission is to deliver products that make a positive difference in consumers' everyday lives. We value innovation and integrity in everything we do. Recycling is part of our vision for the future, where we work to increase the use of recycled materials while balancing the requirements for specific product groups, such as food contact material.

2. Why we participated in CIP

Our participation in the CIP partnership comes from the desire to learn more about plastic recycling and to strengthen our position in a more sustainable direction. With increasingly complex legal requirements and increased expectations from customers and the market, it has been important for us to gain access to TI's specialists.

An important goal has been to build a solid knowledge base about the properties and life cycle of plastics. We shall use this knowledge to both design better products and ensure correct consumer information about how plastics can get a new life after the use phase.

3. Our main activities in CIP

In the partnership, we focused on analyzing and mapping the types of plastic we use in our products. We have worked to identify which types of plastic can be recycled and what opportunities there are to replace existing materials with recycled alternatives.

We have prioritized products without food contact, as this area offers more opportunities for recycling. The collaboration with the TI has resulted in, among other things, a practical guide – a two-pager – that helps our buyers assess recyclability and choose the right materials.

4. Main outputs and challenges

The biggest impact has been the extensive knowledge we have gained about plastic materials and their recyclability. This knowledge gives us a strong basis for making informed decisions in our product development.

There have been several challenges. A significant barrier is that many types of plastic, esp. combinations of plastics, are only recyclable in theory, but not in practice. At the same time, the market is not yet mature enough to pay the additional price for recycled materials. Finding a balance between environmental concerns and commercial sustainability has been a recurring challenge.

5. Our role in the value chain

We are in the middle of the value chain, acting as the link between suppliers and retailers/end users. Our role is to ensure that our products are designed and produced with a focus on quality, functionality and sustainability. This requires a close dialogue with suppliers to choose the right materials and ongoing work on product design to optimize recycling.

Illustration of a proposed value chain for a recycled Hoptimist, produced since 1968. We anticipate testing a Hoptimist made of recycled plastic some time during 2025.

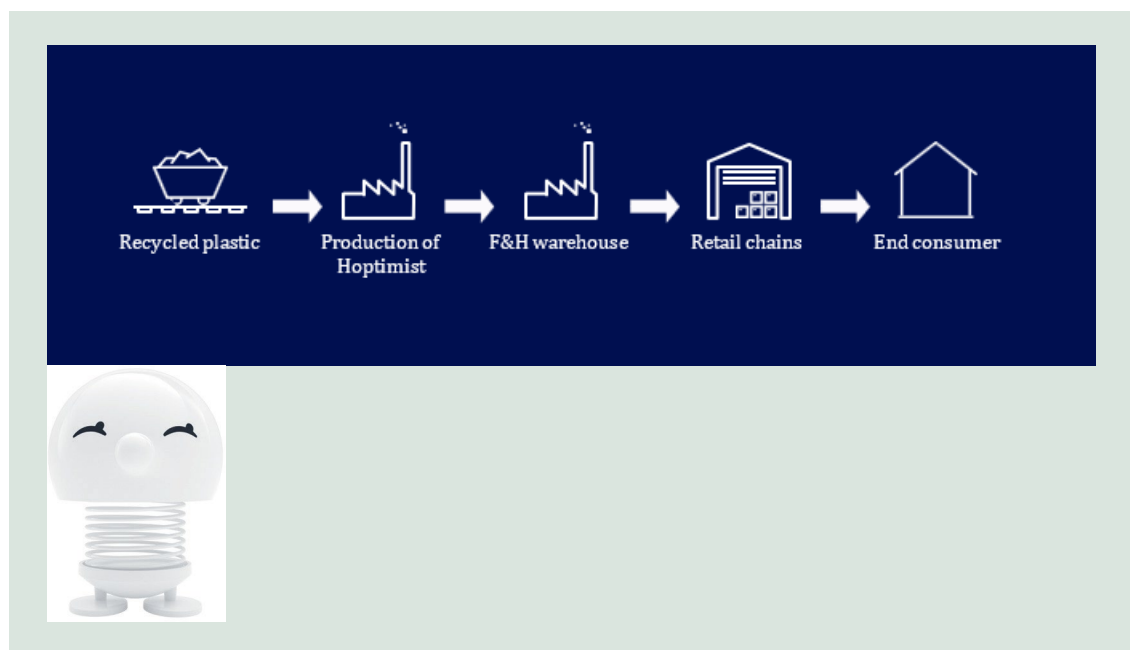


FIGURE 23. F&H Value chain from raw material to end consumer.

6. Our main recommendations to other companies

- **Prioritize expert knowledge:** It is crucial to collaborate with specialists to understand the possibilities within recycling and get concrete solutions.
- **Think circularly from the start:** Recycling should be considered already in the design phase. Ensure that products can be included in a circular economy and be careful with communication to avoid greenwashing.
- **Focus on economics and business cases:** To achieve success, sustainability must be able to be integrated commercially. A realistic business case is necessary to create internal and external support.



FIGURE 24. Trebo logo.

1. Company presentation

Trebo was founded in 2018 as a result of a search for a technology that could solve a fundamental challenge in plastic recycling: the separation of mixed plastic fractions. The problem is that plastic materials often become a useless resource because they cannot be separated efficiently. Without this separation, plastic often ends up as waste for incineration or landfill. Trebo's founders, two engineering students, invented a technology that could effectively separate different types of plastic from each other, and which enables the sorted plastic to return to the original production from which it originated. Shortly after this, the technology was patented and today Trebo operates a 3000 m² sorting factory in Albertslund with 30 employees. Trebo works based on the mission: *to transform the linear life cycle of plastics into a circular and sustainable model*.

Using our advanced sorting technology, we strive to maximize the utilization of existing plastic resources in order to minimize the environmental impact of plastic production. Since 2018, our technology has been further developed, optimized and automated and we have expanded our capacity. This has allowed us to run a profitable business today and offer our customers sorting and closed-loop recycling of their own mixed plastic fractions at a cheaper price than virgin material. In addition, there is a major development in plastic recycling – and we are noticing that there is increased pressure and interest in the sustainable management of plastic waste.

Plastic recycling is the future. Plastic is a necessary material, but the material's *raison d'être* rests on our ability to sort and recycle. Trebo's technology fills a technological gap in recycling – so now it is important that large companies dare to think in new ways and demonstrate readiness to adopt the circular practices that our technology and services pave the way for.

2. Why we participated in CIP

Participating in CIP has given Trebo access to resources and collaboration opportunities that have been crucial to our growth. The financial contribution from the partnership has helped us develop and install our large-scale sorting lines in Albertslund, thus enabling us to take major steps forward. Furthermore, the partnership has brought together several partners across the industry, which has opened valuable networking and collaboration. Knowledge sharing between partners has been a key factor, as it has given us access to expertise and technical solutions. At the same time, access to the background knowledge of research institutions has strengthened our technological development and provided commercial advantages.

3. Our main activities in CIP

New customers and network

- Received around DKK 5 million in support for the implementation of our large-scale sorting system in Albertslund through the CIP partnership. This funding has been crucial for our ability to attract potential customers with large quantities of plastic waste to sort.
- Signed commercial contracts with several of the participants in the CIP partnership.
- Achieved commercial, technical and operational professionalization.

- Expanded our network significantly through the partnership's partners.

4. Main outputs and challenges

Experience from the partnership can be divided into three main areas:

Technical lessons learned:

- Successful implementation of Trebo's sorting system for recycling different plastic waste streams.
- Developed a statistically sound quality control method to ensure sorting quality.
- Optimized pre, core and post processes in relation to the sorting system.
- Conducted feasibility studies for different products and waste streams from companies such as F&H, Coloplast, Novo Nordisk, Danfoss and Grundfos.
- Operated a full-scale sorting line at full capacity for over a year, proving the efficiency and reliability of the technology.

Commercial experience:

- Successful pilot partnerships with Grundfos have resulted in commercial agreements for closed loop recycling.
- Danfoss pilot take-back program for radiator thermostats, with commercial feasibility now being evaluated.
- Investigated methods for open loop recycling with companies such as KD Feddersen Group to overcome closed loop challenges.
- Feasibility studies have laid the groundwork for larger pilot partnerships and potentially long-term contracts with CIP partners.

Operational lessons learned:

- Implemented additional security measures and employee training programs to reinforce safety protocols.
- Developed a comprehensive maintenance program to ensure long-term reliability and performance of the sorting equipment.
- Optimized waste flow infrastructure in production to create a better framework for large-scale production.

Biggest challenges/barriers:

- Closed-loop recycling is a comprehensive process that requires a long process from collection to reintroduction into new products.
- Many companies are not yet ready to implement closed-loop recycling.
- Companies often lack clear goals or strategies for recycling and can be indecisive.
- Slow decision-making processes and often complex bureaucratic structures.
- Large companies are generally less risk-averse, which can hinder collaboration.
- Larger companies require significant resources and attention, which can divert focus from other important partnerships.
- Compliance with relevant regulations and standards for large established companies places high demands on documentation and implementation.
- Uncertainty about the financing of the partnership, esp. what is covered by CIP and what is self-financed.

5. Our role in the value chain

Trebo is an 'enabler' of circularity and recycling. We receive plastic converters' waste, sort and prepare it for recycling and then send it back to the same customer – in a closed loop.

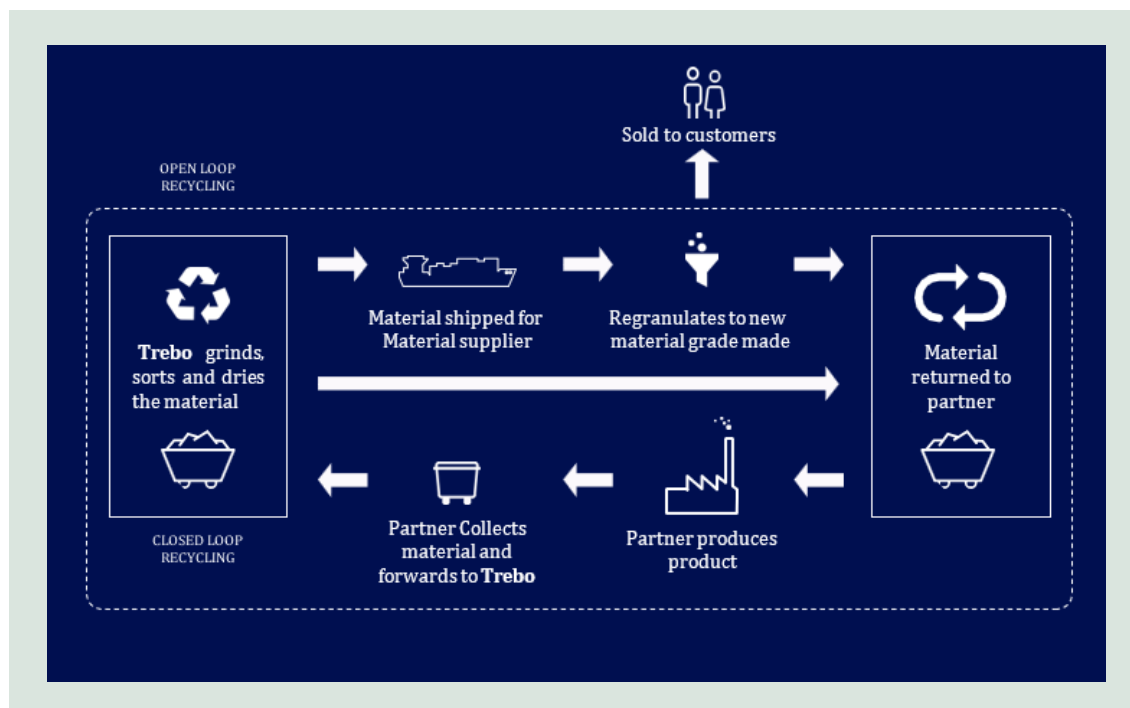


FIGURE 25. Trebo position in the plastic recycling value chain.

6. Our main recommendations to other companies

Collaboration and knowledge sharing across the value chain! Creating circularity in the plastics industry is a super complex task and requires a holistic approach, where recyclers, companies, research institutions and other actors work together to find solutions that no single actor can solve alone.



FIGURE 26. ZIRQ Medical logo.

1. Company presentation

Zirq Medical (ZM), part of Zirq Solutions and ultimate parent NG Group, is a young Danish company, established in 2021. The company employs 15 people, mostly in Stenlille, Denmark. NG Group's vision of Pioneering Circularity is well aligned with ZM's vision of doing so within the health industry.

NG Group is the largest waste & recycling company in the Nordics, with a firm presence in Denmark. ZM have started its journey in Denmark but have international scaling ambitions. ZM have developed unique technologies for decontamination and recycling of hazardous clinical waste. Several thousand tons of medical waste have been processed since inception in 2021, with recycling rates at 75-85%. The target is to scale the solutions in close collaboration with key players in the industry.

2. Why we participated in CIP

ZM believes in the strength of partnerships and close collaborations across the value chain. CIP was a great opportunity to collaborate with likeminded companies from across industries and resulted in very useful with participants from academic and research parts of the specter.

3. Our main activities in CIP

ZM has developed its sorting technologies and capabilities. Especially is this the case for injectables (such as diabetes pens). The collaborations have mostly been with CIP-participants within the medical field, such as Novo Nordisk and Coloplast. ZM's daughter company, Letbek, has been an important collaborator as well, having tested first, and thereafter produced on an industrial scale, a range of plastic products made of recycled plastics from medical devices. A lot of testing, measuring, adjusting, etc., have been necessary to succeed with scaled volume solutions. Examples of products that ZM and Letbek have succeeded with are the R.U.M. chair from Whelers and a water drainage system from Milford. (see photo below).



FIGURE 27. Example on chair produced by recycled injection pens from Novo Nordisk.

4. Main outputs and challenges

The biggest impact of participating in the CIP partnership is learning about other participants' challenges and ways of thinking, as well as collaborating with these partners. A challenge for us has been that our technology is proprietary and thus secret, and therefore not possible to showcase in detail among the other participants.

5. Our role in the value chain

Our role is mainly as a recycler. However, we also act as an advisor regarding design for reuse and recycling, as well as a manufacturer of plastic products from recycled plastics (through Letbek). Additionally, we play a role in being a supplier of recycled raw materials, and the documentation and traceability connected with the benefits of this. See figure below.

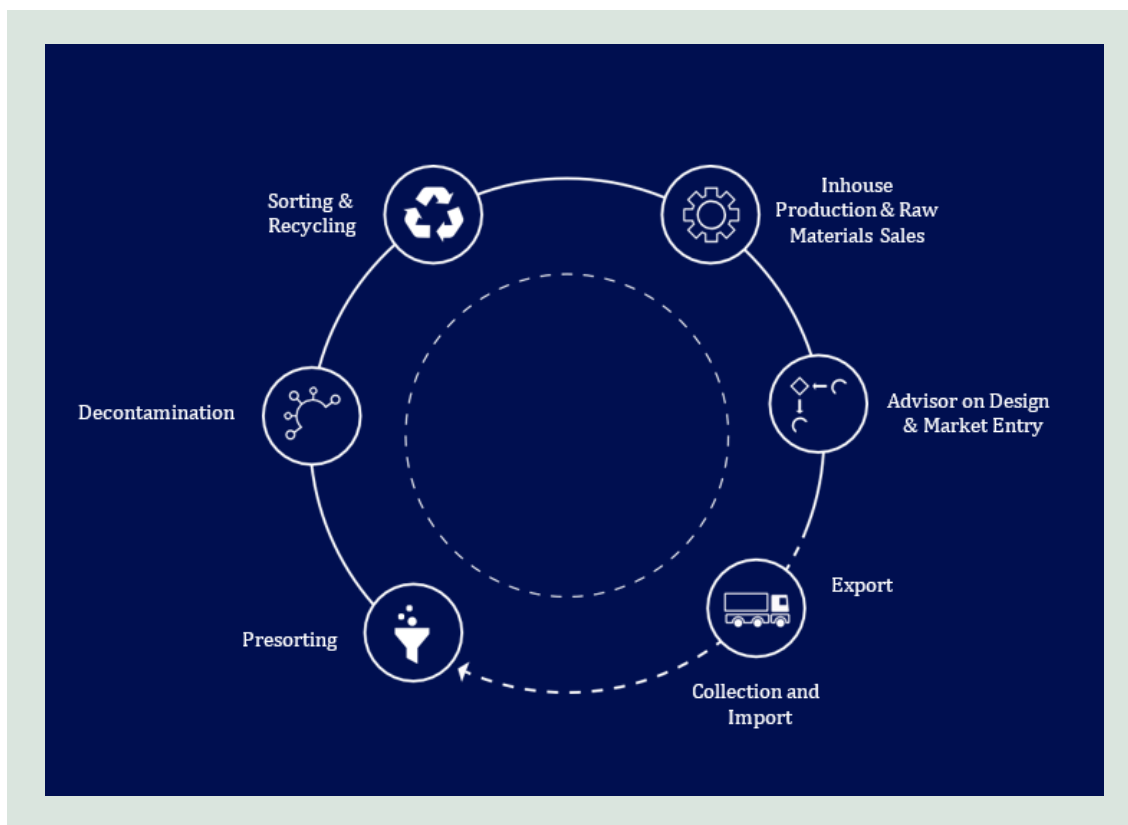


FIGURE 28. Zirq position in the value chain.

6. Our main recommendations to other companies

- Align with likeminded partners that are sharing your vision and ambitions;
- Start small but think big (impact is only achieved on an industrial scale);
- Dare to challenge existing truths (especially internally);
- Be practical – rather go quickly to concrete partnerships, testing, failing, adjusting, testing, iterating, etc – than spend too much time on the drawing board. A lot will be learned through actions and experiences.

Appendix 2.6 Coloplast

1. Company presentation

Coloplast is a global medtech company that specializes in the development and production of medical devices and services in the areas of ostomy care, continence care, advanced wound care, voice and respiratory care, and interventional urology. The company aims to make life easier for people with intimate healthcare needs by providing high-quality products and solutions that improve their quality of life.

Coloplast employs over 16,000 people, owns manufacturing facilities in more than 10 countries and helps people with intimate healthcare needs in over 140 countries.

Mission

Coloplast's mission is to make life easier for people with intimate healthcare needs by developing products, services, and solutions that improve the quality of life for those who use them.

Coloplast's sustainability agenda

At Coloplast, we believe using the planet's resources to create products comes with great responsibility. That's why we are challenging our behaviors and reinventing how we do business to supply our users and healthcare professionals with more sustainable products and services. For us, it's all about finding the right balance that enables people with intimate healthcare needs to maintain fulfilling lives while we focus on minimizing our environmental footprint.

As we grow to create access for even more users, we have made it a clear priority to do so in a sustainable way. With our Strive25 sustainability strategy, we have made it a priority to improve our products and packaging and reduce our emissions while committing to always operating responsibly.

2. Why we participated in CIP

- Expand our network and build potential new partnerships
- Gain information about new and upcoming recycling technologies
- Engage in sparring about challenges and opportunities with like-minded companies and potential partners
- Investigate and test potential recycling cases of our own

3. Our main activities in CIP

- Recycling of catheter production scrap to evaluate Trebo's recycling potential and limitations.
- Investigating the feasibility of a potential catheter take-back initiative by utilizing Zirq Medical's existing lines.
- Evaluating the recyclability of our flexible packaging solutions to enhance our understanding of their compatibility with currently available recycling technologies.

4. Main outputs and challenges:

- Overall, the partnership was an invaluable learning experience that provided us with new perspectives on how design and technology can contribute to more sustainable solutions.
- CIP has strengthened our organizational setup for circular innovation by acting as a lever for dialogues across functions with an eye for circularity in a different way than before
- The CIP partnership has provided the opportunity to test technological and volume/operational feasibility without considering the business case. This has given

us clarity on some questions that we have left open due to the inability to demonstrate a business case

- Valuable networking with interesting learnings
- The partnership inspired us to organize our production scrap into four categories based on the recycling technologies that could be used for handling the waste. Through the learnings from CIP, we have been able to identify suitable end-of-life recycling technologies for many of our waste streams, which is a significant milestone.

5. Our role in value chain (Product developer and product manufacturer)

6. Our main recommendations to other companies

- Complete detailed and specific mapping of your waste streams
- Identify technology providers/partners based on waste stream composition
- Start small tests on your streams with partners – they can do a lot with controlled streams



FIGURE 29. MAKEEN logo.

1. Company presentation

MAKEEN Energy is a global company that provides technological solutions, equipment and customer support to various industries within the energy sector. We have 3,900 employees across 6 continents and operate in more than 140 countries.

With our broad knowledge of innovative technology, we also develop plants for recycling plastic waste: Plastcon. Using pyrolysis technology, the plastic is converted into high-quality pyrolysis oil, which can be used to develop new plastic products that must meet certain requirements and standards, such as food packaging and medical products.

2. Why we participated in CIP

With our pyrolysis plant, Plastcon, we want to contribute to the creation of a circular life cycle for plastic waste. Our participation in CIP was based on testing the need for this solution, as well as to help define standards and methods for the recycling of plastics from the industry. In CIP, we had the opportunity to investigate the connection between industry and consumer consumption of plastic, with the ultimate goal of pushing the development in a circular direction.

3. Our main activities in CIP

We have done batch trials with PA with 30% glass fiber reinforcement. The trial was intended to contribute oil for analysis at Topsoe but only succeeded to a limited extent as working with the glass fibers proved more challenging than expected. The trial was conducted in two rounds, with different set-ups, to try to solve the challenges, which was also partially successful.

In addition to batch trials, we conducted three large trials in our test reactor where the trials were run as continuous trials over 12 hours. The trials were run with MAKEEN feedstock with added PA and ABS to investigate how it affects both the pyrolysis process and the quality of the oil produced. The quality of the oil was evaluated by Topsoe, who compared it to a background experiment.

4. Main outputs and challenges

We have benefited greatly from working with the other companies in CIP, especially Topsoe, where we have had many common interests. We both work with chemical recycling, but at different stages of the process, and have therefore been able to share knowledge without putting too much emphasis on special interests and competition. The partnership has taught us more about where the strengths of our technology lie, and thereby sharpened our focus on which plastic fractions we should focus on and which we should leave to others. Industrial plastics are difficult to get real value out of in a pyrolysis process as they complicate the process and often degrade the final oil quality. There is a risk that the added plastic contributes negatively, and that pyrolysis becomes just a way to get rid of plastics that are difficult to recycle.

We find that many companies, both in and especially outside CIP, still see pyrolysis as a technology that can handle all plastic waste fractions and convert them into oil. This is partially correct, but it's not necessarily a good solution as there are better and more efficient methods of recycling. In addition, manufacturers should consider their own plastic composition for more efficient recycling.

5. Our role in the value chain

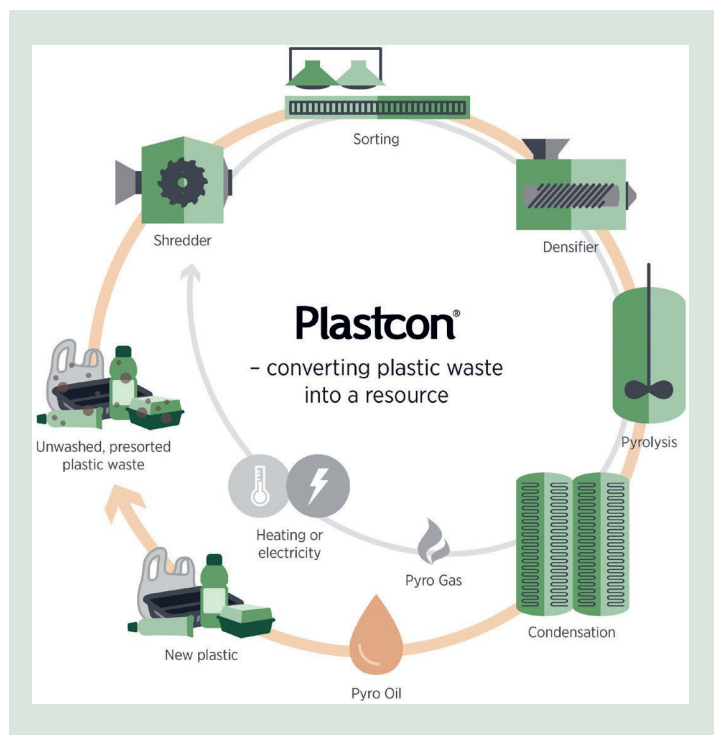


FIGURE 30. Makeen position in the recycling value chain.

16. Our main recommendations to other companies

- Be clear about the types of plastics your technology needs to handle. This allows you to aim more industry-specifically and map relevant companies.
- Consider whether the plastic introduced in the process adds value to the final product or if it's just a way to make it disappear.
- Find good partners, both when it comes to the supply of plastic, as well as when it comes to sparring about the finished product.



FIGURE 31. Marius Pedersen logo.

1. Company presentation

Vision, strategy and business areas

Marius Pedersen is one of Denmark's leading companies within the waste and resource industry. We consider waste as a resource and are constantly working to maximize the share of waste for recycling and to minimize the share of waste for incineration and landfill.

Core competencies:

- Services related to waste and recycling management from the customer to final recycling or disposal, i.e. consulting, equipment rental, transportation and collection services and reporting.
- Production, pre-treatment and sorting of waste at our own facilities for maximum recovery and recycling.
- Trading in recyclable resources and waste

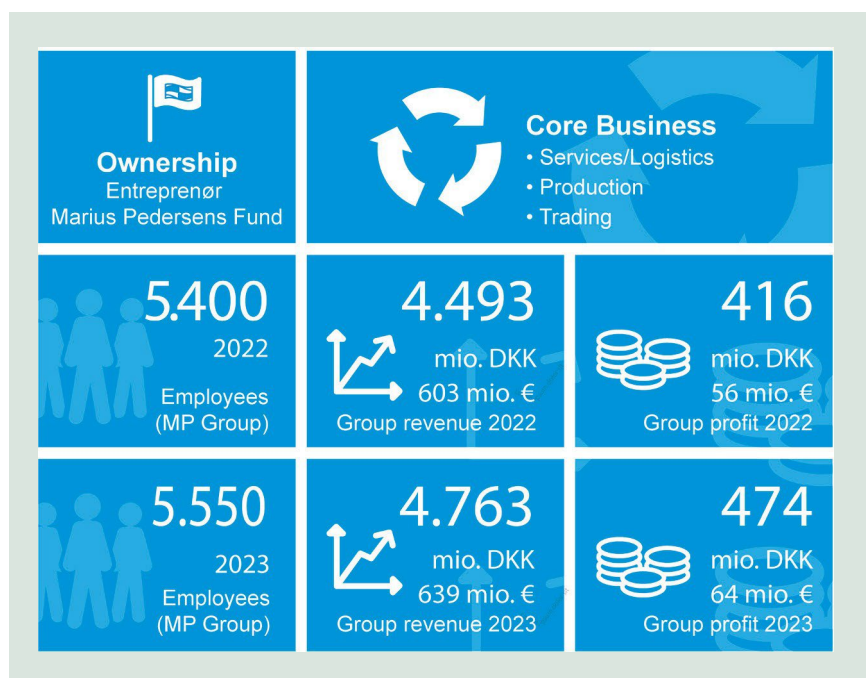


FIGURE 32. Marius Pedersen in numbers.

2. Why we participated in CIP

We serve a number of customers who have challenges with recycling their plastic waste and plastic rejects from their production. It is therefore natural for us - together with both knowledge institutions and companies

- to jointly research and develop new recycling methods and circular business models (e.g. take-back). This gives us up-to-date insight into both challenges and solutions.

3. Our main activities in CIP

Our role has been focused on knowledge and experience sharing. We have extensive experience in handling waste streams from companies of all sizes and from all industries, and we have our hands in the matter both as waste handlers and as plastic recyclers. We have presented and shared this knowledge in CIP.

4. Main outputs and challenges

The CIP Partnership has given us valuable insight into the challenges that exist and those that are on the way - when it comes to industrial plastic waste. The challenges can ONLY be solved together, and the CIP partnership has been an invaluable platform, from innovation and theory/research to practical and executable solutions. Plastic cannot always be replaced by more easily recyclable materials and therefore solutions must be found to increase reuse and recycling and minimize incineration and disposal. That is why partnerships like CIP are necessary.

5. Our role in the value chain

Marius Pedersen A/S plays a central role in the recycling process. From the collection of waste from production - all the way to recycling when the product reaches end-of-life.

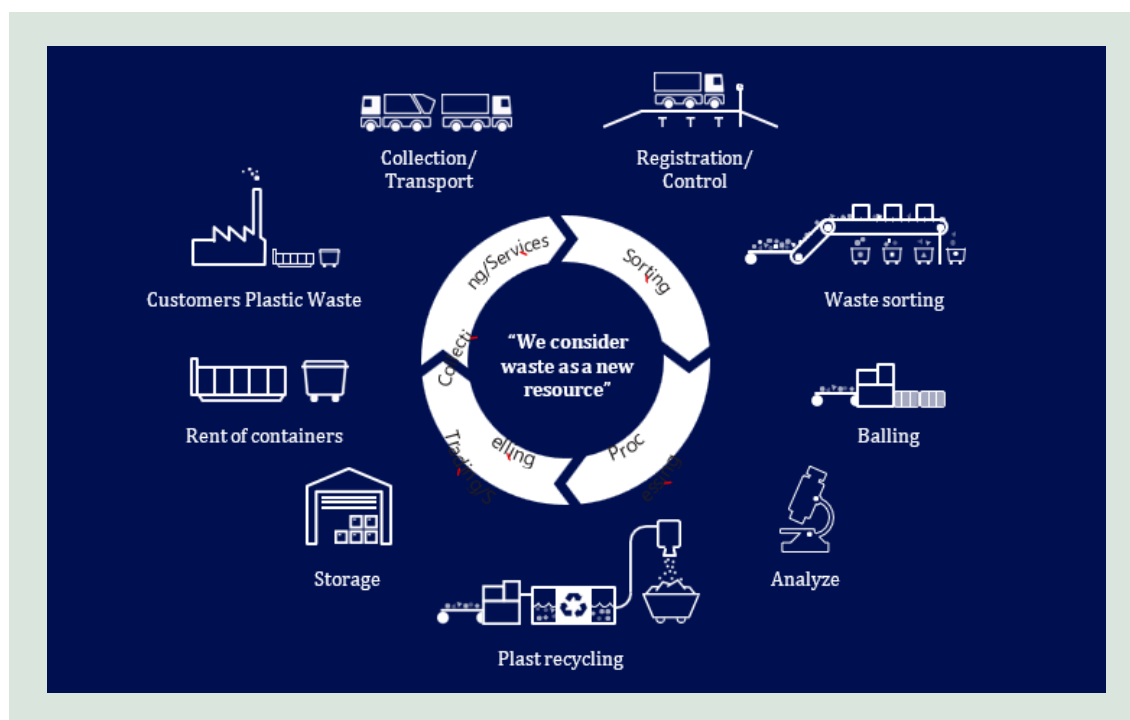


FIGURE 33. Marius Pedersen's role in the waste and recycling value chain.

6. Our main recommendations to other companies

- You are not alone! Recycling plastic requires collaboration across the value chain - so seek out these partnerships
- Think outside the box! New innovative solutions need to be brought to the table!
- Be open and share both problems and solutions



FIGURE 34. Topsoe logo.

1. Company presentation

Topsoe is a leading global provider of technology and solutions for the energy transition. We combat climate change by helping our customers and partners achieve their decarbonization and emission reduction goals. Climate change is one of humanity's biggest challenges. We need to take urgent action to reduce the detrimental effects of how we produce and consume, how we move around, how we live our lives. Some actions are straightforward. Others are more complex. These are the ones we tackle at Topsoe. Based on decades of scientific research and innovation, we offer world-leading solutions for transforming renewable resources into fuels and chemicals for a sustainable world, and for efficient and low-carbon fuel production and clean air. We were founded in 1940 and are headquartered in Denmark, with over 2,800 employees serving customers all around the globe.

Our PureStep™ technology enables production of high-quality naphtha from a variety of plastic waste pyrolysis oils. It is a solution based on decades of know-how within hydroprocessing now applied within the circular economy. It belongs to the chemical recycling technologies portfolio. The technology is commercially available and is expected to be adapted to future feedstocks, as the liquefaction technologies mature and expand their capacities over the coming years.



FIGURE 35. Illustration of the PureStep™ path from raw pyrolysis oil towards high-quality oil for plastic production.

2. Why we participated in CIP

It was specifically of interest to Topsoe to learn more and assess the compatibility/feasibility of our PureStep™ technology with industrial plastic. Most of the commercial dialogues targeting recycling revolve around the use of post-consumer packaging waste as feedstock and industrial plastic is to some extent an unknown. Being able to provide a solution for assessment by others and participate in discussions across the value chain for industrial plastic was seen as very valuable to Topsoe. Additionally, closer interactions with the liquefaction providers gives opportunity for cross pollination between the adjacent technology steps.

3. Our main activities in CIP

Our role in the CIP partnership has been to characterize the properties of liquefied plastics, produced via either the pyrolysis or hydrothermal liquefaction of waste plastics, and to give feedback on the suitability of the liquefied plastics as feedstocks for hydroprocessing and eventual chemical recycling. Some examples from the partnership were generated in connection with the pyrolysis (by MAKEEN Energy A/S) of plastic types relevant to other partners in the CIP partnership, e.g. ABS, PA66 (poly-amide), PC (poly-carbonate), either in pure form, or when mixed with polyethylene/polypropylene rich plastics. It was found that pyrolysis of the pure compounds produced oils containing a broad range of hydrocarbons, indicating that the applied pyrolysis was unsuitable for monomer recovery. Additionally, the produced oils tended to be rich in heteroatoms such as nitrogen or oxygen, due to their presence in the original plastics (e.g. PA66 is high in oxygen and nitrogen). Very high levels of heteroatom contaminants negatively affect the economics of the hydroprocessing/ steam-cracker chemical recycling pathway considered for pyrolysis oils. However, it was found that when diluting ABS, PA66, PC with other polyolefinic plastics (artificial turf in the case for the partnership), the produced pyrolysis oil had properties perfectly suitable for hydroprocessing (reacting with hydrogen to remove heteroatoms and saturate olefins), and thereby for producing feedstocks suitable for steam-crackers that create the monomers for plastics production.

4. Main outputs and challenges

It has been of great value to be in close collaboration with pyrolysis and hydrothermal liquefaction technology providers. The collaborations have aided our understanding of the liquefaction technologies that provide the feedstock for our hydroprocessing solution, and of some of the dependencies between the plastic types and the properties of the liquefied plastics.

5. Our role in the value chain

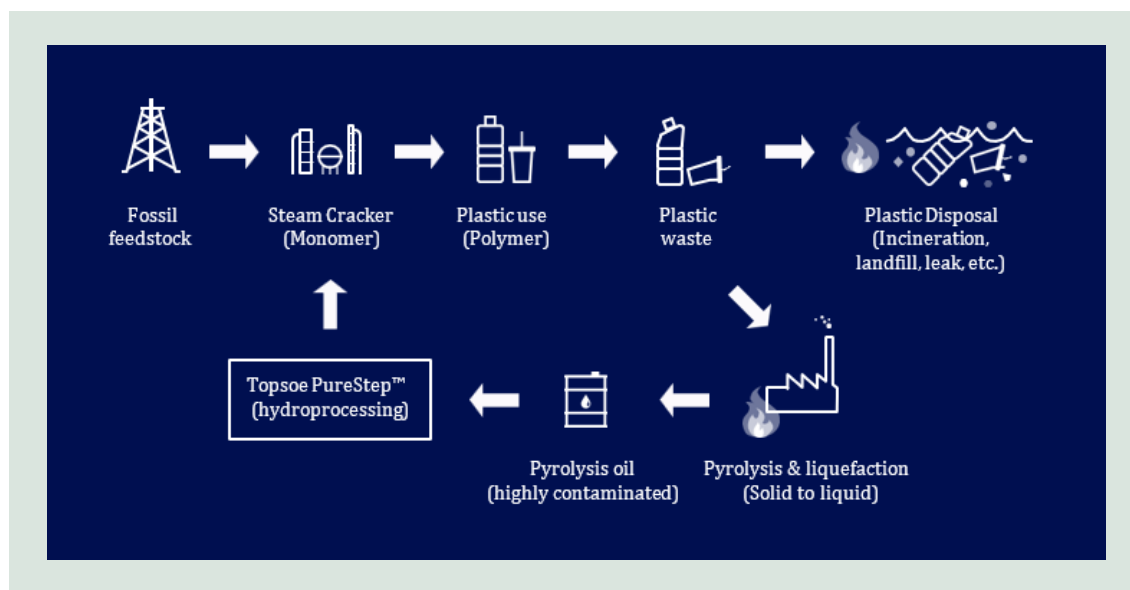


FIGURE 36. Topsoe role in the plastic recycling value chain from pyrolysis oil to feedstock to steam cracker.

6. Our main recommendations to other companies

- Make a good analysis of whether what you are targeting to recycle and how efficiently you can do it – often the efficiency of recycling decreases greatly by expansion of the

feedstock pool; do the math and see where the sweet spot between the cost of solid waste sorting and yield of recycled content lies.

- Use known and proven technologies and existing infrastructure to the extent possible as it greatly de-risks partnerships and decreases the costs.
- Create networks across the value chain and facilitate open dialogue - it can only help to provide a better, well-rounded solution, and it allows for better understanding of the dependencies and provides the possibility to solve a challenge at the optimal point in the value chain while avoiding gaps and overlaps.



FIGURE 37. Aarhus University logo.

1. Company presentation

At the Department of Biological and Chemical Engineering, the focus is on living systems, the biology of organisms, efficient production and transformation of chemicals, materials and energy. We translate knowledge in areas such as biotechnology, food technology, environmental technology, chemical technology, industrial biotechnology, medical biotechnology and electrochemical engineering into new technologies and value-adding solutions that can also be used in business.

A large part of our research and development activities are based on companies' specific innovation needs or special application areas. Close collaboration with both the public and private sectors ensures that the knowledge and technology created in the institute's research environments is clearly rooted in reality and benefits the surrounding society. We also provide research-based public sector consultancy and advice on technology in the agricultural and food sector. At the department, we educate both civil engineers (bachelor and master) and diploma engineers for the Danish society.

Recycling of plastics is crucial for Aarhus University-BCE as it supports our focus on sustainability and innovation in resource management. The institute aims to develop advanced technologies that tackle global challenges such as plastic pollution and resource scarcity. By researching and promoting efficient recycling methods, they contribute to reducing environmental impact, strengthening the circular economy and transforming waste into valuable raw materials for industrial applications. This mission emphasizes our commitment to creating a greener future through scientific progress.

2. Why we participated in CIP

For the university, it is essential not only to educate highly qualified engineers, but also to contribute to society by educating engineers with industry-relevant experience. Participation in CIP has enabled us to apply research developed in the laboratory to plastic samples from real industry. The extensive network of partners from different sectors has given us a unique insight into the challenges faced by industry in recycling and implementing new technologies. This collaboration strengthens the impact of our research, leading to improved outcomes for both our students and the companies involved.

3. Our main activities in CIP

AU investigated a technology known as hydrothermal depolymerization. It is a chemical recycling technology that depolymerizes polymers into monomers. These monomers can then be repolymerized into the original polymer without loss of quality. The method complements pyrolysis as it is suitable for polymers with a heteroatom (e.g. O or N), but it is less suitable for polyolefins such as PP, PE and PS. We evaluated several polymers from industry partners such as PET, PBT, PA66, PC and were able to show high monomer yields for all. AU focused on scaling up the lab results to pilot scale, initially using our existing hydrothermal liquefaction plant, which was designed to process biomass. This proved difficult, especially when feeding

the plastic into the reactor and due to the high glass fiber content of the industrial plastic. A new reactor was therefore designed to process this type of plastic.

4. Main outputs and challenges

The biggest benefit for AU was the networking and collaboration with the CIP partners. It has been extremely valuable to gain industrial insights into the entire value chain from companies that produce products, collect waste, refine the chemical and produce plastics. In terms of scientific learning, we have further developed the hydrothermal depolymerization technology with optimization of process conditions to achieve the highest monomer yield from different plastic types.

5. Our role in the value chain

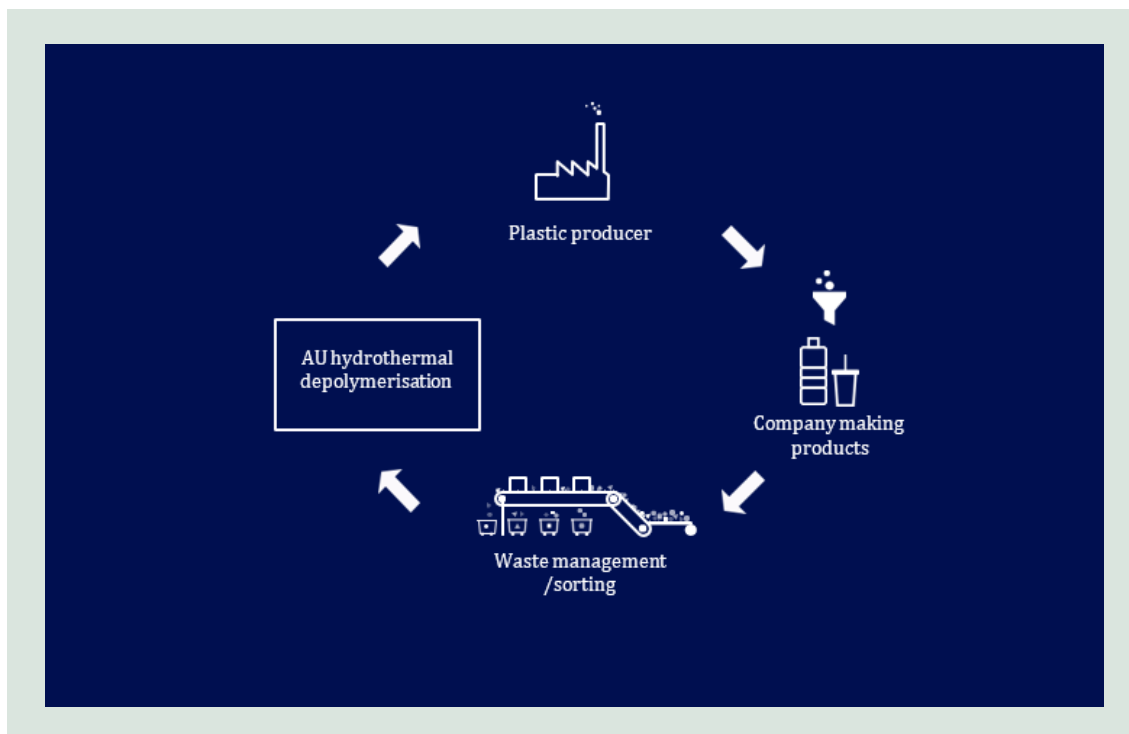


FIGURE 38. Role of AU's HTL process in the plastic recycling value chain.

6. Our main recommendations to other companies

- Don't underestimate how difficult glass fibers can be to handle on a larger scale.
- Be willing to fail and take advice from all partners
- Don't underestimate the time it takes to scale up a technology.



FIGURE 39. Novo Nordisk logo.

1. Partner presentation

Novo Nordisk is a leading global healthcare company, founded in 1923 and headquartered in Denmark. Our purpose is to drive change to defeat serious chronic diseases, built upon our heritage in diabetes. We do so by pioneering scientific breakthroughs, expanding access to our medicines, and working to prevent and ultimately cure disease.

Together, we are driving change to eliminate our environmental footprint. Our ambition is to have zero environmental impact. To get there, we are embracing a circular mindset across our value chain. Through our 'Circular for Zero' strategy, we design and produce our materials so that they can be re-used and reshape our business practices to minimise consumption and eliminate waste by turning it into new resources.

2. Why we participated in CIP

Our Circular for Zero strategy is guiding our actions around sustainability, with 4 'must win' battles, one of which is plastic.

3. Our main activities in CIP

- Worked with the other partners on testing of purity in recycled fractions.
- Learned about ours and other partners challenges and learned from the discussion we had with them.
- Worked to understand chemical recycling and recycling technologies in general.
- Developed the first use cases during our time in the partnership.

4. Main outputs and challenges

Learning from others and working across the industry. Also, showing and talking internally about cross-industry collaboration. It has been a strong message to communicate the industries' interest in circularity. And learning and seeing the differences and the difficulties and challenges to cooperate, due to the differences in our products.

We need to learn from the past to change the future. Circularity such as recycling is created through synergies and standardization.

5. Our role in the value chain

Product developer and product manufacturer.

6. Our main recommendations to other companies

- We cannot change the world alone, circularity and sustainability require partnership
- Start with what you have, although it may be difficult to make a difference
- Use the learnings to change the future through circular design and partnerships.

Appendix 3. Case assessment parameters from other cases than CIP (literature review)

Key perspectives and factors applied for the qualitative evaluation

The following cases are included to provide inspiration beyond CIP's use cases. They originate from a review.

The analysis is based on a qualitative evaluation of the three perspectives and six factors based on the available information in individual cases. All cases are scored qualitatively according to the six factors on a low-to-high scale, see appendices for further details.

Appendix 3.1 Perspectives

Supply chain

The supply chain perspective analyses how material flows, partnerships, and processes support or hinder circular business models. This includes evaluating the availability and quality of recycled feedstock, the role of technological solutions like sorting and traceability, and the importance of logistics and location in minimising environmental impact. By identifying key enablers and barriers, this perspective highlights where investments, collaborations, or operational improvements can drive greater circularity.

Product

The product perspective focuses on how design and production processes enable circular solutions. It examines technological feasibility for integrating recycled materials, design strategies like recyclability and modularity, and commercial viability in terms of cost, quality, and performance compared to virgin alternatives. Regulatory alignment and market dynamics are also considered to assess how circular products can meet sustainability goals while remaining competitive.

Customers

The customer perspective evaluates how end-users influence the success of circular products. It explores drivers such as sustainability benefits, transparency through LCAs, and economic incentives, while also addressing behavioural factors like participation in take-back schemes or preferences for modular solutions. Understanding this perspective is key to identifying how customer trust, awareness, and willingness to engage can accelerate adoption and support material circularity.

Appendix 3.2 Factors

Technological viability

Potential to readily deploy solution based on available technology and innovations that supports circularity or recycling. High scores indicate cases enabled by viable technology matching plastic properties, homogeneity, and traceability. Low scores indicate dependence on immature or undeveloped technology.

Commercial viability

Potential to achieve economic success based on e.g. market demand, cost efficiency, and scalability. High scores indicate commercial success without public financing. Low scores represent uncertain partnerships in demonstration or research phases.

Regulatory viability

Potential to be aligned with existing regulations related to circularity, recycling and waste management. High scores indicate regulatory compliance and support. Low scores indicate unresolved regulatory complexity and uncertainty.

Reputational impact

Potential to impact the public perception of the company's engagement with sustainability. High scores indicate cases with circularity impacts clearly communicated based on data. Low scores indicate cases with claims not backed by substantial evidence.

Climate change impact

Potential to reduce climate change impact. High scores indicate documented emission reductions and use of renewable energy for recycling. Low scores indicate cases that potentially lead to higher carbon emissions than with other available options for plastic management.

Other environmental impact

Potential to reduce other environmental impacts relative to traditional production methods. High scores indicate documented reductions in pollution, waste minimisation, improved waste management, or other environmental impacts. Low scores indicate cases with no documentation or potentially increased pollution levels.

Appendix 3.3 Case: Recycling plastic pipes for construction sector

A four-way collaboration addresses the challenge of recycling hard-to-recycle plastic waste using innovative chemical recycling technology.

ABOUT

In an innovative approach, Neste, Borealis, Uponor, and the Wastewise Group have successfully transformed Uponor's post-industrial waste plastic (PEX) from the production of pipes into new high-quality plastic that Uponor can use in the production of new pipes for the construction sector.

ENABLERS

From a supply chain perspective, the collaboration between Neste, Borealis, Uponor, and Wastewise enables circularity through a seamless closed-loop system, transforming hard-to-recycle industrial plastic waste into high-quality PEX pipes using advanced chemical recycling technologies. On the product side, the chemically recycled polyethylene retains identical quality to virgin materials, meeting strict regulatory standards and ensuring full traceability through ISCC PLUS certification. From a customer perspective, the resulting PEX pipes offer

high performance and sustainability, even for sensitive applications like drinking water systems.

BARRIERS

From a supply chain perspective, barriers include the high dependency on each participant in the loop, where disruptions from any partner can affect the system's functionality, and the need for advanced technologies to handle hard-to-recycle plastics under precise operating conditions. On the product side, competition with cheaper virgin materials and the energy-intensive nature of chemical recycling limit cost-effectiveness and environmental benefits, while potential waste generation from residual by-products adds complexity. From a customer perspective, skepticism about the sustainability of chemical recycling, and the association of outputs with petrochemicals, may hinder adoption.

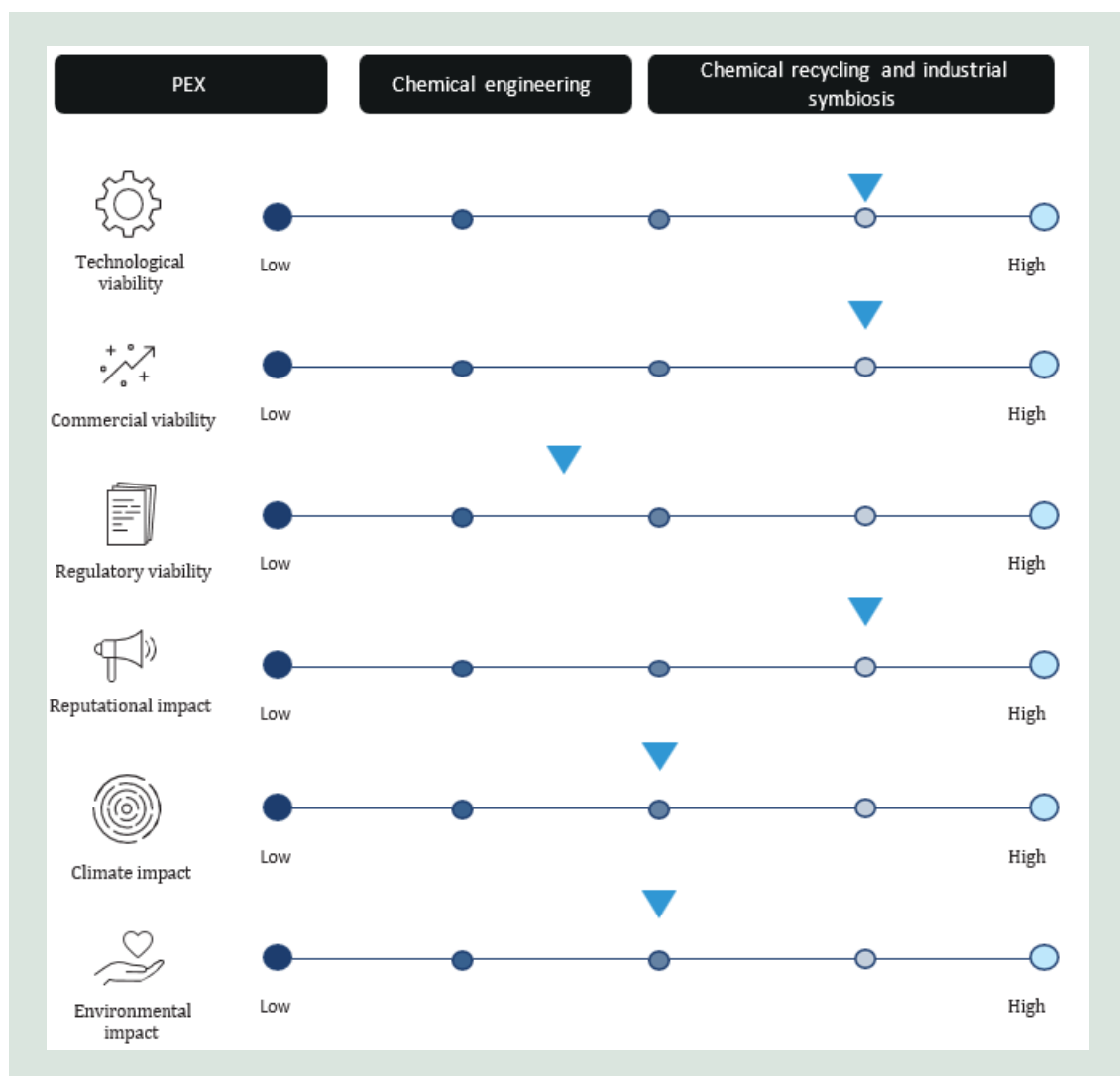


FIGURE 40. Overview of status and impact of different parameters of the case of chemical recycling of Udonor post-industrial waste plastic.

Appendix 3.4 Case: Circular Foam

A cross-industry collaboration, with EU funding support, to improve the collection and recycling of polyurethane foam in three countries.

ABOUT

The Circular Foam Partnership is a consortium partnership aiming to develop and demonstrate all the steps to create a circular loop for polyurethane rigid foam, which is used for insulation in refrigerators and in the construction industry. The partnership is led and coordinated by Covestro, which is a major producer of polymers for a variety of industries. Also included in the partnership are companies from across the value chain, including waste collection, chemical recycling, and manufacturers of refrigerators and insulation for buildings.

ENABLERS

The partnership is taking a full value-chain perspective, so it can take an iterative approach to constructing a functional circular value chain. Advancements in recycling technologies, such as smart chemolysis and improved material designs (e.g., monolayer facers), are making PU foam recycling more viable. Digital tools like Circularise enhance data transparency and support process efficiency.

The partnership has EU funding and support, which enables the participation of private companies, universities and municipalities. Partnership deliverables can thus include technical, commercial, economic and societal knowledge.

BARRIERS

High costs of recycling processes and limited infrastructure for material recovery pose economic constraints. Complex material compositions and the nascent stage of chemical recycling technologies create challenges in potentially scaling up operations. The lack of standardization in dismantling and recycling further complicates implementation.

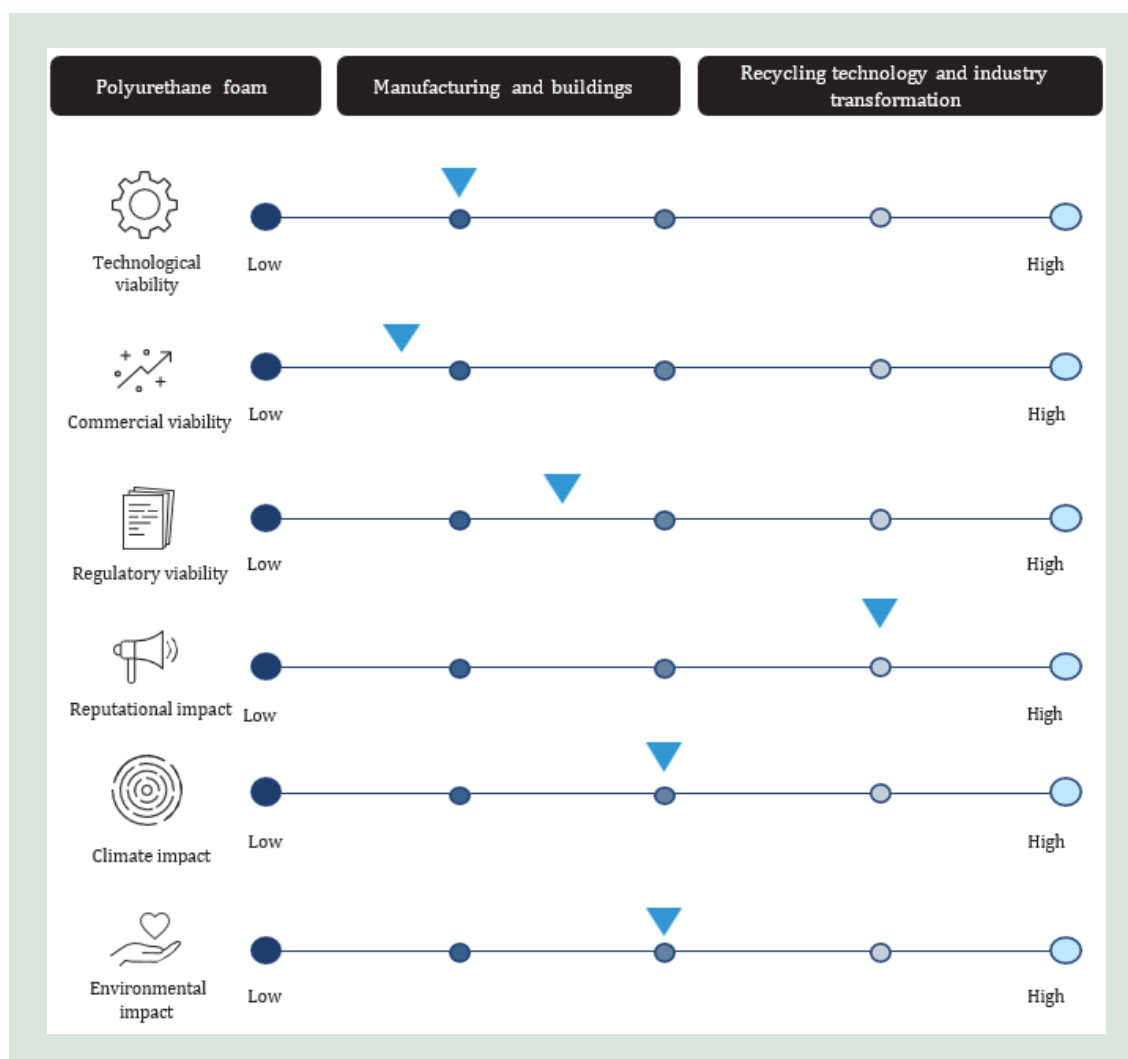


FIGURE 41. Overview of status and impact of different parameters of the case of recycling of polyurethane foam aiming to create a circular solution.

Appendix 3.5 Case: FAERCH Group Tray 2 Tray

Successful transition to 57% recycled content in food trays and has a take-back scheme, effectively managing a closed loop.

ABOUT

The FAERCH Group's Tray 2 Tray initiative focuses on creating a closed-loop recycling system for food trays. The company is an integrated plastics producer and recycler, meaning it designs the trays for circularity and with 57% recycled content, establishes take-back schemes with partners, and then recycles the trays into new trays.

ENABLERS

From a supply-chain perspective, the initiative is enabled by Faerch's ability to make use of household waste and manage a take-back scheme, ensuring available feedstock for recycled content. On the customer side, there is sufficient demand for this product, because customers are seeking to reduce their carbon and material footprint, mainly driven by new and upcoming regulatory requirements, such as the EU Packaging Regulation. On the product side, Faerch produces trays able to meet industry food safety standards, which is key.

BARRIERS

From a supply-chain perspective, a barrier in the coming years will be feedstock availability, as demand for plastic from household waste is increasing, so the supply will be limited.

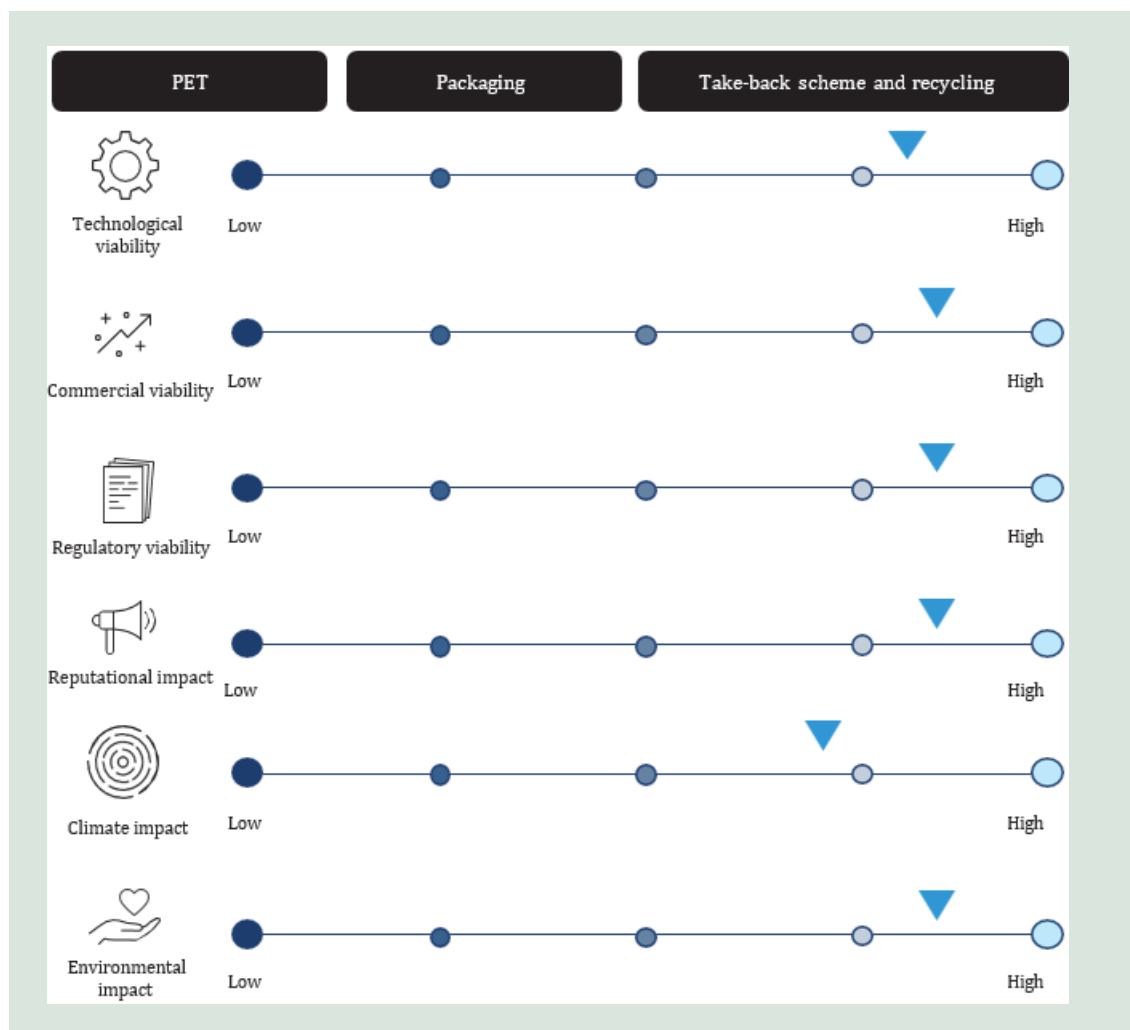


FIGURE 42. Overview of status and impact of different parameters of a closed-loop recycling system for food trays.

Appendix 3.6 Case: Recycling PVC window frames in Germany

Rewindo operates Germany's longstanding take-back system, recycling PVC window frames into granulate for new frames and construction profiles.

ABOUT

Rewindo is a German company that operates a nationwide take-back system for PVC window frames. This system has been in place for decades, making it one of the most well-established examples of a plastic recycling system. The frames are then processed into PVC granulate that is used to manufacture new window frames or other construction profiles.

ENABLERS

From a supply chain perspective, collection of used PVC frames is enabled by a nationwide network of partnerships with construction companies and waste collection facilities. The initiative is decades old, so these partnerships are well-established. From a product perspective, PVC is highly recyclable and does not lose its quality when being recycled.

several times, so recycled PVC frames can compete directly with frames produced from virgin materials. Initial start-up costs for the initiative were high, but the initiative had funding support from the German government, allowing it to build scale and produce products. From a customer perspective, recycled PVC window frames help building and constructions companies to achieve sustainability certifications that are established by the German Sustainable Building Council.

BARRIERS

Recycling legacy materials with hazardous additives requires advanced processing, while bulky PVC frames result in high transportation costs and logistical challenges. On the product side, competition with cheaper virgin PVC and the energy-intensive recycling process limit cost-effectiveness and environmental benefits, compounded by stricter regulations and limited demand for high-value applications. From a customer perspective, scepticism about the quality and sustainability of recycled PVC highlights the need for clear communication of environmental benefits and alignment with carbon neutrality goals. Addressing these barriers requires innovation and collaboration across the value chain.

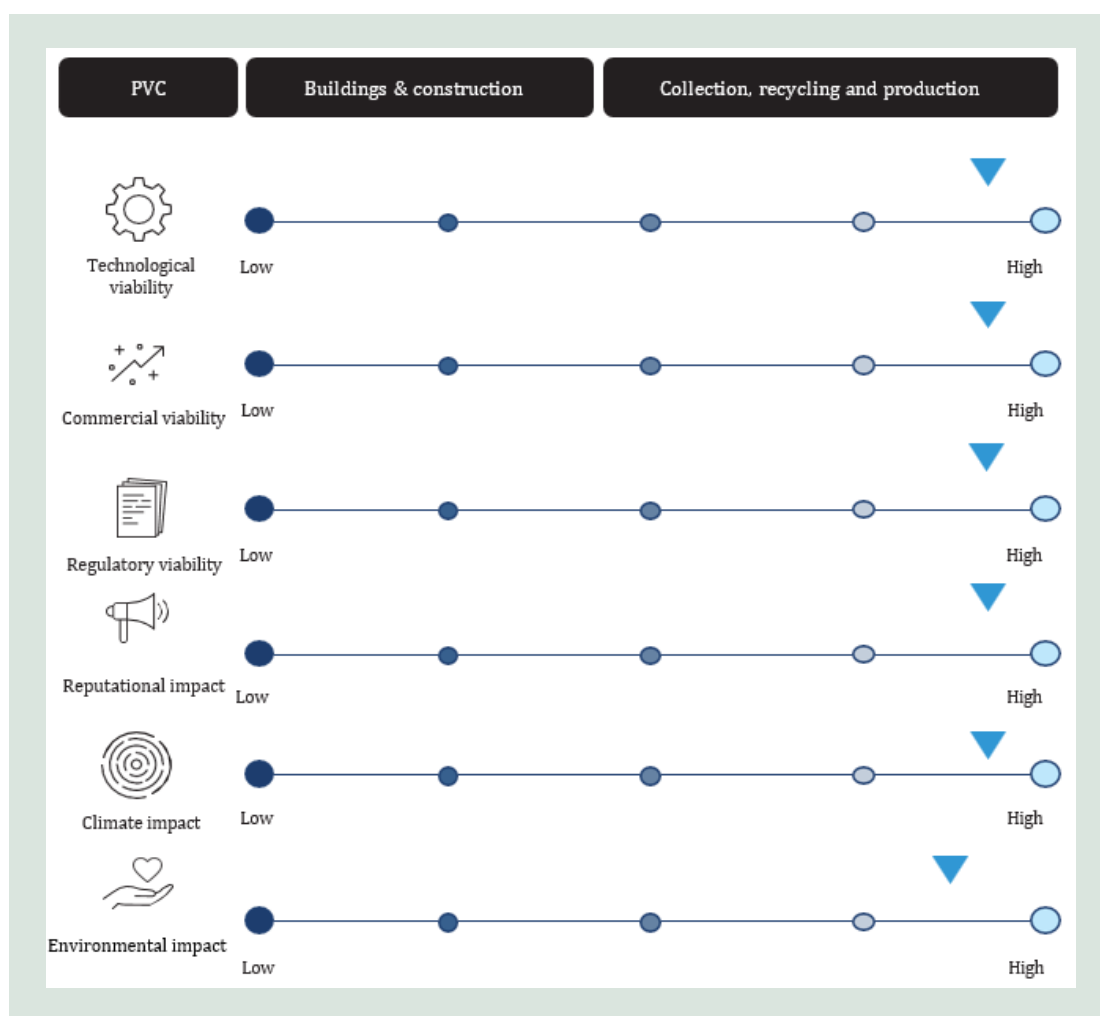


FIGURE 43. Overview of status and impact of different parameters for recycling PVC window frames into granulate for new frames and construction profiles.

Appendix 3.7 Case: Philips

Philips integrates recycled plastics and modular designs to lead sustainable innovation in premium consumer electronics.

ABOUT

Philips is a global leader in health technology and sustainable innovation, committed to advancing circular economy principles. Through its PolyCE partnership, Philips integrates high-quality post-consumer recycled plastics into products such as coffee machines, vacuum cleaners, and shavers. By leveraging modular designs, advanced recycling processes, and partnerships with material suppliers, Philips demonstrates how circular materials can be successfully incorporated into premium, durable, and high-performing consumer electronics.

ENABLERS

From a supply chain perspective, Philips' PolyCE partnership is enabled by collaborations with recyclers and material suppliers, ensuring a consistent supply of high-quality post-consumer recycled plastics such as rABS and rPC. On the product side, advanced manufacturing techniques and modular designs allow recycled plastics to meet stringent performance and aesthetic standards, while simplifying disassembly and recycling at the product's end of life. From a customer perspective, Philips offers durable and sustainable consumer electronics, such as the Senseo Eco coffee machine, that align with growing consumer demand for eco-friendly and high-quality products.

BARRIERS

From a supply chain perspective, barriers include the inconsistent quality and limited availability of high-grade post-consumer recycled plastics, which can complicate manufacturing and increase costs. On the product side, challenges arise in ensuring that recycled plastics meet the strict performance, durability, and aesthetic requirements for premium electronics, particularly for specialized applications like food contact or high-temperature resistance. From a customer perspective, higher production costs can result in increased retail prices, potentially deterring price-sensitive consumers, while lingering perceptions of recycled materials as lower quality may impact adoption.

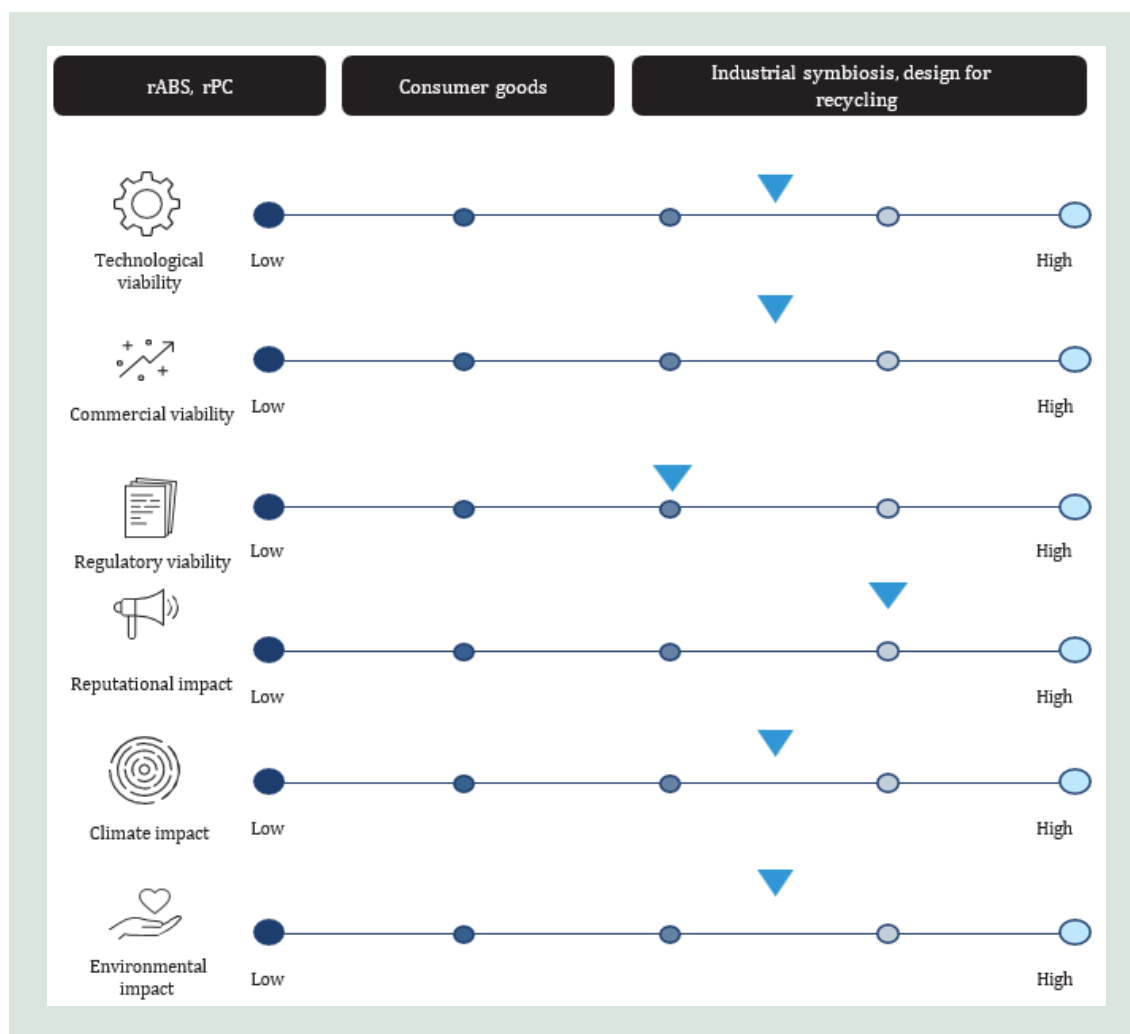


FIGURE 44. Overview of status and impact of different parameters of Philips' work of integrating high-quality post-consumer recycled plastics into products.

Appendix 3.8 Case: Whirlpool

Whirlpool advances sustainability by incorporating recycled plastics into durable appliances without compromising quality or design.

ABOUT

Whirlpool is a global leader in household appliances, committed to advancing sustainability and circular economy principles. Through the PolyCE partnership, Whirlpool integrates high-quality post-consumer recycled (PCR) plastics into key components like washer tubs and refrigerator liners. By leveraging innovative clustering techniques, advanced material recycling, and strategic collaborations with recyclers and material suppliers, Whirlpool demonstrates how durable, high-performing appliances can incorporate recycled materials without compromising quality or aesthetics.

ENABLERS

From a supply chain perspective, Whirlpool's PolyCE partnership is enabled by innovative clustering and pre-treatment techniques that ensure the high purity of post-consumer recycled plastics, such as rPP and rHIPS, and strong partnerships with recyclers and material suppliers.

like MGG Polymers. On the product side, the use of drop-in recycled plastics allows seamless integration into existing production moulds while maintaining performance and durability standards. From a customer perspective, the partnership meets growing consumer demand for sustainable appliances, showcasing high-quality, durable products that incorporate recycled materials without compromising functionality or aesthetics.

BARRIERS

From a supply chain perspective, barriers include the inconsistent quality and contamination of post-consumer recycled plastics, as well as challenges in maintaining a steady supply of high-grade materials for large-scale applications. On the product side, ensuring that recycled plastics meet stringent performance, durability, and regulatory requirements—such as chemical resistance and food-contact safety—can be complex and resource-intensive. From a customer perspective, higher production costs may result in increased retail prices, potentially deterring price-sensitive consumers, while lingering perceptions of recycled materials as lower quality could impact broader market adoption despite growing interest in sustainability.

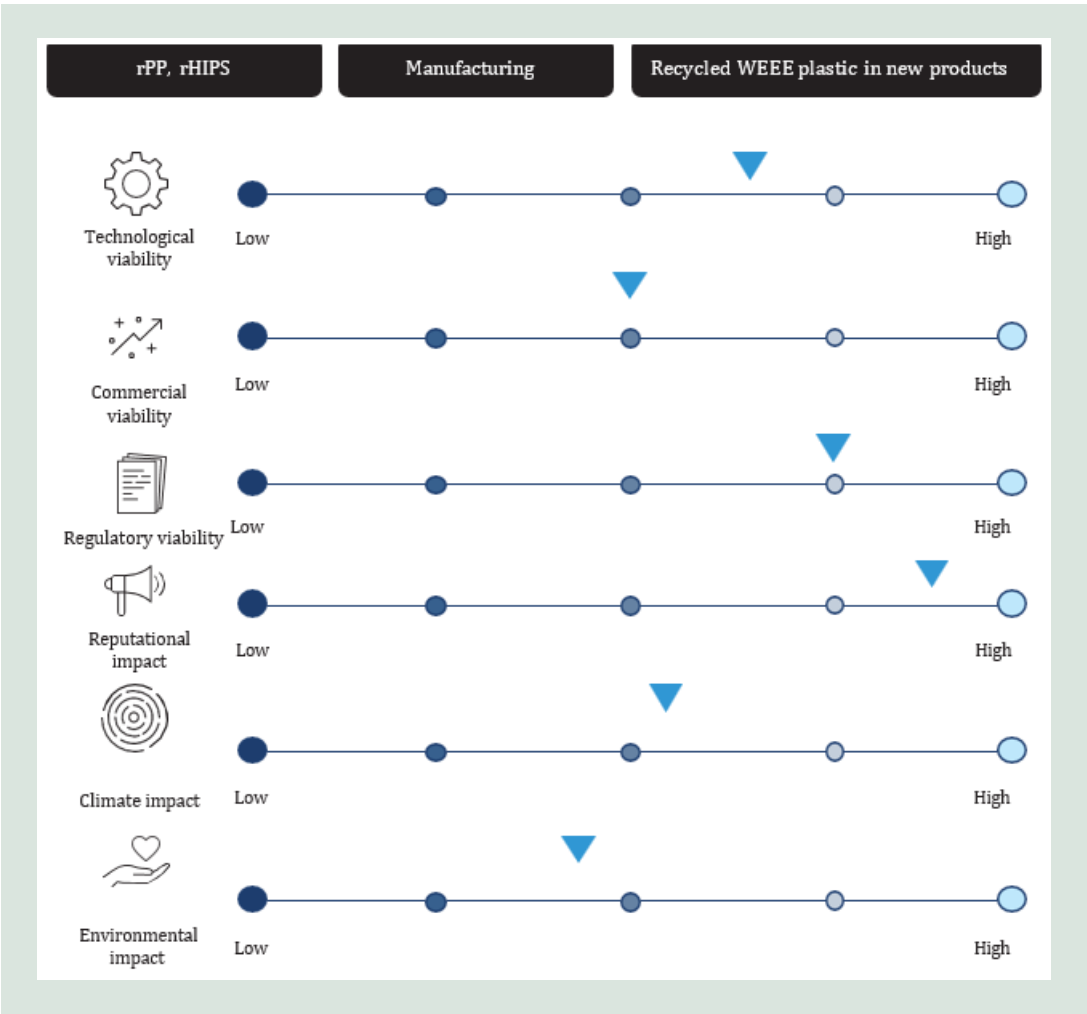


FIGURE 45. Overview of status and impact of different parameters of Whirlpools integrating of high-quality post-consumer recycled (PCR) plastics into key components.

Appendix 3.9 Case: Recycled ABS plastics

ENGEL, in partnership with bage plastics and ROCTOOL, is recycling end-of-life ABS plastics into high-quality feedstock for new components.

ABOUT

ENGEL, in collaboration with bage plastics and ROCTOOL, is leading an initiative to develop a closed-loop system for ABS (Acrylonitrile Butadiene Styrene) components. The partnership focuses on recycling end-of-life ABS plastics into high-quality feedstock to produce new components.

ENABLERS

The initiative is enabled primarily by a collaborative effort between companies operating different parts of the value chain. Combining ENGEL's manufacturing technologies, bage plastics' recycling know-how, and ROCTOOL's thermal innovation creates a holistic approach to ABS recycling and production. From a customer perspective, the partnership enables the production of plastic electronic box components, from recycled content.

BARRIERS

From a supply chain perspective, barriers include integrating technologies from multiple partners, ensuring consistent quality of variable ABS feedstocks, and high initial investments for scaling closed-loop systems. On the product side, risks of material degradation and complex certification processes add challenges, while compliance with regulations like REACH increases processing demands. From a customer perspective, competition with alternative materials and concerns over energy use and measurable carbon footprint reductions may hinder confidence and market adoption of recycled ABS.

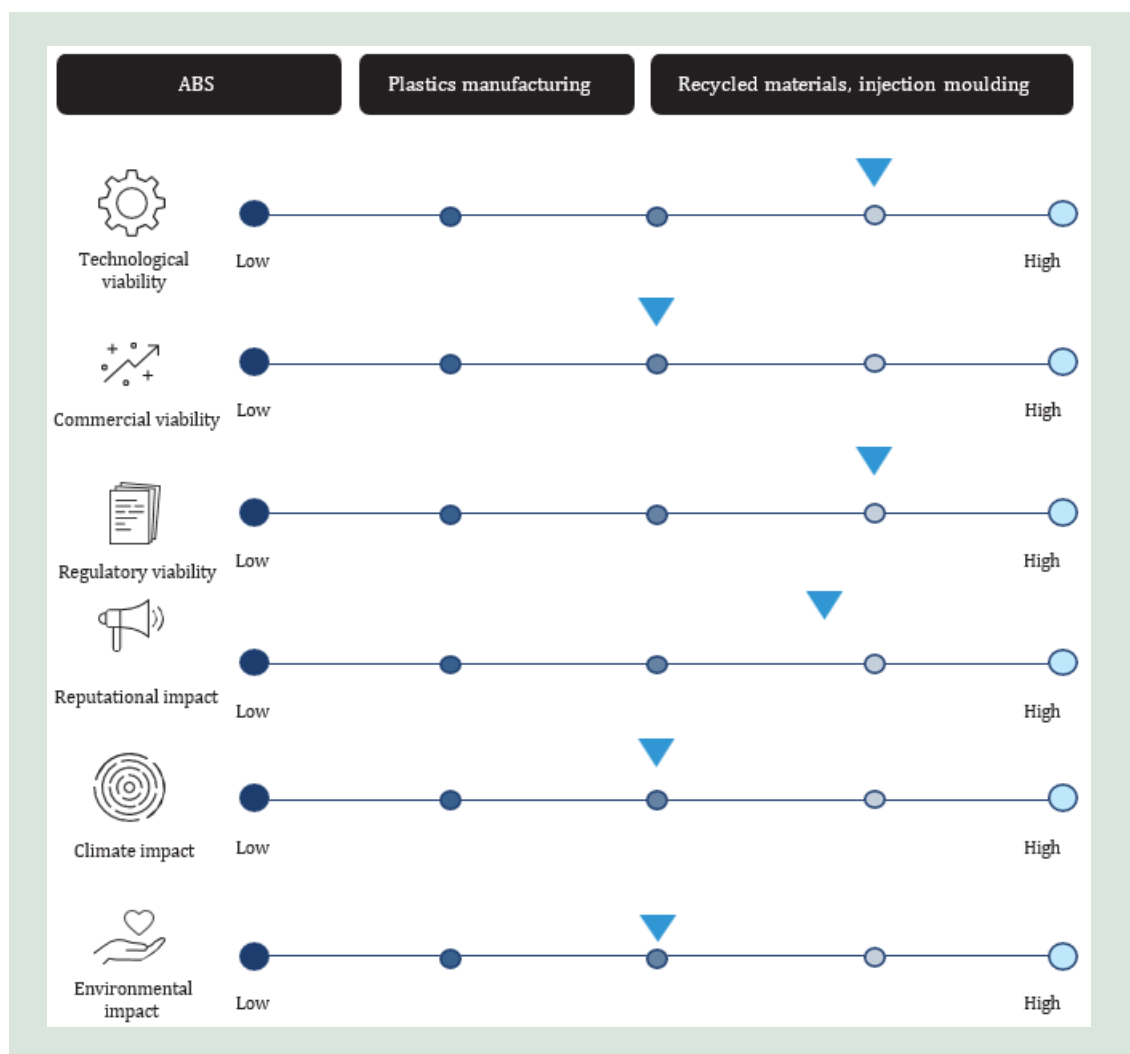


FIGURE 46. Overview of status and impact of different parameters of ENGEL's work on recycling end-of-life ABS plastics into high-quality feedstock to produce new components.

Appendix 3.10 Case: partnership for production of 100% circular plastic

Dow and Fuenix Ecology Group tackle plastic waste challenges by transforming it into 100% circular polymers through advanced feedstock recycling technology

ABOUT

Dow has partnered with Fuenix Ecology Group to create 100% circular plastic by converting mixed plastic waste into pyrolysis oil, which is processed into new polymers at Dow's Terneuzen facility in the Netherlands. These polymers are identical to those made from traditional feedstocks and can be used in applications such as food packaging, marking a significant step toward advancing feedstock recycling and promoting circularity in plastics.

ENABLERS

From a supply chain perspective, the Dow and Fuenix partnership is enabled by Fuenix's advanced pyrolysis technology, which converts mixed plastic waste into pyrolysis oil. This oil serves as a reliable feedstock for Dow's European operations, supporting their commitment to integrating 100,000 tonnes of recycled plastics by 2025. On the product side, the resulting polymers are of virgin quality and suitable for high-demand applications such as food packaging, ensuring performance standards are maintained. From a customer perspective,

this collaboration provides businesses with sustainable plastic solutions, helping them meet growing consumer and regulatory demands for environmentally responsible products.

BARRIERS

From a supply chain perspective, barriers include the variability in the quality of plastic waste feedstock, which can affect the efficiency of Fuenix’s pyrolysis process, and the significant investment required to scale the technology to industrial levels. On the product side, the energy-intensive nature of the pyrolysis process poses challenges in maintaining environmental benefits, especially if powered by non-renewable energy sources. From a customer perspective, market adoption is hindered by concerns over the perceived quality of recycled plastics for sensitive applications like food packaging, as well as the complexity of navigating regulatory certifications required for such uses.

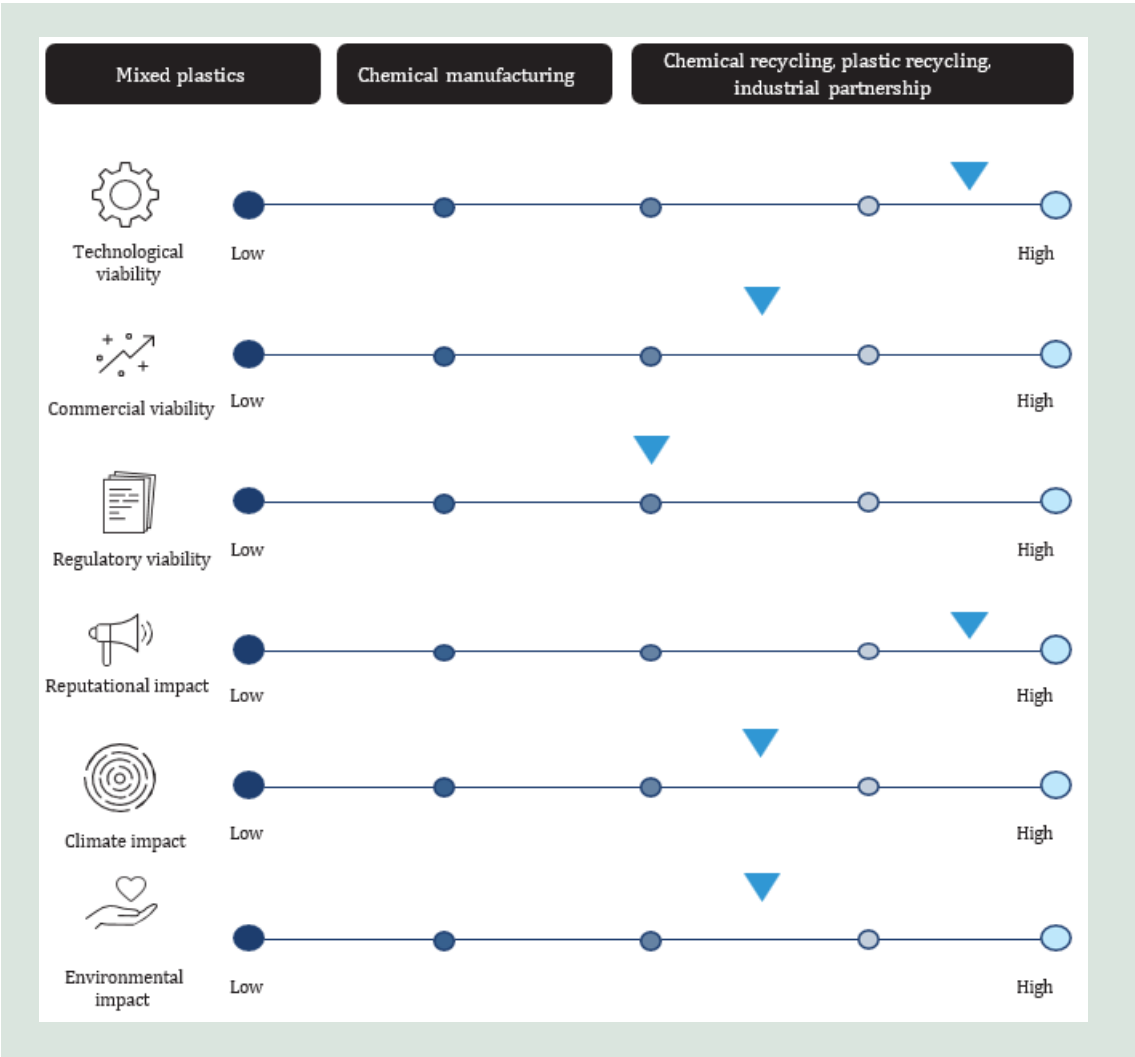


FIGURE 47. Overview of status and impact of different parameters of Dow’s activities on creating 100% circular plastic by converting mixed plastic waste into pyrolysis oil.

Appendix 3.11 Case: Cirplus

Cirplus innovates the recycled plastics market with a digital platform that support efforts to match supply with demand.

ABOUT

Cirplus is a digital marketplace dedicated to facilitating the global trade of recycled plastics, aiming to streamline the procurement and sale of recyclates and feedstock. By standardizing and digitizing the circular plastics supply chain, Cirplus addresses key challenges in the recycled plastics market.

ENABLERS

From a supply chain perspective, Cirplus is enabled by its digital platform, which connects suppliers and buyers of recycled plastics globally, and the adoption of DIN SPEC standards, ensuring standardized and reliable material data. The platform's extensive network, encompassing over 4 million tons of circular materials, facilitates efficient transactions and access to high-quality recyclates. On the product side, Cirplus supports industries across packaging, automotive, and construction by ensuring that recycled plastics meet performance and regulatory standards. From a customer perspective, Cirplus provides a cost-effective, transparent, and user-friendly solution for sourcing sustainable materials, meeting the growing demand for recycled plastics in a wide range of applications.

BARRIERS

From a supply chain perspective, barriers include the inconsistent quality of recycled plastics across suppliers, limited adoption of DIN SPEC standards, and challenges in integrating the platform into existing procurement systems. On the product side, competition with cheaper virgin plastics and the variability in recycled material quality can hinder broader market adoption. From a customer perspective, the complexity of compliance with fragmented regional regulations and the perceived complexity of the platform, particularly for smaller players, may discourage participation. Additionally, price volatility and trust issues in emerging markets add further challenges to scaling Cirplus's marketplace.

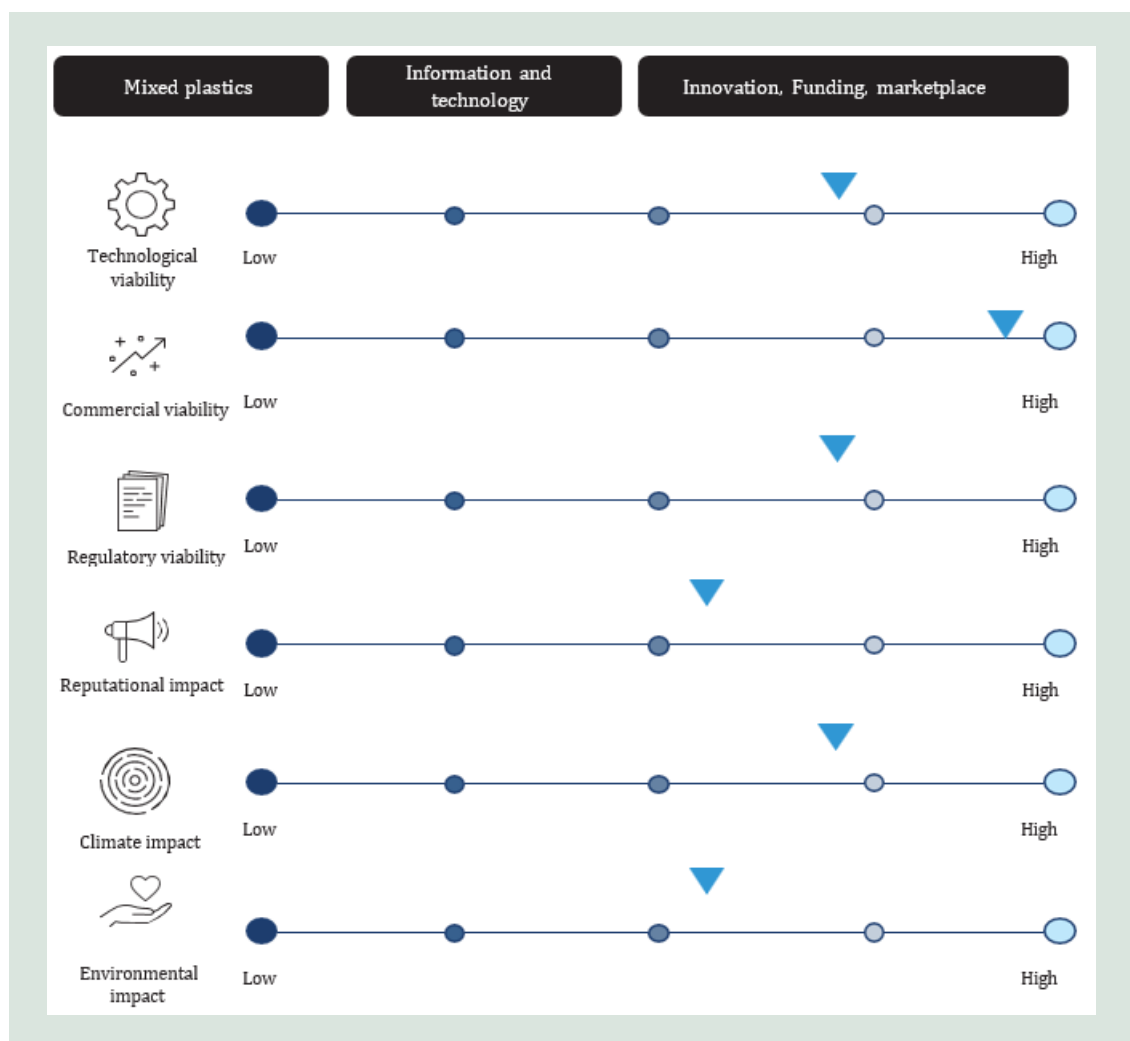


FIGURE 48. Overview of status and impact of different parameters of Cirplus's digital marketplace dedicated to facilitating the global trade of recycled plastics.

Appendix 3.12 Case: Igus

The igus® chainge program creates a closed-loop system by recycling plastic components into high-quality granulates for sustainable production.

ABOUT

The igus® chainge program is a global recycling initiative aimed at creating a closed-loop system for plastic components, such as energy chains and other industrial materials. By enabling customers to return used products, igus® processes these materials into high-quality granulates that are reintroduced into production for new products. With a focus on sustainability, advanced recycling technologies, and customer engagement, the chainge program exemplifies igus®'s commitment to driving the circular economy and reducing plastic waste worldwide.

ENABLERS

From a supply chain perspective, the igus® chainge program is enabled by an efficient global collection system for used energy chains, supported by partnerships with logistics and recycling facilities. The integration of advanced recycling technologies allows igus® to process returned plastics into high-quality granulates that can be reused in new products. On the

product side, igus® ensures that its energy chains are designed for recyclability, simplifying disassembly and material recovery. From a customer perspective, the program incentivizes participation with vouchers and provides an accessible way to reduce environmental impact, aligning with growing demand for sustainable industrial solutions.

BARRIERS

From a supply chain perspective, barriers include the complexity of recovering and processing mixed or contaminated plastics, the high initial investment required for advanced recycling infrastructure, and challenges in scaling the program globally in regions with underdeveloped recycling systems. On the product side, achieving consistent quality and material properties with recycled granulates can limit their applicability for certain high-performance uses. From a customer perspective, logistical challenges in returning used energy chains, limited awareness of the program, and potential perceptions of recycled materials as inferior may hinder widespread participation. Additionally, price competition with cheaper virgin plastics and fragmented recycling regulations across regions add further challenges to the program's scalability and adoption.

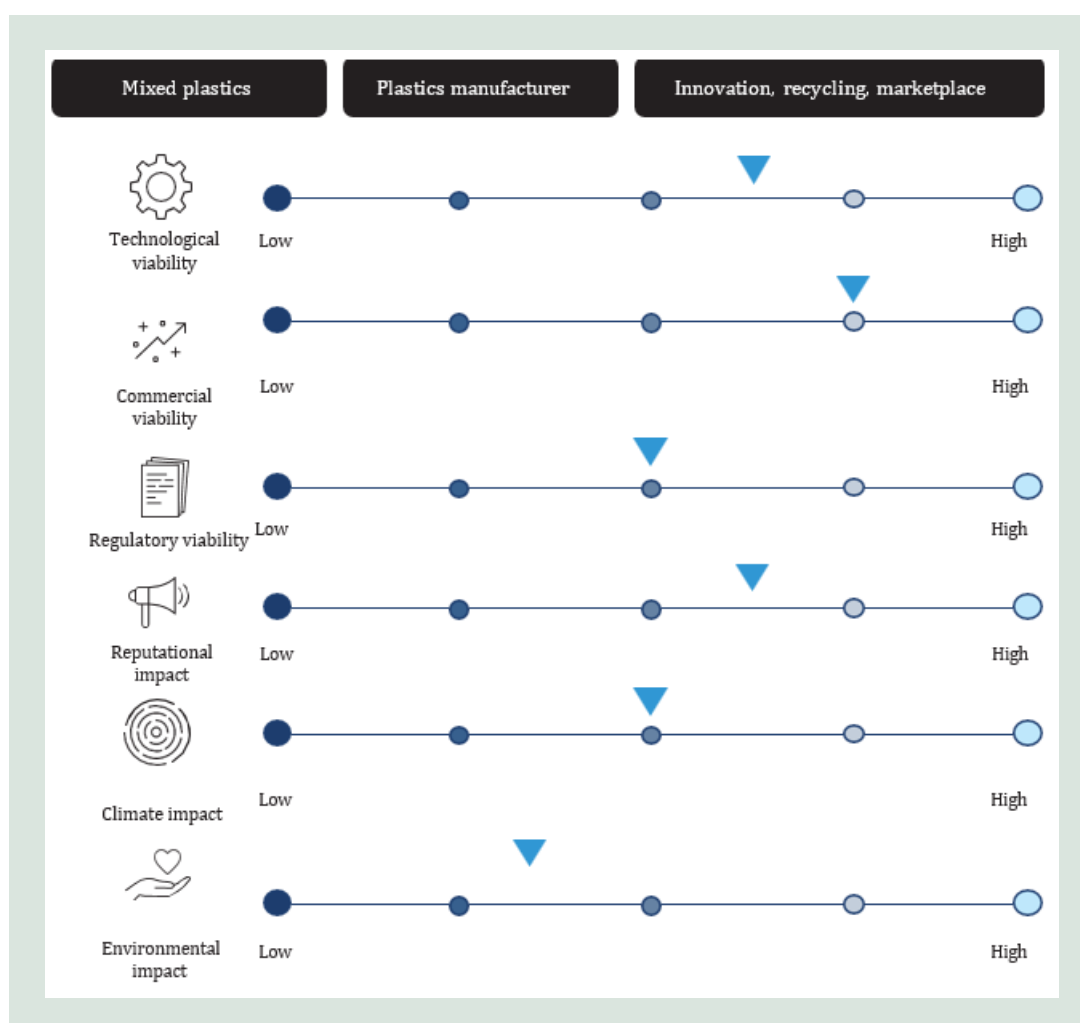


FIGURE 49. Overview of status and impact of different parameters of The igus® change program - a global recycling initiative aimed at creating a closed-loop system for plastic components.

Appendix 3.13 Case: Transportation packaging products

Cabka is a Dutch recycler and manufacturer, that produces transportation packaging products of almost entirely recycled plastic.

ABOUT

Cabka is a plastics recycling company working to turn post-consumer and post-industrial plastic waste into reusable transport packaging products, including pallets, containers and boxes. They procure some virgin plastic, so the share of recycled plastic in their products ranges from 70-90%.

They are the recycler, and work with customers to procure plastic and ensure product buyback, effectively managing a closed loop.

ENABLERS

The primary driver of Cabka's success is that it designs and produces a product that is economically beneficial for its customers, because the cost of ownership of a Cabka product is lower than that of a conventional product (boxes or pallets), due to reusability and Cabka's buyback schemes. Furthermore, Cabka has been able to secure long-term framework agreements with large companies, including Tesla and BMW, demonstrating there is a demand for the product. From a supply-chain perspective Cabka uses a mix of post-consumer and post-industrial plastics and recycles much of it in its own plants, meaning it is less reliant on other recyclers.

BARRIERS

From a supply-chain perspective, Cabka states in its reporting that feedstock availability and prices are a growing challenge, because more and more companies need access to recycled plastics in order to meet their own targets and regulatory requirements. While Cabka sources plastic waste and recycles on its own, it also needs to procure recycled material from other recyclers to secure enough feedstock. The prices of these materials are rising, due to limited supply and increasing demand. From a product perspective, demand for their product is sensitive to the price of substitutes, so they are challenged when wood prices fall, and a wood pallet becomes a more attractive choice for potential customers.

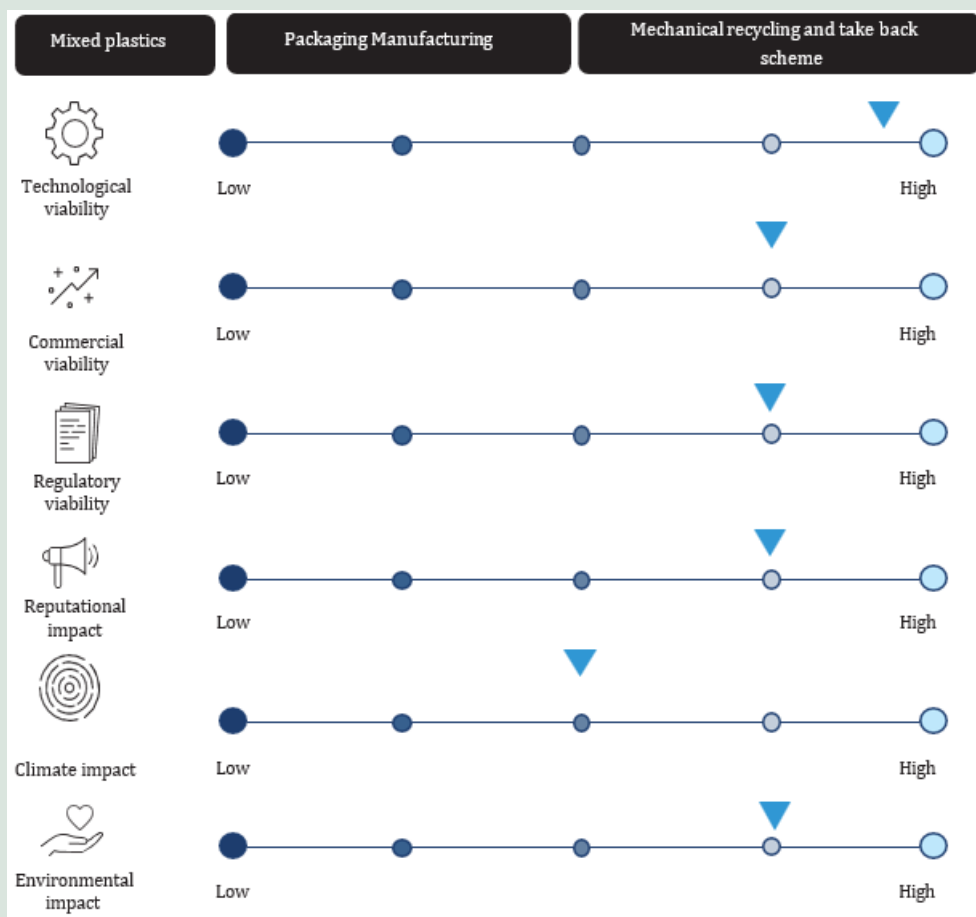


FIGURE 50. Overview of status and impact of different parameters for Cabka's activities within plastics recycling turning post-consumer and post-industrial plastic waste into reusable transport packaging products.

Appendix 3.14 Case: Modular mixer made with recycled content

Made from 100% recycled plastic sourced from items like cosmetic containers and car parts, the re:Mix embodies circular economy principles.

ABOUT

Open Funk is a Berlin-based company focused on sustainable and modular kitchen appliances. Their flagship product, the re:Mix blender, features a modular design that allows for easy repairs and upgrades, significantly extending its lifespan. Made from 100% recycled plastic sourced from items like cosmetic containers and car parts, the re:Mix embodies circular economy principles.

ENABLERS

From a supply chain perspective, Open Funk's re:Mix blender is enabled by the use of 100% recycled plastic sourced locally from items like car parts and cosmetic containers, combined with 3D printing technology for efficient and low-waste manufacturing. On the product side, the modular design of the blender ensures easy repairability and extended lifespan, reducing waste and aligning with circular economy principles. From a customer perspective, the re:Mix

blender offers customisable color panels and high-quality sustainable materials, appealing to eco-conscious consumers looking for durable and personalised kitchen appliances.

BARRIERS

From a supply chain perspective, barriers include the limited availability and variability of recycled plastic feedstock, which can affect the quality and consistency of the re:Mix blender's components. Additionally, reliance on 3D printing for production may face scalability challenges when expanding beyond local manufacturing. On the product side, the modular design, while sustainable, requires robust systems for part recovery and recycling to ensure end-of-life materials are effectively reused. From a customer perspective, the higher cost of recycled plastic products and lingering perceptions about the durability of recycled materials could hinder broader market adoption, despite growing interest in sustainability.

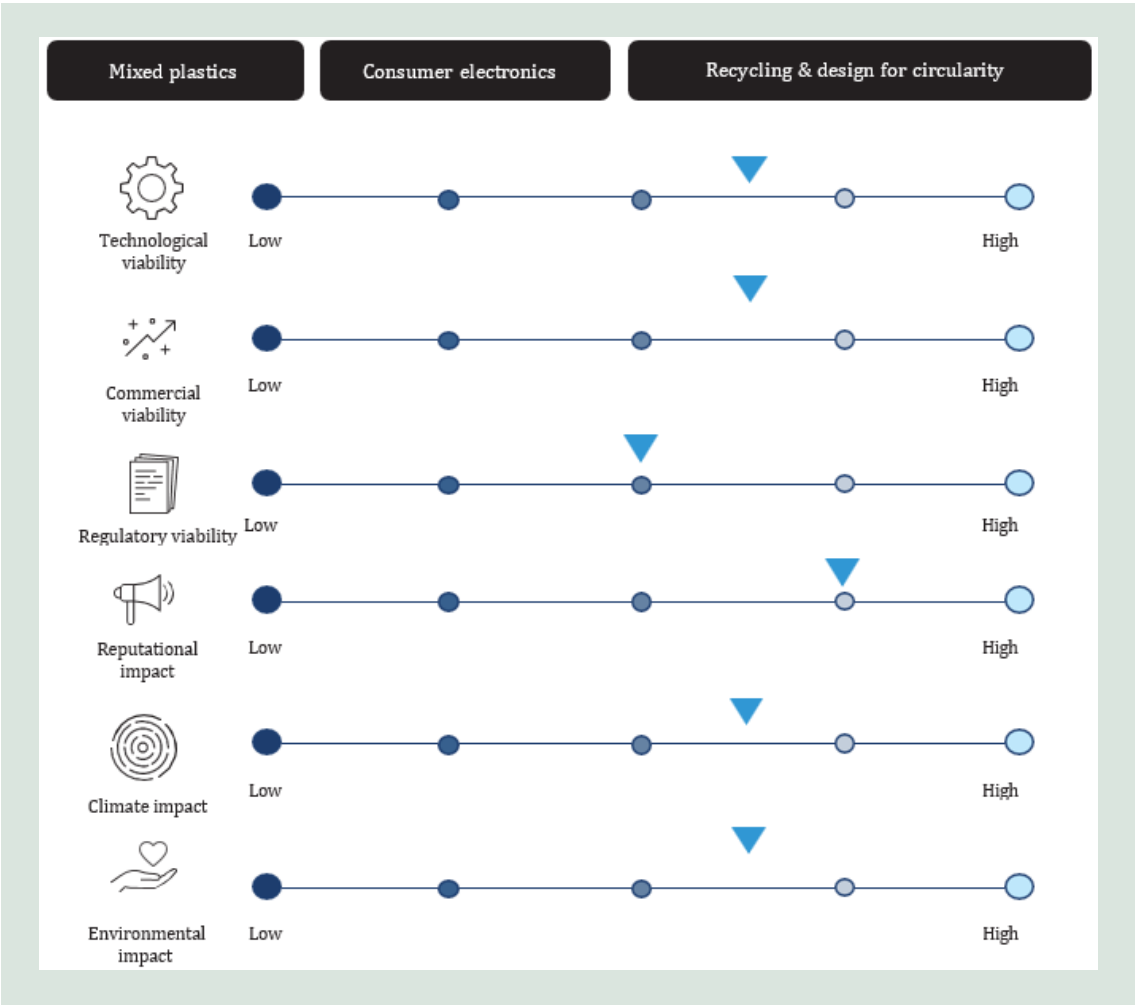


FIGURE 51. Overview of status and impact of different parameters of the company Open Funk focusing on sustainable and modular kitchen appliances that allows for easy repairs and upgrades.

Appendix 3.15 Case: Gomi

By integrating circular economy principles, Gomi transforms waste into high-quality, durable, and innovative audio solutions.

ABOUT

Gomi is a Brighton-based company dedicated to creating sustainable products by recycling flexible plastics that are traditionally non-recyclable. Their speaker products are crafted using 100% recycled materials, such as shopping bags and bubble wrap, and are powered by repurposed lithium batteries from damaged e-bikes.

ENABLERS

From a supply chain perspective, Gomi's speakers are enabled by the use of 100% recycled flexible plastics, such as shopping bags and bubble wrap, and repurposed lithium batteries from damaged e-bikes, creating a sustainable material loop. On the product side, the innovative design integrates recycled materials without compromising quality, offering a durable and sustainable alternative to traditional speakers. From a customer perspective, Gomi's speakers appeal to eco-conscious consumers by delivering high-performance audio products while promoting waste reduction and environmental responsibility.

BARRIERS

From a supply chain perspective, barriers include the inconsistent quality and contamination of flexible plastic waste, which can complicate the recycling process, as well as challenges in sourcing sufficient quantities of suitable materials. On the product side, integrating recycled plastics and repurposed batteries can result in higher production costs and technical challenges, such as ensuring the durability and safety of components. From a customer perspective, barriers include potential concerns about the perceived quality and longevity of products made from recycled materials, as well as limited market awareness or willingness to pay a premium for sustainable alternatives.

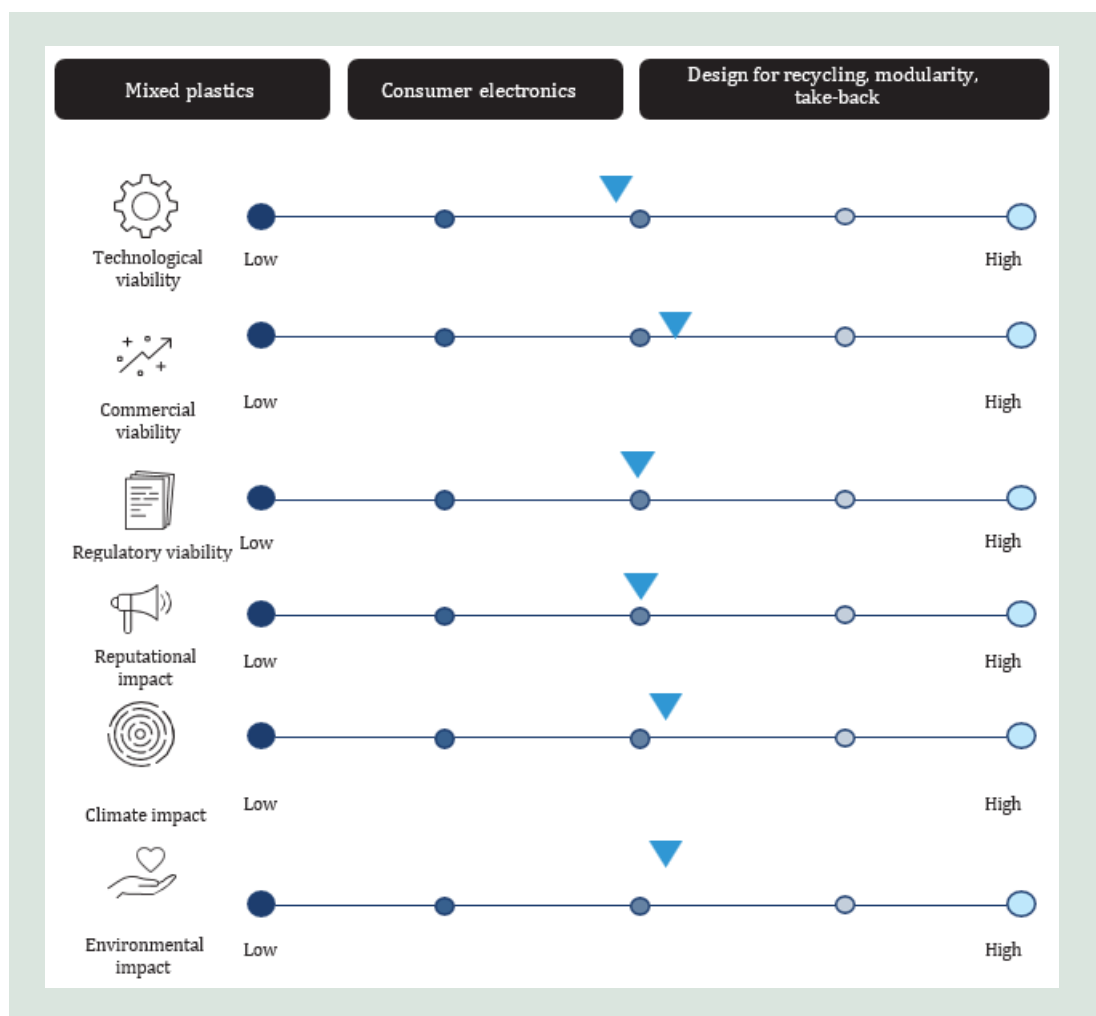


FIGURE 52. Overview of status and impact of different parameters of the company Gomi which create sustainable products by recycling flexible plastics and repurposed lithium batteries from damaged e-bikes.

Dansk resume – Executive summary

Det Cirkulære Industrielle Plast (CIP)-partnerskab

Formålet med det Cirkulære Industrielle Plast (CIP)-partnerskab

Det overordnede formål med CIP-partnerskabet var at tage en holistisk tilgang til, hvordan man udvikler og demonstrerer genanvendelsesløsninger for industrielle plastmaterialer på tværs af sektorer. Målet var at modne, skalere og implementere eksisterende teknologier samtidig med at skabe værdikæder for genanvendelse. Specifikt var det primære fokus på genanvendelse af eksisterende produkter og på at undersøge, om og i hvor høj grad nye værdikæder for genanvendelse kunne etableres, samtidig med at erfaringer blev integreret i design af fremtidens produkter. Disse ambitioner var kun mulige ved at samle partnere på tværs af værdikæden, hvilket gjorde det muligt at:

- Matche produkter og materialer med komplementære genanvendelsesteknologier.
- Sikre teknologisk udvikling og demonstration af genanvendelighed gennem pilotprojekter.
- Opskalere pilotprojekter understøttet af LCA-screeninger for at bevæge sig mod implementering i nye værdikæder.
- Etablere en base for fremtidens produkter, der er 'designet til genanvendelse'.

Baggrund for CIP-partnerskabet

Motivationen for at etablere CIP blev drevet af de forskellige virksomheders ambitioner om at tage miljøansvar for deres produkter ved at reducere mængden af virgin plast og herved, ideelt, reducere CO₂ samt deres ambitioner om at overgå til en cirkulær økonomi. Overgangen og skabelsen af nye værdikæder er uden tvivl komplekse opgaver, der kræver forskellige kompetencer og bidrag fra forskellige partnere. Derfor etablerede Teknologisk Institut tilbage i 2021, CIP-partnerskabet, som inkluderede virksomheder fra forskellige sektorer på tværs af værdikæden samt vidensinstitutioner. Centrale barrierer for en cirkulær omstilling, som partnerskabet stod overfor, var:

- a. Manglen på kommercielt bæredygtige genanvendelsesteknologier og affaldshåndteringsinfrastruktur for forskellige plastmaterialer.
- b. Komplexiteten af historiske kemikalier i indsamlede produkter, der er beregnet til genanvendelse: blandede, uadskillelige eller komplekse plastprodukter samt plast, der indeholder tilsætningsstoffer og kemikalier, som i dag betragtes som problematiske.
- c. De logistiske udfordringer ved håndtering af returnerede produkter både organisatorisk, nationalt og internationalt: Mens forsyningskæder er blevet optimeret til produktion gennem årtier, er effektive værktøjer til omvendt logistik stadig begrænsede, og organisatoriske udfordringer ved at tilpasse sig cirkulære initiativer i høj grad til stede.
- d. Produkter, der i øjeblikket er på markedet, er designet og optimeret til produktion, funktion og omkostninger – ikke til genanvendelse.

Partnerskabet blev gennemført fra 2022 til 2025, delvist støttet af Miljøteknologisk Udviklings- og Demonstrationsprogram (MUDP) under Miljø- og Ligestillingsministeriet.

Værdiskabelse for CIP-partnere

CIP-partnerskabet gav et solidt fundament for fremtiden for industriel plastgenanvendelse i Danmark og fremhævede det transformative potentiale ved strategiske partnerskaber og innovative teknologier som centrale elementer for forandring. Den værdi, der blev skabt gennem deltagelse i CIP, var individuel for de mange forskellige partnere, men de tre mest essentielle værdiskabere var som følger:

- **Viden gennem netværk:** Den samarbejdsorienterede tilgang i CIP-partnerskabet demonstrerede den enorme værdi af at opbygge et robust netværk af interessenter på tværs af forskellige sektorer. Fremtidige bestræbelser på at skabe et mere cirkulært samfund bør fokusere på at udvide partnerskaberne for at lette udvekslingen af viden og bedste praksis, fremme innovation og overvinde fælles udfordringer inden for genanvendelse.
- **Eksempels magt:** CIP leverede eksempler på succesfulde genanvendelsesinitiativer, der fungerede som pilotcases og var vigtige for at fremskynde implementeringen af strategier blandt partnerne samt for at bevæge sig fra teoretisk planlægning til praktisk anvendelse. CIP opfordrer andre til at tage lignende tiltag, hvilket fremmer en handlingsorienteret kultur for bæredygtighed, samtidig med at det sætter standarder for industrien.
- **Strategiske indsigter:** CIP gav partnerne vigtige strategiske indsigter, som hver enkelt partner kunne bruge til at informere deres egne strategier og forretningsudvikling. CIP tydeliggjorde betydningen af at integrere genanvendelsesteknologier og principper for cirkulær økonomi i forretningsdrift og strategier. Partnerne understregede vigtigheden af ledelsesmæssig støtte og fremhævede, at cirkulære forretningsmodeller kunne drage fordel af at inkludere KPI'er med nye bæredygtighedsmål. Fremtidige initiativer bør bygge videre på dette og udvikle skalerbare modeller for lukkede eller semi-lukkede kredsløbssystemer, hvilket forbedrer både økonomisk levedygtighed og miljømæssig bæredygtighed.

Hovedkonklusioner og udvalgte pilotcases

Produktionsvirksomhederne i CIP havde en fælles vision om at udvikle genanvendelseslandskabet, var de meget forskellige: Nogle producerede Fast-Moving Consumer Goods (FMCG), nogle var primært aktive på B2C-markeder, mens andre hovedsageligt opererede på B2B-markeder. De arbejdede under helt forskellige vilkår og repræsenterede varierende grader af modenhed inden for cirkularitet i deres organisationer. Partnerne repræsenterede således en mangfoldighed, der er typisk for den danske industri. På trods af deres forskelle fremhævede alle CIP-partnere værdien af at dele viden og opnå indsigt i forskellige virksomheders udfordringer med at etablere en mere cirkulær produktion og/eller et takeback-system. Mens nogle partnere formåede at skabe en komplet brugssag, havde andre behov for mere tid til at omstille sig til en cirkulær tankegang, før de kunne begynde at anvende genanvendte materialer. Blandt både fælles og individuelle organisatoriske erfaringer er de vigtigste konklusioner fra CIP som følger:

- Genanvendelse af selv komplekse produkter og materialer er ofte teknisk muligt ved brug af tilgængelige genanvendelsesløsninger, som bedst identificeres gennem praktisk test og demonstration.
- Partnerskaber og en grundig forståelse af dit produkt inden for værdikæden er afgørende for succes.

- Termomekanisk genanvendelse er den mest modne og tilgængelige genanvendelsesteknologi, mens sorteringsmetoder tilbyder betydeligt potentiale i mange tilfælde. Dissolution og kemisk genanvendelse, såsom pyrolyse og HTL (Hydrothermal Liquefaction), spiller en komplementær rolle, især i forhold til historiske kemikalier, men disse metoder skal stadig modnes og skaleres, før de kan fungere som standardalternativer.
- For at fremme og accelerere overgangen til en cirkulær økonomi er der stadig barrierer, der skal overvindes, såsom forbedring af affaldshåndteringsinfrastrukturen, fortsat teknologisk udvikling, økonomiske incitamenter og lovgivning.
- De generelle konklusioner er baseret på erfaringer fra mere end 20 pilotcases, der blev skabt gennem matchmaking mellem produkter og potentielle genanvendelsesteknologier, som gennemgik forskellige faser illustreret i Figur 1.

Udvalgte cases ses nedenfor:

- **Novo Nordisk** forbedrede sit ReturpenTM-program (nu ReMed) gennem et partnerskab med Zirq Medical med fokus på sortering og dekontaminering af multikomponent-medicinske penne. Samarbejdet prioriterer i øjeblikket genvindingen af to hovedmaterialer, mens der udvikles åbne genanvendelsesprocesser som en forudsætning for at opnå ekspertise til fremtidig integration af lukkede kredsløb i produktionen.
- **Grundfos** indgik et samarbejde med Trebo med målet om at opnå lukket kredsløbsgenanvendelse ved at opnå en ekstremt høj renhedsgrad i flere materialetyper, der blev genvundet fra komplekse materialer via fluidmekanisk sortering. Grundfos validerede genanvendt materiale i prøveproduktioner. Derudover blev pyrolyse- og dissolution-processer udforsket for fraktioner, der ikke var egnede til termomekanisk genanvendelse.
- **Danfoss** gennemførte succesfuldt tests med genanvendt materiale fra brugte radiatortermostater og observerede ingen signifikant nedbrydning af egenskaber i genanvendt materiale, der var flere årtier gammelt. Prototypekomponenter til termostater fremstillet af genanvendt materiale bestod funktionelle tests, hvilket validerede den mekaniske gennemførlighed af et lukket genanvendelsessystem. Der blev indført en pilot returordning for at fremstille prototyper af håndtag til radiatortermostater med genanvendt indhold, som bestod alle funktionelle tests, og som kan skaleres og teknisk set implementeres.
- **Coloplast** adresserede de specifikke udfordringer ved genanvendelse af post-industrielle og post-forbruger medicinske produkter. I tæt samarbejde med Trebo (post-industriel genanvendelse) og Zirq Medical (post-forbruger genanvendelse) gennemførte Coloplast flere forsøg og demonstrerede med succes sortering af produktionsrester i højt rene og anvendelige fraktioner. Sammen med Trebo vurderede Coloplast yderligere kompatibiliteten med nuværende genanvendelseslinjer, hvilket resulterede i en plan for skaleringstests og potentiel implementering ud over CIP-projektets rammer.
- **Kemiske genanvendere** (Makeen EnviroTech og Aarhus Universitet (AU, der driver et HTL-pilotprojekt)) fokuserede på udviklingen af pyrolyse- og HTL-genanvendelsesteknologier. Samarbejder med BASF og Topsoe identificerede kommercielt interessante fraktioner fra ABS og PA66, selvom disse endnu ikke var

levedygtige på grund af umodenhed og kompleksiteten i raffineringsteknologierne. På trods af tekniske fremskridt halter teknologiernes parathed og kommercielle levedygtighed stadig efter termomekanisk genanvendelse, hvor massbalance-betragtninger anses som en forudsætning for at accelerere kemisk genanvendelse mod kommercialisering.

De mest modne CIP-cases – repræsenteret ved produkterne i Figur 1, der nåede brugssagsniveau – blev evalueret på seks kritiske faktorer for at skabe en struktureret ramme til vurdering af værdien og gennemførligheden af de endelige brugscases. En central indsigt er, at teknologisk udvikling, bæredygtighedsimpact og ressourceinvestering var centrale elementer for at muliggøre fremgang, især i forhold til at fremme genanvendelsesløsninger og integrere dem i værdikæden.

Anbefalinger til industrien og politiske initiativer

Selvom tekniske løsninger til genanvendelse af komplekse plastmaterialer viste sig mulige, er der stadig behov for både tekniske og politiske initiativer:

Forbedring af kemiske genanvendelsesteknologier: Selvom der blev gjort fremskridt under CIP, kræver genanvendelsesteknologier, der supplerer termomekanisk genanvendelse, såsom pyrolyse, HTL og Dissolution, fortsat investeringer og innovation for at realisere deres skalerbarhed og effektivitet.

Forbedring af produktdesign med fokus på genanvendelighed og ægte substitution: Det vil være afgørende at fremme produktdesign, der prioriterer genanvendelighed. Dette inkluderer at designe produkter med hensyn til deres slutbrug. Cirkulære forretningsmodeller bør sikre, at nye produkter fremstillet af genanvendte materialer repræsenterer ægte substitution, dvs. at de nye produkter er efterspurgt og erstatter ellers jomfrueligt kulstof – ideelt set endda med radikal innovation frem for inkrementel, hvor jomfrueligt kulstof muligvis stadig er mere konkurrencedygtigt.

Styrkelse af regulerings- og politiske rammer: Fremskridt på dagsordenen med politikere for at etablere klare regler og incitamenter for genanvendelse og bæredygtighedspraksis vil understøtte en bredere industrimæssig adoption af disse initiativer. Langsigtede politiske strategier for en cirkulær økonomi bør understøtte de nødvendige investeringer på tværs af værdikæden og gøre de økonomiske incitamenter tydelige for alle partnere. Udvalgte anbefalinger er angivet nedenfor.

TABLE 1. Politiske anbefalinger og drivers.

Politisk anbefaling	Drivkraft for anbefaling
Introducer udvidet producentansvar på produktniveau	Sikr, at producenter tager ansvar for deres produkters livscyklus, herunder design, materialebrug og genanvendelighed.
Skab incitamenter for samarbejde og nye cirkulære genanvendelsesveje	Priorité partnerskaber, innovation og samarbejde på tværs af industrier for at udvikle nye genanvendelsesveje og forbedre cirkulariteten.
Subsidier genanvendte materialer og tilskynd til genindtræden i lignende produktkvalitet	Gør genanvendte materialer mere økonomisk konkurrencedygtige og sikre, at de bruges i anvendelser, der er ækvivalente med jomfruelige materialer.
Støt tværindustrielle indsatser for standardisering	Tilskynd til ensartethed i materialetyper, dokumentation og genanvendelsesprocesser for at forenkle genanvendelse og tilpasse industripraksis.

Udvikling af CIP-partnerskabet

om resultat af CIP-partnerskabet er flere usikkerheder og løsningsscenarier blevet reduceret, og partnerne har nu en mere klar retning for at fokusere og fortsætte med at skalere løsningerne. Den fremtidige udvikling vil blive drevet af partnerne selv, i samarbejde med deres værdikæde eller gennem innovationsinitiativer.

Succesen med CIP-partnerskabet understreger nødvendigheden af kollektiv handling for at fremme genanvendelse og bæredygtighed mod cirkularitet. Interessenter på tværs af plastindustrien opfordres til at:

1. Indgå i samarbejdspartnerskaber: Søge partnerskaber, der fremmer vidensudveksling og giver adgang til nye partnere for at adressere udfordringer inden for genanvendelse og bæredygtighed.
2. Investere i forskning og udvikling, der muliggør genanvendelse fra starten: Investering i F&U er afgørende for at fremme genanvendelsesteknologier og udvikle metoder til at forbedre materialegenindvinding og produktdesign.
3. Adoptere bæredygtige praksisser: Virksomheder opfordres til at integrere bæredygtighed i deres kerneforretningsstrategier, herunder at opstille Key Performance Sustainability Indicators (KPSI'er), der fokuserer på at reducere affald, øge energieffektivitet og bruge genanvendte materialer, samtidig med at de samarbejder tæt med organisationen om disse ændringer.
4. Argumentere for politisk støtte: Engagere sig med beslutningstagere for at fremme støttende reguleringer og incitamenter, der fremmer genanvendelse og initiativer inden for cirkulær økonomi.

Ved at udnytte disse værdidrivere og tage de foreslåede handlinger baseret på CIPs samarbejdsmetode kan danske industrier accelerere transformationen mod en mere cirkulær fremtid. Støtte vil i de kommende år være tilgængelig for forskellige industrier og specifikt for SMV'er gennem flere initiativer, såsom denne rapport og dens mange anbefalinger, konferencen, der afslutter CIP, og det nye projektinitiativ "Cirkulær plast – en ressource til fremtidens produktion", finansieret af Industriens Fond.

I sidste ende kan dette føre til en mere bæredygtig fremtid, hvor industrielt plast effektivt genanvendes, og ressourcer udnyttes mere effektivt.

Resume

Det Cirkulære Industrielle Plast-partnerskab (CIP) (2022-2025), etableret af Teknologisk Institut og støttet af MUDP, har haft til formål at udvikle, demonstrere og opskalere tværsektorielle genanvendelsesløsninger for industriel plast. Gennem et stærkt værdikædesamarbejde har målet været at overvinde barrierer som umoden affaldsinfrastruktur, komplekse kemikalier i historiske produkter, logistiske udfordringer og produkter, der ikke oprindeligt er designet til genanvendelse.

Med udgangspunkt i over 20 pilotcases har partnerskabet vist, at genanvendelse af selv komplekse plastprodukter er teknisk muligt. Virksomheder som Novo Nordisk, Grundfos, Danfoss og Coloplast har med succes testet alt fra avancerede sorteringsmetoder til lukkede kredsløb. En hovedkonklusion er, at termomekanisk genanvendelse i dag er den mest modne teknologi, mens kemiske metoder som pyrolyse og HTL (Hydrothermal Liquefaction) fungerer som vigtige, men endnu umodne supplement.

For at accelerere den cirkulære omstilling peger CIP på et behov for både industrielle og politiske tiltag:

- Design til genanvendelse: Fremtidens produkter skal designes med henblik på genanvendelighed og reel substitution af jomfruelig plast.
- Stærke rammevilkår: Der anbefales politiske initiativer som udvidet producentansvar, økonomiske subsidier til genanvendte materialer og tværgående standardisering.
- Strategiske partnerskaber: Fortsat samarbejde, investering i forskning samt vidensdeling på tværs af sektorer er afgørende for succes.

CIP-partnerskabet har skabt et solidt fundament for fremtidens plastgenanvendelse i Danmark. Selvom projektet er afsluttet, fortsætter de deltagende virksomheder med selv at drive den fremtidige udvikling og skalering af løsningerne i deres egne værdikæder.



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