CIRCULAR FOAM

Deliverable 1.6: Roadmap and starting point of joint action

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Executive Summary

This document, Deliverable 1.6 from the CIRCULAR FOAM project funded by the EU's Horizon 2020 program, outlines a roadmap and practical starting points for achieving a circular system for high-performance plastics, specifically PUR rigid foam, by 2050.

Building on prior work, this report focuses on "transformation knowledge" to bridge future scenarios and stakeholder actions. This knowledge is essential for fostering and implementing systemic changes, bridging the gap between plausible future scenarios and concrete, stakeholder-based actions. Following a selective literature study on closing the loop in complex waste streams, the roadmap is structured around various interconnected factors, categorized by PESTEL (Political, Economic, Social, Technological, Ecological, Legislative) influence factors.

Collaboration and governance have a critical role in driving systemic change. The document adapts the Transition Management (TM) framework to the CIRCULAR FOAM project, proposing a phased approach that includes stakeholder engagement, vision-building, and experimentation. Regulatory sandboxes are highlighted as a practical tool within this framework, allowing for the systematic testing of innovative solutions by temporarily mitigating existing regulatory barriers and accelerating learning in real-world environments.

Considering social factors, regional differences, and relevant societal debates, this analysis reflects the complexities of the system. It aims to provide a structured and actionable plan that can serve as a starting point for collaborative action towards transitioning to a fully circular system for high-performance polymers in general, and PUR rigid foam in particular.

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Table of Contents

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No. 101036854

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List of Abbreviations

AI	Artificial Intelligence
BAT	Best Available Technique
BEP	Best Environmental Practice
C&D	Construction and Demolition
CE	Circular Economy
CSRD	Corporate Sustainability Reporting Directive
D1.1-1.6	Deliverable 1.1-1.6 of the CIRCULAR FOAM project
DPP	Digital Product Passport
EoL	End-of-Life
EPR	Extended Producer Responsibility
EPS	Expanded Polystyrene
ESG	Environmental, Social and Governance
ETS	Emission Trading System
EU	European Union
GDP	Gross Domestic Product
GZM	Górnośląsko-Zagłębiowska Metropolia (Metropolis GZM)
HPP	High-Performance Plastics
LCA	Life Cycle Assessment
NIR	Near-infrared
PE	Polyethylene
PIR	Polyisocyanurate
PUR	Polyurethane
R&D	Research and Development
SME	Small and medium enterprise
TM	Transition Management
VAT	Value Added Tax
WEEE	Waste Electrical and Electronic Equipment
WP	Work Package

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1 Introduction and Theoretical Background

In our Work Package 1 (WP1) report on "Dialog-based format for implementation with partners in industry, science, administration" (D1.5, Wegener et al., 2025), we have selectively fused system knowledge gathered by WP1 in D1.1-1.4 as well as participatively developed target knowledge in the form of plausible scenarios. Overall, D1.5 serves as a conceptual transformation framework that provides potentially impactful information for the implementation of circular solutions around waste management and recycling of high-performance plastics (HPP), such as PUR rigid foam.

To rationalise and assign the knowledge gathered by WP1, a fundamental differentiation between three knowledge types from the scientific field of sustainability science was used in D1.5 (Brandt et al., 2013, p. 8; ProClim, 1997, p. 15):

1. **System knowledge**: strategic elements concerning the context of the given system and sustainability issue, such as underlying systemic drivers and barriers that cause and determine the extent of change.
2. **Target knowledge**: socio-cultural conditions in the three regions combined with a comprehensive evaluation of desired target states, potential risks and benefits under prevailing uncertainties.
3. **Transformation knowledge** that refers to practical implications, such as "habits, practices and institutional objectives that enable practitioners to evaluate different problem-solving strategies and to achieve the competence to foster, implement, and monitor progress and to adapt and change behavioural attitudes (Hirsch Hadorn et al., 2006).

The diverse body of system knowledge that had been gathered and analysed in D1.1-D1.4 was selectively fused for D1.5 and assigned to **PESTEL**-categories considering **p**olitical, **e**conomic, **s**ocial, **t**echnological, **e**cological, and **l**egislative influence factors (Wegener et al., 2025, pp. 17-21). The development and conduction of a context sensitive dialog-based collaboration process in the three regions through scenario development workshops with diverse stakeholder groups has then provided target knowledge in the form of four narrated scenarios for each of the three regions (Wegener et al., 2025, pp. 33-74). In chapter 4 of D1.5, our insights on system and target knowledge were then finally synthesised in the form of a discussion structured around the PESTEL categories.

In our report D1.6 we now focus on the transformation knowledge that builds upon the previous report and synthesis of results. Our first aim is to derive and describe strategies and actions in chapter 2 that can help to bridge the gap between plausible futures – inspired by the participatively developed scenarios – and short-, medium- and long-term stakeholder-based processes for each PESTEL category until the year 2050.

In chapter 3, we propose key approaches concerning "collaboration and governance", which is crucial for building a joint cluster in the regions, outlining practical starting points for joint action. This section distinguishes between participatory governance, which emphasises democratic legitimacy and inclusivity in decision-making, and collaboration, focusing on cooperative interaction and goal-oriented problem-solving among diverse stakeholders. A central framework for guiding this transformation is Transition Management (TM), which advocates for new governance strategies to foster coordination and strengthen networks for societal change. These integrated approaches aim to systematically identify, test, and scale innovative solutions, providing practical means to overcome regulatory barriers and accelerate learning towards a circular economy for high-performance plastics like PUR rigid foam.

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1.1 Transformation knowledge

Transformation knowledge refers to the knowledge required to foster change processes and shape the transition from a current to a desired target state (Brandt et al., 2013; ProClim, 1997). Transformation knowledge empowers actors to evaluate problem-solving strategies, and to foster, implement, and monitor progress, as well as adapt behaviours to accelerate necessary systemic changes (Brandt et al., 2013; Sharpe et al., 2016).

Our report D1.5 provided systemic knowledge about the current context and target knowledge concerning plausible future scenarios for circular solutions and hubs for circularity[1]. In Germany, the scenarios that were developed range from minimal progress due to mutually dependent crises to radical changes driven by severe ecological impacts, highlighting the need for a proactive approach to integrate various circular economy strategies. The Netherlands' scenarios underscore the contrast between refrigerator recycling, supported by strong regulations and collaboration, and the fragmented construction sector, which requires stronger incentives and clearer regulations to improve recycling rates. Poland's scenarios emphasize the critical role of regulation, strong political support, and business innovation, with varying degrees of state intervention and public awareness shaping the future of recycling.

In the following, we will firstly draw on insights from literature that have high relevance and potentially transferable impact for the transformation knowledge and our roadmap development. It has the purpose to outline potential strategies and concrete starting points for joint action that aim to bridge the gap between the participatively developed scenarios in D1.5 and stakeholder-based goals and processes for each PESTEL factor until the year 2050. This helps us to develop concrete roadmaps and agendas for the implementation of circular systemic solutions in waste management and the recycling of high-performance plastics within the CIRCULAR FOAM project.

Sharpe et al. (2016) emphasize the need for "researching practices of transformation in ways that bridge different kinds of knowledge, including […] logically built up, teachable knowledge and […] practical wisdom, knowing how to act appropriately to achieve 'good ends'". They highlight that rather abstract academic knowledge alone is insufficient to bring about the necessary societal changes, instead requiring practice-oriented knowledge forms such as know-how and practical wisdom. For D1.6, one task is to translate our systemic and target knowledge into "transformation knowledge" that includes "practical implications" to foster, implement, and monitor changes, from the current state towards circular solutions for, e.g., PUR rigid foam. Collaborative hubs for circularity, and plausible futures for the development of the three European regions of interest are key ideas behind our roadmap development.

Furthermore, by developing "future consciousness" - "an awareness of the future potential in the present moment" (ibid.) - knowledge can be utilized on "how the future emerges from what is done now", and participants are encouraged "to develop their own role in shaping the future in a reflexive and reflective way, so that they can take responsibility for the process of making transformation happen". This summarizes our approach to qualitative scenario development, displayed in chapter 3 of D1.5 (Wegener et al., 2025, pp. 22-74). By actively involving stakeholders in dialog-based formats,

[1] A ***hub for circularity*** is a key concept for the European Union and for our work in WP1. We define it as a physical and/or digital space in which an intertwined and mostly symbiotic value chain is formed along a specific circular material flow – as part of the overall goal of developing a net-zero circular economy in a region (cf. Del. 1.1).

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we leveraged their accumulated experiential knowledge and fostered their "future consciousness". This enabled them to recognize and actively shape their respective roles in implementing circular systemic solutions for high-performance plastics. The resulting scenarios and agendas reflect the jointly developed understanding and shared responsibility for the necessary transitions in waste management and recycling of PUR rigid foam, which significantly drives practical implementation within and after the CIRCULAR FOAM project.

1.2 Closing the Loop

On a more concrete level, there are several studies aiming for 'closing the loop' of materials in complex industrial networks and with complex waste streams that inspired our roadmap development. These deal e.g., with the development of reverse logistics and closed-loop supply chains in different industrial fields, such as waste from electrical and electronic equipment (WEEE) or from construction and demolition (C&D). In the process of conducting a critical review study (Piorunek et al., 2025), we have identified a sample of 14 studies that address comparable circularity challenges in an integrative way, comparable to the approach of CIRCULAR FOAM.

We selected three studies for this report from our review sample that show high relevance for the transformation knowledge and our roadmap development, since they demonstrate scientific proximity to the sustainability challenge of 'complex waste streams'. Thus, the following discussion offers us transferable insights and recommendations to facilitate our own roadmap development (chapter 3).

How Can We Measure the Prioritization of Strategies for Transitioning to a Circular Economy at Macro Level? A New Approach (Guarnieri et al., 2023)

Guarnieri et al. (2023) argue that the transition to a circular economy (CE) necessitates the measurement and prioritization of strategies at the macro level, encompassing countries, regions, and cities. In their opinion, however, there has been a notable lack of validated instruments for performing such macro-level assessments. To address this gap, Guarnieri et al. (2023) developed and validated a novel questionnaire which was based on an integrative literature review identifying 24 CE strategies and 10 criteria for evaluation. These criteria covered technical, social, environmental, and economic dimensions of sustainability. Participants were asked to evaluate each strategy on a five-level ordinal scale. The questionnaire underwent a two-step validation process using firstly, semantic validation which involved 17 experts from five countries (Brazil, Italy, Spain, Argentina, United Kingdom) who reviewed the questionnaire for coherence, clarity, and readability, leading to several adjustments. Secondly, statistical validation utilized responses from 347 individuals across 25 countries, employing exploratory and confirmatory factor analysis (EFA, CFA), Cronbach's alpha coefficient, and other statistical tests to confirm the instrument's reliability and validity.

The developed questionnaire appears to be a reliable and valid tool for prioritizing CE strategies at the macro level which were effectively grouped into four distinct factors or dimensions:

- Factor 1 includes strategies related to eco-innovation and eco-design, **eco or circular cities**, industrial symbiosis, sharing economy, and **sectoral agreements**.
- Factor 2 encompasses strategies concerning getting value out of biomass, water reuse, energy efficiency, food waste reduction, and **construction and demolition (C&D) waste management**.
- Factor 3 groups **financial incentives and/or support and fiscal measures**, **stakeholder involvement**, **partnerships with research and development (R&D) organizations**, **sustainable product policy**, and **green or sustainable procurement**.

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- Factor 4 consists of **inter-firm collaboration**, **waste management directives**, and **reverse logistics**.

According to our assessment, most strategies from factors 1-4 have been addressed by tasks and deliverables across various WPs in CIRCULAR FOAM. Concerning the work of WP1 (Wegener et al., 2025, pp. 9-21), the boldly highlighted circular economy strategies have high relevance for our final task of roadmap development. The multi-criteria evaluation (social, environmental, economic, technical) provides guiding criteria for proposed circular solutions and starting points for joint action.

In addition and with respect to the political and legal framework in the European Union, Guarnieri et al. (2023) emphasize that the diverse set of European directives and action plans are highly relevant for the success of circular solutions concerning high added value in general, which can also be translated to the circularisation of high-performance polymer, such as the chemical recycling for PUR rigid foam. They state that "**[m]aking the circular economy a reality will, however, require long-term involvement at all levels, from Member States, regions and cities, to businesses and citizens"**, to which we fully agree based on our findings in CIRCULAR FOAM. Furthermore, the study emphasizes that by creating a more favorable environment at the macro level, it becomes possible to induce the adoption of circular economy strategies at the meso (eco-industrial parks, industrial symbiosis) and micro (company, product) levels.

Modeling the principal success factors for attaining systemic circularity in the building construction industry: An international survey of circular economy experts (Oluleye et al., 2023)

This study identifies success factors for achieving systemic circularity in the building and construction industry recognizing the substantial environmental impact of this industrial branch. The goal of the study was to address a gap in understanding actionable factors, particularly across developed and developing economies. The research team employed a multi-stage methodological framework, including a questionnaire survey of 140 CE experts across 39 developed and developing economies. Data were analyzed using a series of participative assessment and statistical validation tools to determine principal success factors for circularity, e.g., by quantifying their criticality.

Thus, **four principal success factors** for circular economy in the building and construction industry could be identified: **(i) Data-driven digital tools and circularity plan**, **(ii) capacity building and pre-demolition auditing**, **(iii) systemic circularity guidelines and commitment**, and **(iv) circular metric and secondary market development**. A fuzzy synthetic analysis showed that all principal success factors are paramount for successful circular economy implementation in both economic contexts – developed and developing countries. However, the prioritization differs: (iii) and (iv) are most significant in developed economies, while (i) and (ii) are key in developing economies. These findings emphasize the **critical need for a context-conscious approach** when implementing CE in the building and construction industry, as the optimal mix of actionable factors varies between economies.

Comparing the insights from Oluleye et al. (2023) on success factors for circular economy in the building and construction industry with the scenarios from our report D1.5, especially the Dutch

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scenarios 3 and 4 (Wegener et al., 2025, pp. 50-55)[2], we can draw several analogies that can help to develop our roadmap:

Addressing fragmentation, limited collaboration, and low circular economy awareness/ commitment: The success factor **(iii) systemic circularity guidelines and commitment** is vital given the Dutch scenarios' depiction of the construction sector lacking clear direction and implementation of circular economy principles. Oluleye et al. (2023) emphasize that establishing relevant guidelines for systemic circularity and effective governmental regulations for cost allocation for circular products, such as recycled PUR rigid foam, are significant factors, underscoring the need for targeted political and financial support. **(ii) Capacity building and pre-demolition auditing** could also directly address the need for expertise and proper management in the fragmented building and construction industry, by means of **promoting workshops among experts on circular economy principles** and **familiarising decision-makers with circular economy benefits.** These strategies could be key to **improving competencies for architects, designers, and demolition contractors**, as well as significantly improve waste management for PUR rigid foam, which is currently often treated as mixed waste and incinerated due to a lack of separation. **Pre-demolition auditing** is also seen as crucial for estimating material quantities for reuse, a process currently not fully documented or regulated for construction waste, cf. (European Commission, 2025, 2018).

Overcoming Limited Digitization and Technological Development: Oluleye et al.'s success factor **(i) data-driven digital tools and circularity plan** can be a countermeasure to the Dutch scenarios' plausible projection for the year 2050, that digitization still plays a "limited role". Oluleye et al. stress that e.g., **digitalisation initiatives and product/ materials passport promotion** along with **data management tools**, are paramount for reshaping waste management practices in this industrial sector. These tools can enhance materials tracking, and efficient recycling/recovery of high-performance polymers like PUR rigid foam.

Developing Markets and Financial Incentives: Oluleye et al.'s proposition of **(iv) circular metric and secondary market development** highlights that construction and demolition waste is only recycled, if there is a monetary incentive and that PUR-containing materials are often incinerated because they are not separated for economic value. Oluleye et al. find **secondary market establishment** to be the most significant factor within this strategic field. This aligns with the need to make the macroeconomic benefit of chemical recycling, predominantly for chemical and recycling companies, also financially attractive for stakeholders that contribute to the circular solution by collection, sorting, and treatment of PUR rigid foam. The study also underscores the **development of CE metrics and indicators** for measuring and tracking progress, which would enable performance benchmarking and goal setting for stakeholders that are participating in new circular business models around chemical recycling of PUR rigid foam.

The findings from Oluleye et al. (2023) emphasize the **critical need for a context-conscious approach** to circular economy implementation, which can be, to some extent, **compared to our three regions with their different political, economic, social, technological, environmental, and legislative conditions** (Wegener et al., 2025, pp. 18-21). The distinct challenges faced by the construction sector

[2] In D1.5, we have presented four scenarios for each of the regions of the CIRCULAR FOAM project: North Rhine-Westphalia in Germany, Greater Amsterdam in the Netherlands and Upper Silesia in Poland (Metropolis GZM). Due to the context-sensitive research approach, the specific product type was only chosen for the Dutch scenario analysis. Consequently, the following paragraphs refer to Dutch scenarios 3 and 4, which focused on construction and demolition waste, while the other regions discussed high-performance plastics as a whole (cf. D1.5, p. 25).

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for PUR rigid foam, as detailed in the Dutch scenarios and thoroughly investigated also by other WPs, contrast with the relatively more advanced circularity for refrigerators (Wegener et al., 2025, pp. 46-50).

Therefore, our envisaged roadmap could target strategies to relevant stakeholders that align the necessary mix of actionable factors with the specific barriers. This includes, for example, promoting data-driven technologies for material tracking and sorting, enforcing regulations, building capacity through training, ensuring strong government commitment from the upper European down to the regional level, as well as specific guidelines for the building and construction industry, and actively supporting developing a viable secondary market for recycled PUR rigid foam.

Public administration strategies that stimulate reverse logistics within the construction industry: a conceptual typology (Brandao et al., 2022)

The study by Brandao et al. (2022) highlights that public administration can be a critical driver for reverse logistics, and thus, investigates how it influences reverse logistics implementation in the construction sector based on a systematic literature review. The purpose of the study was to map government strategies, propose a typology, and identify interactions, of which key insights are shortly discussed with respect to our roadmap development for CIRCULAR FOAM.

A theoretical roadmap for strategy implementation is proposed by Brandao et al. (2022), starting with legislation to enforce deconstruction and recycling, followed by government inspection and penalties, then financial incentives, and finally, market demand creation through quality standards and public buildings' usage, culminating in landfill disposal fees. The authors emphasise that this roadmap is a theoretical framework adaptable to different contexts and that assessing the actual impact of each strategy and tactic requires further investigation.

Overcoming Fragmentation and Lack of Incentives through Combined Strategies: Since the construction/demolition industry is fragmented and waste is only recycled if there is a monetary or other incentive, Brandao et al. propose that **a combination of strategies is more effective rather than single measures**.

- **Legislation** was identified as the most cited and effective driver for reverse logistics, based on their systematic literature review. Implementing **"laws to enforce a level of deconstruction"** and **"laws to enforce a level of recycling"** as proposed in Brandao et al.'s roadmap would directly address this gap for PUR rigid foam.
- **Government Subsidies:** The second most cited strategy, subsidies, is also seen as crucial by Brandao et al. (2022). As part of our second German scenario "recycling hubs in the intra-European circularity competition", we discussed this legislative factor as follows: **"targeted subsidies for energy-intensive chemical recycling of high-performance plastics are essential for viable business models"** (Wegener et al., 2025, p.35). A specific measure in that regard from Brandao et al. (2022) could be financial incentives for recycling/remanufacturing centers and tax benefits for construction companies, which secure PUR rigid foam waste streams and increase their use of recycled material.
- **Incineration Fees:** Brandao et al. highlight that increasing disposal fees generally makes recycling a preferred practice, as it directly influences the recycling ratio and allows the government to manipulate and control the total cost of waste management. For **PUR rigid foam** waste from construction and demolition, the material is **still mainly part of mixed waste streams and thus, transferred to incineration plants, instead of being recycled**. Applying higher incineration fees would serve as a powerful economic instrument, directly increasing

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the cost of this prevalent disposal method. This would further strengthen the economic incentive for chemical recycling.

- **Government Inspection and Penalties/Fines:** Brandao et al. emphasize that legislation and penalties need reliable government control to be effective. This is particularly relevant for construction waste, since in some countries large amounts of waste are illegally dumped in public places or rivers when only weak regulations or enforcement is in place (ibid.).

Addressing Quality Standards and Technological Advancements: Brandao et al. (2022) also stress the need for **"quality standards for the [C&D waste] delivered to the Recycling/Remanufacturing Centers" and "Quality Standards for recycled" C&D waste**. The significant difference in maturity and degree of regulations concerning WEEE and C&D waste (European Commission, 2020, 2023), underscores the focus of Brandao et al.'s roadmap on creating quality standards as a prerequisite for demand creation, and also highlights the need for dedicated investment in **technological innovation (e.g., automated sorting)** to e.g., improve the quantity and quality of collected PUR rigid foam waste.

Integrated Collaborative Processes for Roadmap Development: The conceptual typology and roadmap framework by Brandao et al. demonstrate the **complex interactions between different legislative strategies for public administration** (e.g., legislation requiring government inspection, penalties regulating behaviour, and subsidies encouraging participation). This multifaceted perspective is in our opinion essential for complex waste streams from construction and demolition, such as for PUR rigid foam, where different stakeholders (manufacturers, demolition companies, recyclers, government, consumers etc.) need to collaborate to overcome purely economic interests in a fragmented market, and to collaboratively drive systemic change. Thus, the roadmap by Brandao et al. for C&D waste serves as inspiration and source for developing specific strategies for PUR rigid foam, considering, e.g., legislative mandates, financial incentives, and robust control mechanisms, as well as their appropriate combination to incentivize waste collection and chemical recycling.

1.2.1 Take-aways for chapter 2 "Roadmap towards a Circular System for High-Performance Plastics"

We learn from the selective literature study that **closing the loop for PUR rigid foam necessitates drawing on valid and comprehensive frameworks to develop an effective roadmap**. The selected publications by Brandao et al., 2022, Guarnieri et al., 2023 and Oluleye et al., 2023 are relevant for CIRCULAR FOAM and provide crucial insights into measuring and **prioritizing circular economy strategies at different levels, offering a structured approach for evaluating proposed transformation knowledge and circular solutions for high-performance plastics**.

Furthermore, identifying principal success factors, such as data-driven tools, capacity building, and secondary market development, directly informs the concrete steps and objectives for systemic circularity in the roadmap. The research also underscores the **critical role of public administration and governance strategies, including legislation, financial incentives, and strict controls, in driving reverse logistics and enabling the necessary regulatory and price developments**. These collective insights emphasize the **importance of a context-conscious and integrated strategy to ensure the roadmap is grounded in effective, multi-level actions for achieving circularity in PUR rigid foam systems**.

1.2.2 Take-aways for chapter 3 "Collaboration and Governance"

The principles and factors derived from the three studies, which are discussed above, underscore the **necessity of robust collaboration processes and governance structures, which are outlined detailed**

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in chapter 3. Guarnieri et al.'s (2023) findings on the requirement of stakeholder involvement and partnerships, as well as the **long-term engagement of diverse actors from all levels** (Member States, regions, businesses, citizens) can directly be referred to the emphasis on participatory governance and broad collaboration in chapter 3. Oluleye et al.'s (2023) argue for **overcoming fragmentation and limited collaboration in industrial sectors**, which in turn requires structured transformation frameworks and the **establishment of a core group for coordinating change among multiple actors**. Brandao et al.'s (2022) argument for **integrated collaborative processes to overcome purely economic interests and drive systemic change** aligns with the core principles of collaboration and collective decision-making, which are **essential for forming joint action clusters**. The **concept of regulatory sandboxes discussed in chapter 3**, which facilitates experimentation by granting exemptions from regulations, **builds upon** insights from Brandao et al. (2022) regarding **adaptable regulatory frameworks and government control to incentivize new practices**.

Collectively, key insights from the three reviewed studies emphasize the critical role of coordinated efforts and flexible governance mechanisms for successful circular economy implementation.

2 Roadmap towards a Circular System for High-Performance Plastics

This chapter presents a structured overview of key developments needed to enable a circular economy for high-performance plastics by 2050. For each of the 13 factors identified in Del. 1.5, we outline the long-term goals and identify concrete intermediate goals to be achieved, and steps to be taken over the next 25 years. The temporal horizon is divided into short-term (until 2030), mid-term (until 2040) and long-term actions (until 2050).

The findings are based on the comprehensive timeline (chapter 2.12) that was synthesised through configurative expert input across EU, national, and regional levels, as well as theoretically founded on chapter 1 and our previous deliverables. The two categories (columns) 'LEVEL' and 'STAKEHOLDERS' refer the specific goals and steps to relevant stakeholders at the EU, national and regional level. The subject 'we' is frequently used below to express that the roadmap implementation requires a collective and collaborative process that can only be successfully and effectively implemented through the cooperation of various stakeholders from business, science, politics and society around high-performance polymer networks, such as for PUR rigid foam.

2.1 Regulatory Environment

The regulatory structures needed to support the transition to circular economy must be aligned at all levels (EU, national, regional, civic) in order to support industry and the public. Thus, they can facilitate overcoming the hurdles and challenges of creating the structures needed to manufacture, distribute, collect end-of-life (EoL), sort, and chemically process the PUR waste back to a usable source material.

To accomplish this, existing regulations may need to be reviewed and modified, and new regulations and policies adopted to allow the manufacturing, collection, and recycling/ processing companies to all work seamlessly and efficiently. The agency of legislative bodies and stakeholders should not only be concerned with the European level, but also national, regional, and municipal stakeholders need to be included in the process (see chapter 3.1, "regulatory sandboxes").

2.1.1 What do we want to achieve in the years up to 2050?

1. Standardised **classifications** exist with extensive controls on high-performance plastics, especially PUR rigid foam insulation materials:

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a. Use appropriate control instruments and create framework conditions to express the internalization of external effects and reduce the price disadvantages of sustainable products. This includes financial incentives for low carbon and circular products throughout the value chain, e.g. by reducing VAT rates.
b. Steady grow in the amount of PUR foam that needs to be reclaimed is introduced over several years from Extended Producer Responsibility (EPR) requirement, which requires not only financial responsibility but also recycling (reuse) of the PUR foam.
c. Governments recommend best available technique (chemical recycling) / best environment technique (BAT/ BEP) as the preferred method for recycling to align the collection and recycling industries.
d. At the EU and national levels, it is recommended that by 2050 all EU-produced and all products imported to the EU containing PUR rigid foam be made partly with recycled PUR foams.
e. Enforcement activities must be in place to monitor collection and recycling of PUR foams, especially at the regional or municipal level, or when cross-border transportation is necessary.

2. Strongly increased **recycling quotas** for high-performance plastics, especially PUR rigid foams:
    a. In the uniform classifications of waste, PUR rigid foam is not listed as a waste. At the EU level is it necessary to have extracted end-of-life PUR rigid foam to be listed as a manufacturing material, after its EoL.
    b. Strict recycling quotas for products with PUR rigid foams are put in place. In the mid-term, it is necessary for national governments to put in place recycling quotas for refrigerators and PUR rigid foams that they contain. These quotas would then be monitored and enforced as specified in activity 1e (above).
    c. With a recommended standard extraction and recycling process in place (1d above) and strict monitoring processes in place (1e above), in the mid-term at regional levels the amounts of PUR foams that are used as input to waste incinerators should be greatly reduced in the mid-term.
    d. In the long-term, following proper regional enforcement of 1e (above), and 2b (above), by 2050 there should be no PUR rigid foam material going to waste incinerators in any region in the EU.
3. Increase **incentives** for PUR recycling.
    a. In the mid-term, at the EU level, there must be tax incentives for PUR foams made from recycled material. As recycling processes are established and are put in place, price disadvantages of circular products need to be reduced to create fair competition. It is important that a fairer CO_2-market is in place at mid-term, so that targeted financial measures, such as subsidies, can then be phased out.
    b. To support the recycling industry for PUR rigid foams, it may be necessary for national governments to put in place incentive schemes in the mid-term for the investment in the equipment, facilities, and technology for the industry to properly extract, recycle, and transport the PUR rigid foams.
    c. At the regional level, there must be support in the mid-term for the waste and recyclers to set up regional collection and recycling facilities for end-of-life refrigerators and insulation boards, where it makes sense economically, in order to meet the requirements for the standardized processes that must be followed.

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2.1.2 What could the steps look like for the next 25 years?

1. **At the EU level**, in the short-term and early mid-term, there must be regulations put in place to guide the industry to a standardized best available technique (chemical recycling) / best environmental practice (BAT/ BEP) for the recycling of PUR rigid foams from refrigerators. Once the PUR rigid foam is being consistently extracted, supported by an EPR scheme for manufacturers, ease of transport within the EU must be facilitated by classification of the PUR rigid foam as a general industrial material rather than a waste product. As well, financial incentives should be put in place to encourage the use of recycled PUR rigid foam in insulation and in refrigerators.
2. **National governments within the EU** in the mid-term must support the waste / recycling industry by providing incentives and development areas/ facilities for the establishment of proper recycling facilities for end-of-life refrigerators. Once proper facilities are in place, the national governments must put in place strict quotas for the collection and recycling of end-of-life refrigerators. Additionally, national governments in the long-term must enforce the manufacturing process to ensure that PUR foam is generated from recycled PUR and that imported products are manufactured to the same standards.
3. Supporting the EU and national level programs, the **regional governments** in the mid-term must monitor the collection and recycling industries to ensure the recommended process is being followed and extracted PUR rigid foams are not going to waste incinerators. The long-term goal is that no PUR rigid foams are going to the regional waste incinerators, but rather for proper recycling, not only from refrigerators, but also from C&D waste.

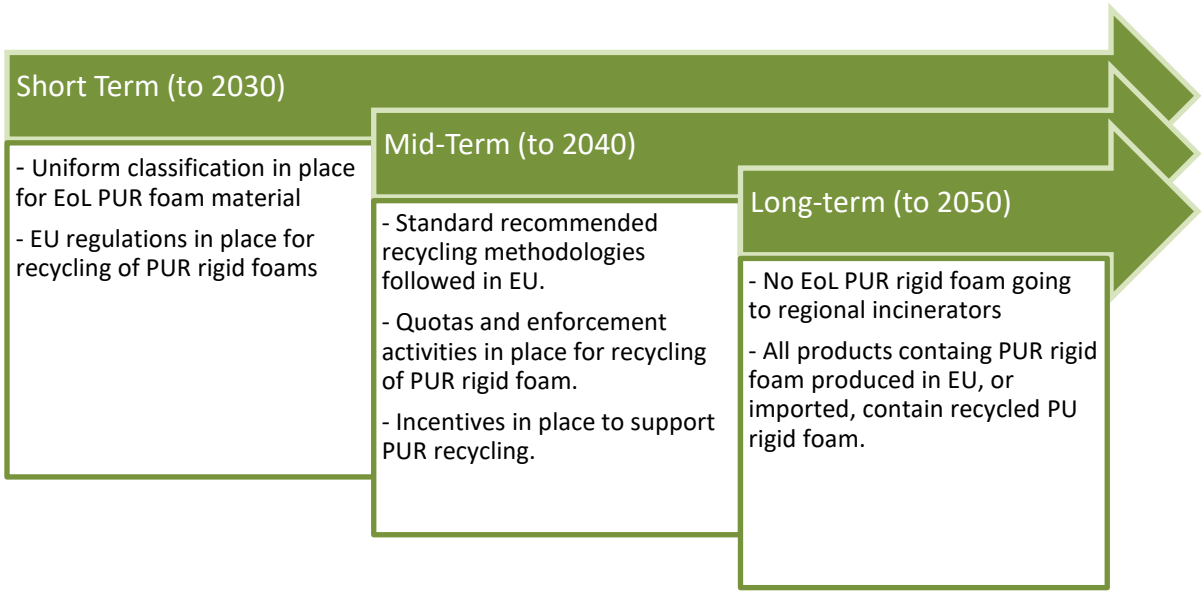

Figure 1: Overview of possible development steps for waste regulations

2.2 Price Development of the Primary Production

Assuming that the **price development for primary production** will be either steady or increasing slow over the next 25 years based on current growth rates (Eurostat, 2025), incentives, price protections,

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and guarantees for recycling can render the use of recycled materials more attractive and acceptable. Thus, an environment that is more stable and which offers stability to recyclers and industries that use recycled materials can be established.

2.2.1 What do we want to achieve in the years up to 2050?

By 2050 there should be structures in place at all levels (EU, national, regional) that support the use of recycled materials and recycled high-performance plastics rather than the use of virgin plastics. This includes taxation schemes and funds to support recycling and the recycling industries, with specific targets for the use of recycled materials in new products.

2.2.2 What could the steps look like for the next 25 years?

1. At the **EU level**, the need to support the use of recycled plastic is critical. This can be accomplished by the implementation of mandatory minimum recycled content targets, and the gradual imposition of limits on the production of primary plastics from fossil sources. This can eventually lead to a full prohibition of non-essential use of virgin plastics when high-quality recycled alternatives are available. This should be supported by harmonised carbon pricing mechanisms (including imports) for primary plastic production through an adjusted Emissions Trading System (ETS). Currently, a revision of the EU ETS is anticipated and could entail the inclusion of waste incineration under the ETS as of 2028. This would make waste incineration subject to carbon price mechanisms and thus, make this practice more expensive. Likely, this could encourage other more sustainable and low-carbon waste treatment options, like material recycling and better waste management (Carbon Market Watch 2021, p. 2; Agora Energie & Systemiq 2023, p. 72). The use of recycled plastic can also be fostered by the implementation of an integrated regulatory and (non-)financial framework, like through the Corporate Sustainability Reporting Directive (CSRD), promoting recycling processes and the high-end regranulation of technical plastics.
2. This should be supported at the **national levels** with the introduction of financial incentives for the production of circular products so that price disadvantages are reduced and the use of recycled material is promoted.
3. Supporting and working with industry **at the local levels, the regional governments** support this with grants for the modernisation of facilities that process recycled high-performance plastics, and the introduction of regional tax incentives for companies using recyclates and implementing energy-efficient technologies. Regions will be able to position themselves as hubs for circularity and advanced technical plastic recycling, integrating research, industry, and energy systems. In the end, facilities relying exclusively on virgin material inputs, and which are not apt for remanufacturing or repairing, are then decommissioned, since recycling infrastructure alternatives are technically and economically more viable.

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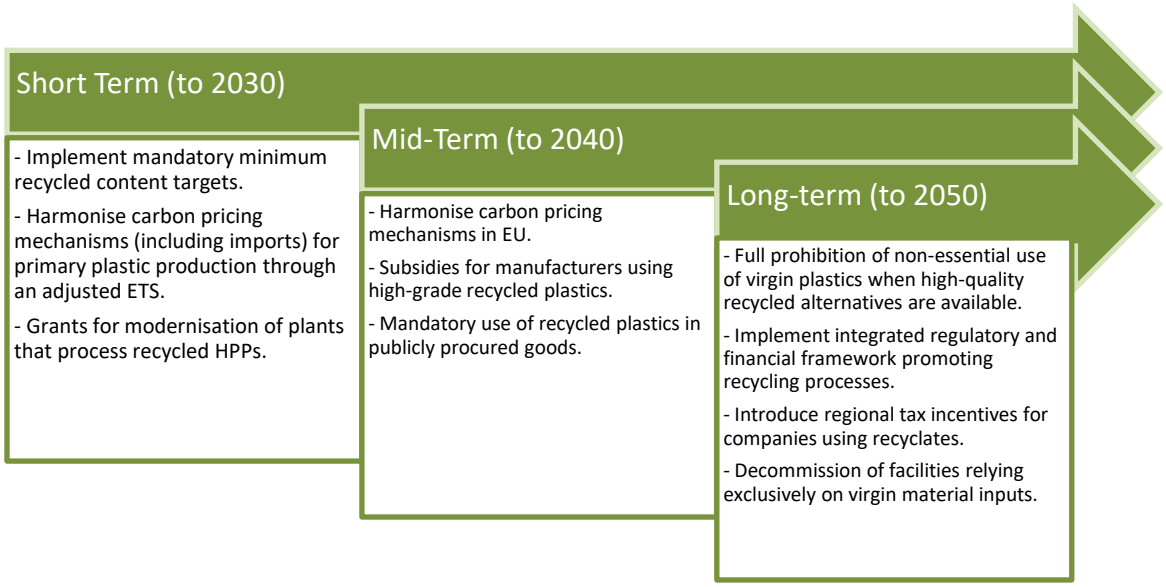

Figure 2: Overview of possible development steps for price development of primary production

2.3 Viability of Recycling-Oriented Business Models

By 2050, full recycling and circular economy activities should be standard business models, still receiving necessary support from EU, national, and regional levels to level the economic playing field. This includes direct financial assistance, support through standardized labelling requirements and product information, and for the adoption of BAT/ BEP practices across industries.

2.3.1 What do we want to achieve in the years up to 2050?

In the years leading up to 2050, a number of steps will need to be put in place to achieve full circularity of PUR rigid foams. This includes incentive programs for supporting recycling-oriented business models, introduction of EPR fees and incentives, and establishment of an **EU-level** observatory for **circular business viability**.

Taking this a step down to the **national levels**, this cascades to the creation of national-level platforms for plastics transparency, seed grants and funding for circular business models, risk guarantees for high-risk recycling investments, and tax reforms promoting recycled products. Further, it is critical that there are long-term public procurement contracts put in place for recycled plastics, that there is a national circular business scoring model and rating system, and that there is full integration with the EU for subsidies into EU industrial competitiveness policies.

With these activities in place, **regional governments and industry** can then work together to effectively set up and operate high quality recycling operations. This includes development of regional CE investment funds, setting up of CE hubs, establishment of benchmarking systems for circular business models, and establishment of regional CE zones and hubs.

2.3.2 What could the steps look like for the next 25 years?

1. Seed grants and business incubation programmes should be launched at national and regional levels to support startups and SMEs working on technical plastics recycling and circular business innovations. This includes forming regional circularity coalitions or industrial clusters to foster collaboration and market access.

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2. Eco-modulated Extended Producer Responsibility (EPR) fees should be implemented across Member States to create market incentives for design-for-recycling and closed-loop systems. National governments should also establish risk-guarantee funds to de-risk private investment in innovative but high-risk recycling technologies.
3. The EU should establish a permanent subsidy scheme for high-quality recyclers and launch EU-backed guarantee mechanisms to support long-term supply and off-take contracts in the recycling sector. These mechanisms would help stabilize business models dependent on volatile secondary materials markets.
4. Circular business model viability indicators should be fully integrated into EU and national public funding, procurement, and industrial competitiveness policies. An EU Observatory for Circular Business Viability should be operational to track, benchmark, and guide ongoing support for viable, scalable circular business models.

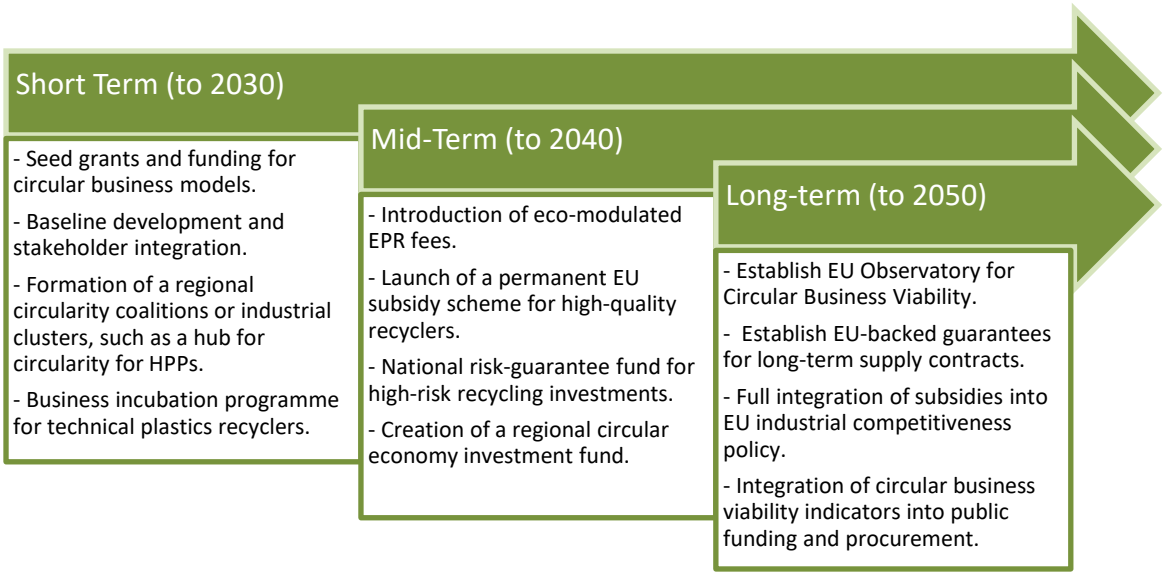

Figure 3: Overview of possible development steps for the viability of business models

2.4 Development of Digital Services and Data Availability

Digitalization plays a crucial role in enabling circularity by providing the tools needed to track material flows, optimize recycling operations, and ensure recyclate quality and compliance. Reliable digital services and data-sharing platforms can support transparency, efficiency, and predictive planning across the PUR value chain, helping companies and stakeholders achieve circularity goals.

2.4.1 What do we want to achieve in the years up to 2050?

By 2050, digital systems will fully support circular material flows, providing transparency, efficiency, and predictive capabilities for the collection, recycling, and reuse of PUR rigid foam **across all sectors in the EU**.

2.4.2 What could the steps look like for the next 25 years?

1. To support this goal, environmental data platforms will be developed to monitor, report, and manage PUR waste flows across the value chain, providing reliable information to all stakeholders. Digital product passports (DPP) and tracking systems will be introduced,

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enabling clear documentation of material composition, product history, and end-of-life requirements.

2. Real-time data sharing between collectors, recyclers, and manufacturers will allow for the optimization of logistics and processing, ensuring efficient recovery and recycling of PUR rigid foam.
3. The use of digital twins for products containing PUR will support predictive planning for collection and recycling activities, improving recovery rates and recyclate quality.
4. Regulatory frameworks are already scheduled and will enforce the use of digital tracking and reporting systems, ensuring compliance with circularity targets while creating incentives for transparency and data-driven circular business models.

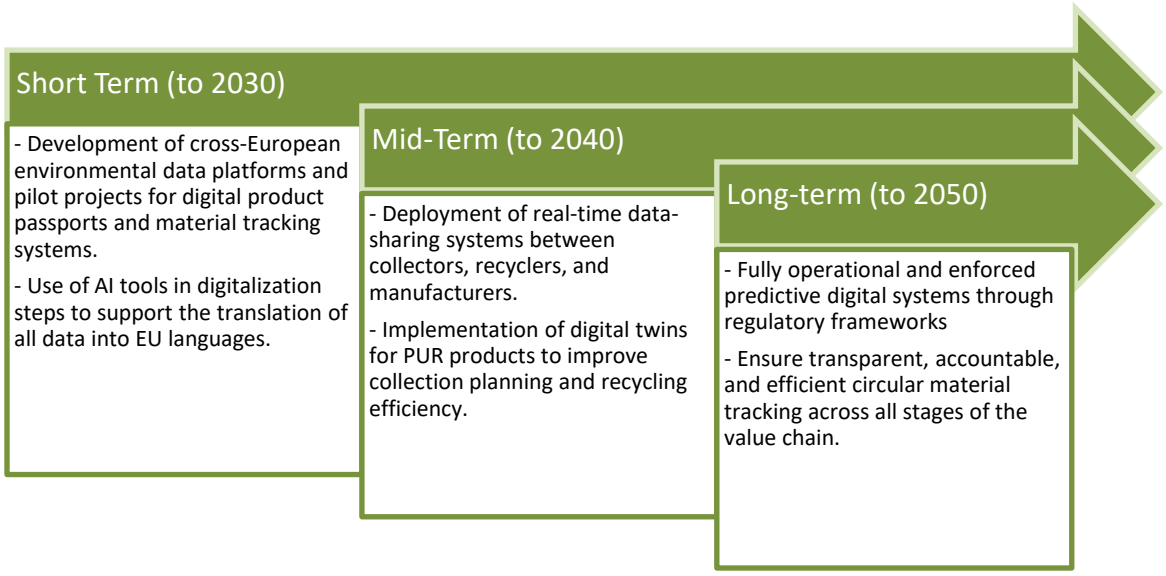

Figure 4: Overview of possible development steps for digital services

2.5 Global Responsibility and Coordination

To align all levels of government and industry to Circular Economy (CE) activities, governments and industry must work together to align public policy and strategies with the steps needed to establish hubs for circularity for HPPs, such as PUR rigid foam.

2.5.1 What do we want to achieve in the years up to 2050?

By 2050, there should be in place a **strong political stance at all levels in favour of CE**, and active participation in international trade to return EoL materials back to manufacturers to ensure the value of the commodity is not lost and it can be reused after processing.

2.5.2 What could the steps look like for the next 25 years?

1. At the **EU level** there must be a reliable definition and strategy for mandatory ESG reporting throughout the supply chain (an extension of the CSRD), while maintaining the reporting obligation for large entities and gradually introducing it to the SME sector. This will be supported by harmonisation of environmental labelling schemes and the mandatory display of carbon/ material footprint on packaging (such as DPP).
2. At the **national levels**, over the next 25 years governments must launch a central register of the carbon and material footprint of traded products and integrate the national CE strategy

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with industrial and energy policies. This will be supported by the introduction of tax preferences for products that are recycled and those with a reduced carbon footprint, create economic incentives for circular consumer behaviour (e.g. VAT cuts), and integrate circular economy policies into education, vocational training, and urban planning systems.

3. At the **regional levels**, governments should work with industry to establish hubs for circularity, and offer development or land recycling areas, for recycling of EoL products and materials. Furthermore, the establishment, development and improvement of CE hubs that foster all R-strategies, e.g., through material/product libraries, repair cafés, exchange points, etc. should be facilitated by local authorities, companies, craftspeople, and many more.

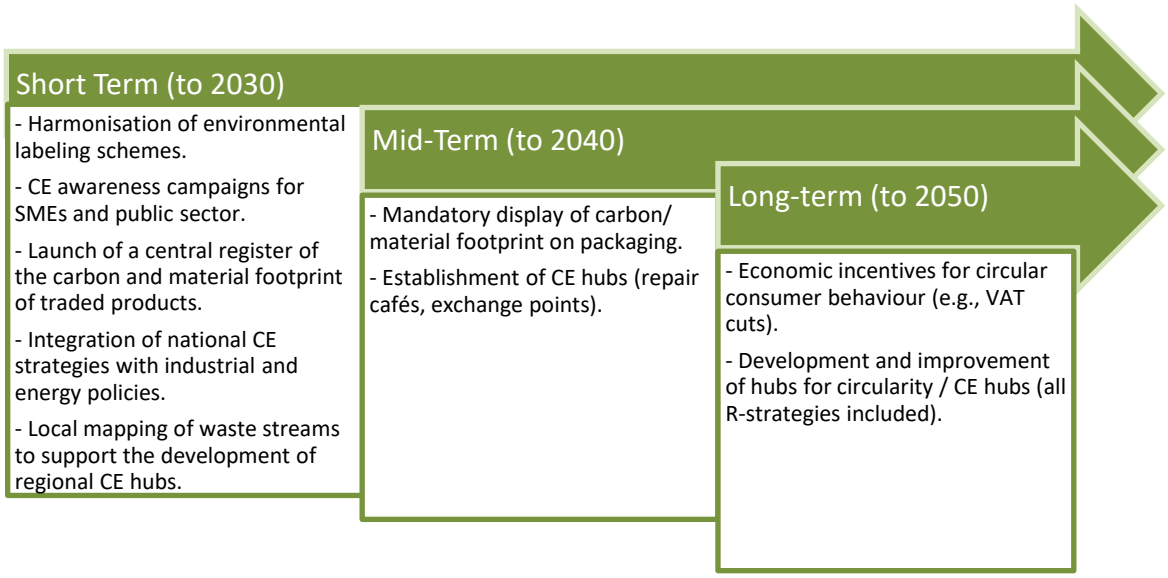

Figure 5: Overview of possible development steps for global responsibility and coordination

2.6 Awareness for Circular Economy

The concept of circular economy has developed over the past decades from the concept of recycling, to reusing all components of an EoL product to manufacturers so that they can be broken down, in cases chemically recycled, and the end-product used to generate new materials (Kirchherr et al., 2023; Kirchherr et al., 2017). While CE may be known by governments and some industries, it is neither completely known or understood in industry, nor in the public (Kirchherr and Hartley, 2025). This must be overcome.

The transition to a CE for HPP, such as chemically recyclable PUR rigid foam, depends not only on regulatory mandates but also on systemic and sustained education and dissemination. Legal frameworks may define the rules, but their societal implementation hinges on a well-informed and engaged public.

Education and communication strategies must therefore be designed to support — and be **supported by — EU, national, and regional regulations**. Regulatory requirements (e.g., for separate collection, extended producer responsibility, and environmental labelling) must be accompanied by broad public understanding and behavioural alignment. Only through this dual approach can the circular economy model be successfully realized.

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Public authorities, businesses, academia, and civil society must collaborate to embed circularity into **both formal education** (from primary schools to universities) **and informal mechanisms** (such as awareness campaigns, community programs, and incentive systems). Moreover, **communication and educational tools should be closely aligned with EU policy/regulatory language to ensure consistent and effective messaging across Member States.**

2.6.1 What do we want to achieve in the years up to 2050?

1. The concepts and approaches of circular economy and sustainability are systemically integrated into primary, secondary, and tertiary education through curriculum reform and the development of specialized academic and vocational tracks that align with labour market needs in the CE.
2. Universities activate their third mission by fostering public engagement, promoting lifelong learning, and driving innovation activities that are directly linked to circularity and regulatory literacy.
3. The EU has implemented coordinated public information campaigns—funded by programs such as Horizon Europe and LIFE—that translate legal obligations into accessible knowledge, empower citizens, and promote sustainable behaviour.
4. Behavioural incentive mechanisms, including deposit-return systems, eco-loyalty schemes, digital reward platforms, and urban gamification challenges, should be deployed and linked to legal obligations such as separate collection requirements and take-back schemes.
5. Regional and civic actors—such as municipalities, NGOs, and local media—should be empowered through decentralized approaches to adapt circular economy education to local contexts by co-creating initiatives like Repair Cafés, Circularity Hubs, and CE education centres.
6. Social research and behavioural insight studies should be supported to inform future policy design, communication campaigns, and adaptive strategies based on real-world motivations and barriers to circular practices.
7. By 2050, the concept of CE should be widely known across the EU, with programs in place to provide awareness and full education on the topic. This also includes standardization of labelling, packaging, and of methods to disclose amounts of carbon consumption of products.

2.6.2 What could the steps look like for the next 25 years?

1. At the **EU level**, funding of educational campaigns and social projects on the CE of HPP through programs such as LIFE and Horizon Europe are necessary, along with information campaigns on the CE of HPP. These efforts should be complemented by public information campaigns, harmonized environmental labelling, mandatory sustainability reporting for businesses, and integration of CE and conscious consumption into formal and informal education. An EU-wide platform should coordinate digital engagement, and behavioural research should guide communication strategies. Education and awareness must be treated as foundational tools for legal and systemic circularity.
2. At the **national levels** within the EU, Member States should revise core curricula across all levels of education to embed CE principles and regulatory literacy, and develop university programs aligned with labour market needs. The Third Mission of universities should promote lifelong learning and public engagement. In addition, national governments should

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build consumer-oriented recycling infrastructure (e.g. deposit-return systems), institutionalize circularity training across public services and professional sectors.

3. At the **regional levels**, regional authorities, NGOs, and education institutions should localize CE education through community-based initiatives such as Repair Cafés, Circularity Hubs, and lifelong learning centres. They should implement and maintain behavioural incentive systems (e.g. eco-loyalty points, digital rewards) and co-create civic platforms to support regulatory compliance and sustained citizen engagement.

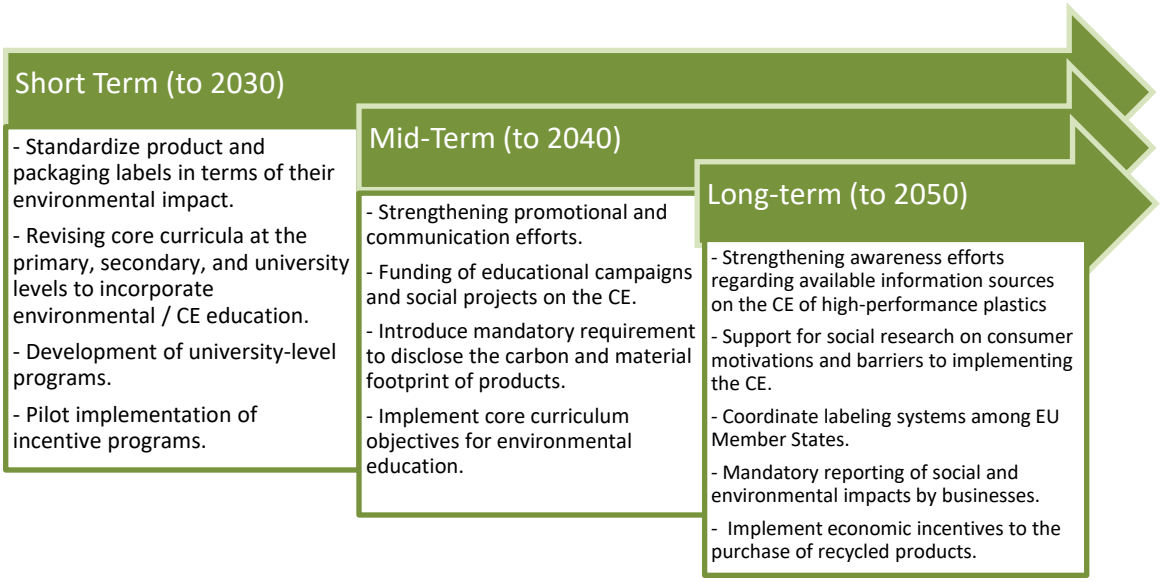

Figure 6: Overview of possible development steps for awareness for CE

2.7 Cooperation Between Companies Along the Value Chain

Effective circularity requires seamless cooperation between companies in the collection, recycling, and manufacturing stages. By working together, companies can improve the recovery and reuse of PUR rigid foam, reduce waste, and increase the availability of high-quality recyclates. Regulatory frameworks and shared investment in infrastructure and logistics are needed to remove current barriers and enable efficient material flows across the value chain, especially for C&D waste (cf. chapter 1.2).

2.7.1 What do we want to achieve in the years up to 2050?

By 2050, PUR rigid foam should flow efficiently and seamlessly across the EU, from collection and recycling to manufacturing, within a harmonized system that ensures high recycling rates and effective reuse of materials.

2.7.2 What could the steps look like for the next 25 years?

1. To achieve this, **EU regulations** will be established to support the cross-border transport of PUR rigid foam and harmonize material quality standards for recyclates.
2. **Industry bodies and regulators** will **facilitate agreements and frameworks** that encourage transparent data sharing and cooperation between collection, recycling, and manufacturing companies, enabling efficient material exchange and processing.
3. **Recycling clusters** will be developed **across the EU** to **enable shared investment in advanced recycling facilities and logistics networks**, while ensuring the quality and consistency of recyclates. These clusters must facilitate coordination across the four key stages of the PUR recycling value chain: collection facilities, recovery and treatment facilities, chemical

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processing facilities, and downstream purification facilities. Smooth and high-quality material flows between these specialized stages require **cooperation on data exchange, logistics, and infrastructure planning**. Companies will work together to align product design and recycling processes, ensuring that recovered materials meet the requirements for reuse in new products and supporting joint ventures that integrate circularity throughout the value chain.

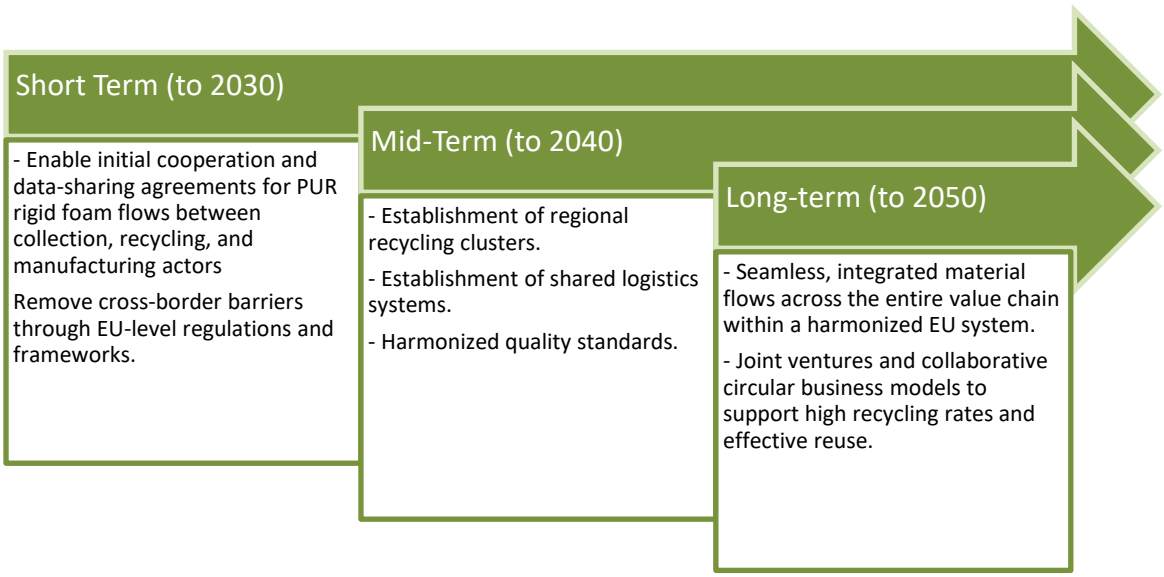

Figure 7: Overview of possible development steps for cooperation between companies

2.8 Importance of Ecological Transformation for Companies

The transition to a circular economy requires that companies actively embrace ecological transformation within their design, production, and end-of-life strategies and processes. Companies play a central role in ensuring products are designed for applicable R-strategies, such as reuse, repair or recycling, produced with low environmental impact, and responsibly managed at the end of their life. To achieve full circularity, ecological considerations must be embedded in business models and supported by clear frameworks and incentives that encourage eco-design, material efficiency, and accountability.

2.8.1 What do we want to achieve in the years up to 2050?

By 2050, ecological transformation should be a standard part of business practices across all sectors, ensuring that all products containing PUR rigid foams are designed to reduce the environmental impacts and emissions, e.g., though reuse and recycling, responsibly managed throughout the value chain.

2.8.2 What could the steps look like for the next 25 years?

1. To achieve this, **companies** will begin by **incorporating ecological objectives** into their strategies and daily practices, **supported by local authorities, universities, and NGOs** through awareness-building initiatives, training, and technical assistance.
2. Support schemes and incentives will help businesses adopt eco-design principles and integrate circular use of materials into product development, production processes and recycling technologies.

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3. Companies will work together in **cross-regional networks** to reduce their reliance on virgin raw materials by incorporating recycled content wherever possible, aligning production with circularity principles.
4. Gradually, **ecological impact reporting** will become mandatory alongside financial reporting, ensuring transparency and accountability **on the EU level**.
5. **Public procurement and market incentives** will encourage companies to prioritize circular and low environmental impact solutions, and **industry leaders** will be recognized and **rewarded for advancing ecological transformation within their operations and supply chains**.

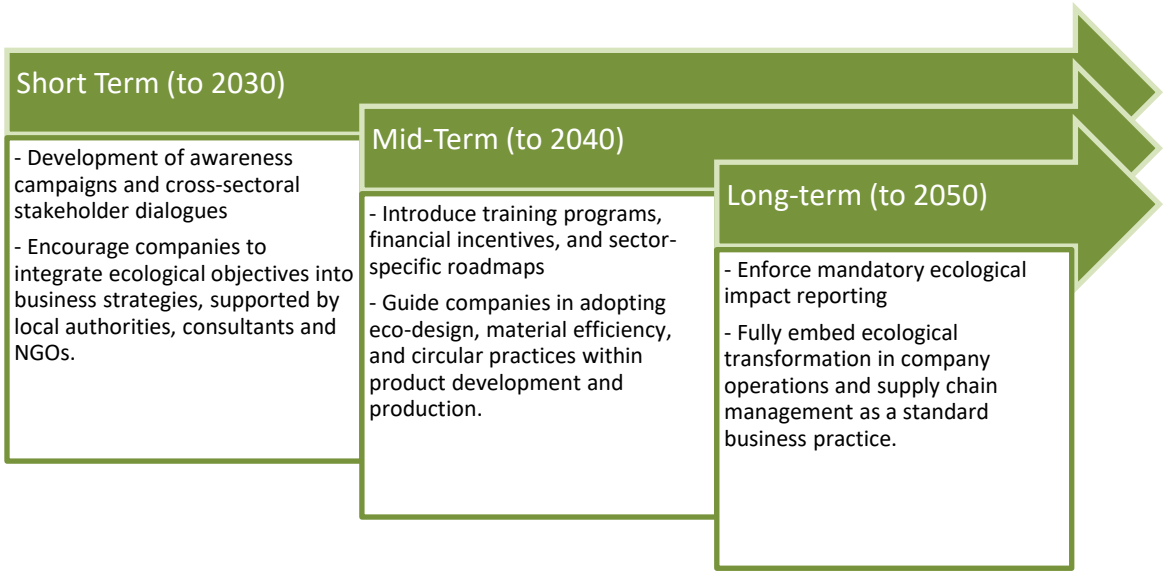

Figure 8: Overview of possible development steps for the importance of ecological transformation for companies

2.9 Design for Circularity (Refuse, Rethink/-design, Reduce)

Designing products for circularity (including refuse, rethink/-design, and reduce) is critical for preventing waste before it occurs. By rethinking products and reducing unnecessary materials or complexity, products become easier to repair, reuse, and recycle. This reduces virgin material use, minimizes environmental impact, and enables companies to align with increasing EU regulatory and customer demands for circular products. Early design decisions determine the ease of future disassembly and recyclability, making this a key enabler for circularity in the PUR and HPP value chains.

2.9.1 What do we want to achieve in the years up to 2050?

By 2050, all products on the EU market will be designed with circularity as a standard, ensuring materials can be recovered efficiently and reused without loss of quality. Products will be easy to disassemble, allowing for straightforward parts replacement, repair, and recycling. Mandatory eco-design standards will ensure full material recovery while also enabling components to be reused where possible before recycling. Design for circularity will become a default expectation across all manufacturers, reducing waste to a minimum and enabling high-quality recyclate streams for PUR rigid foam and related materials.

2.9.2 What could the steps look like for the next 25 years?

1. To support this goal, **EU and national eco-design standards** are and will be developed and gradually enforced, ensuring that PUR-based products are designed for disassembly, parts

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replacement, and recyclability from the outset. Industry guidelines and training will be provided to manufacturers to implement circular design principles, enabling clear documentation of material composition and dismantling procedures.

2. Public procurement will integrate circularity criteria, incentivizing the market for products designed for reuse and recycling.
3. Tax incentives and funding will support companies adopting circular design, while regulatory frameworks will gradually require design for circularity as a compliance standard across sectors. This approach will enable efficient parts replacement and repair before recycling, reduce complexity in material streams, and improve the quality of recovered PUR, ensuring circular material flows in the PUR value chain.

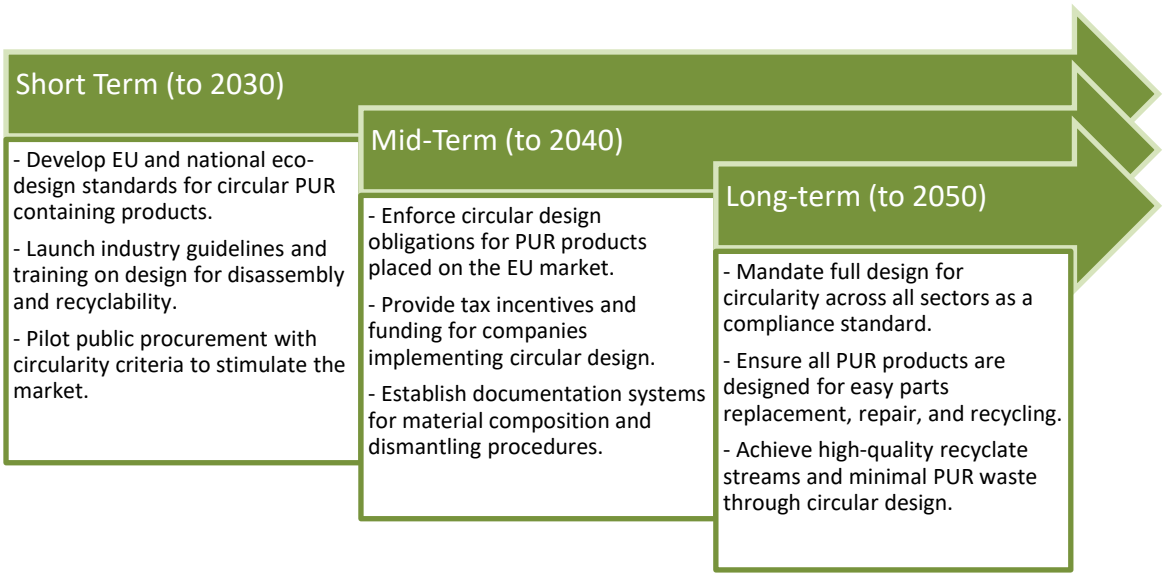

Figure 9: Overview of possible development steps for circular design

2.10 Life Cycle Optimization and Recycling Technologies

Life cycle optimization and advanced recycling technologies are essential for ensuring that PUR and HPP are used efficiently, recovered at end-of-life, and recycled into high-quality secondary raw materials. Optimizing each stage of a product's life cycle reduces environmental impacts and supports the circular economy by closing material loops. Advanced recycling technologies improve recovery rates and recyclate quality while reducing dependency on virgin resources, ensuring sustainable material flows in the EU.

2.10.1 What do we want to achieve in the years up to 2050?

By 2050, advanced recycling technologies and life cycle optimization practices will be fully implemented across all sectors, ensuring that HPPs in general, and PUR in particular, are recovered at the highest possible quality and with minimal environmental impact. Material recovery will be maximized, and closed-loop recycling will be standard practice, reducing the need for virgin resources and aligning industry practices with EU circularity targets.

2.10.2 What could the steps look like for the next 25 years?

1. To support this goal, **EU guidelines and national strategies** for advanced recycling and life cycle optimization will be developed and implemented, focusing on PUR and HPP.

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2. **Investments and incentives** will **support** the development of **advanced recycling technologies** capable of recovering high-quality recyclate while minimizing environmental impacts such as chemical recycling in the form of catalytic pyrolysis for PUR rigid foam.
3. **Regional hubs for circularity** will **test and demonstrate innovative recycling methods**, enabling effective scaling across sectors. Standards for material identification and recyclability will be introduced to facilitate sorting and processing, while digital tools and data-sharing platforms will optimize logistics and tracking for end-of-life PUR rigid foam.
4. **Regulatory frameworks will enforce the use of best available recycling technologies and mandate high recovery rates, ensuring compliance** with circularity targets and supporting the shift toward closed-loop life cycle management in the PUR value chain.

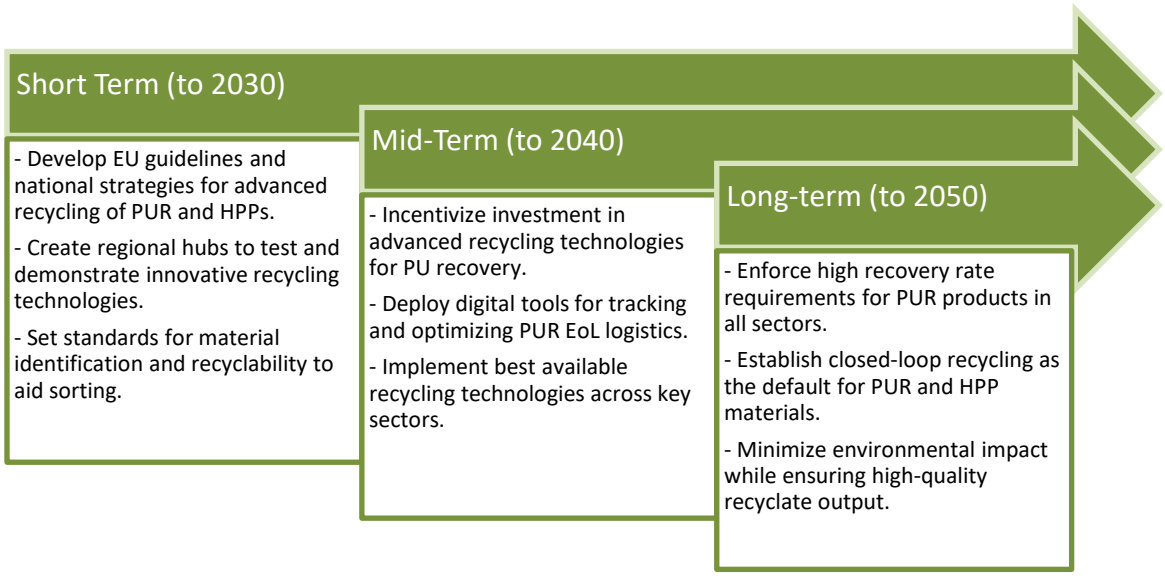

Figure 10: Overview of possible development steps for lifecycle optimization and recycling technologies

2.11 Collection and Sorting in the Waste System

The transition to circularity for PUR rigid foams requires a regulatory environment that supports this initiative, as well as support at that national and regional levels for the collection and recycling of PUR rigid foam.

2.11.1 What do we want to achieve in the years up to 2050?

Long before 2050, an adjustment of the EU waste framework directive on separate collection and classification of waste containing HPP needs to be well-established and functioning. This then will cascade to national and regional governments with EPR for products containing HPPs and a common European system for HPP labelling and identification. These actions will lead to regional governments and local industries working together to support the collection, dismantling, and recycling of PUR rigid foams from refrigerators and insulation panels.

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2.11.2 What could the steps look like for the next 25 years?

1. At the **EU level**, the waste framework directive supports the separate collection and classification of waste containing high-performance plastics, and extended producer responsibility for products containing high-performance plastics are implemented.
2. **National governments, business, and industry** receive support from EU funds and invest in the development of advanced recycling centres. They will also implement a common European system for HPP labelling and identification in the value chain (including in products that incorporate different materials), with certified/standardized national classification and efficient labelling schemes for wastes containing high-performance plastics – aiming for recyclate targets.
3. **Regional governments and industry** implement and support targeted regional programs for separate collection of C&D waste, with the goal of building regional closed-loop chains. For PUR rigid foam, this means that insulation boards and sandwich panels should be separated from other waste types directly at demolition sites to reduce contamination and labour costs, before being transported to collection facilities and then to recovery and treatment facilities.

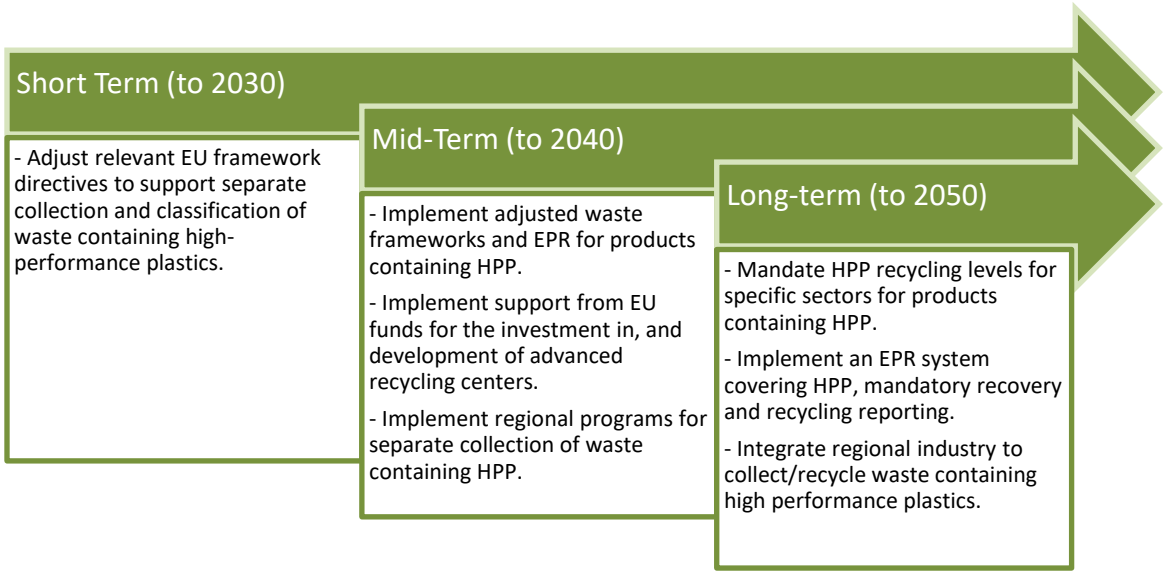

Figure 11: Overview of possible development steps for collection and sorting

2.12 Comprehensive Timeline and Stakeholder Actions

The following table (next pages) outlines the key factors, agency levels (EU, national, regional) responsible stakeholders, and concrete goals and steps needed to build a circular system for HPP across the short, medium, and long term.

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KEY FACTOR	LEVEL	STAKEHOLDERS	TIME					
			Short term		Mid term		Long term	
			2028	*2030*	*2035*	*2040*	*2045*	*2050*
Waste regulations	*EU Level*	*European Commission*	EU regulations in place for supporting recycling of high-performance plastics, such as required level of reclaiming PUR by producers					
				Steady growth of % of PUR that needs to be reclaimed introduced over several years (EPR) - not only financial responsibility but also recycling (reuse)				
	National Level	*National government*			Governments recommend BAT (chemical recycling) / BEP is preferred method for recycling		All refrigerators produced in EU need to be made partly with recycled PUR. Imported refrigerators need to be produced according to European standards (recycled materials)	
	Regional level	*Regional government, municipalities*			Enforcement activities in place to monitor collection and recycling			
Recycling quotas (waste collection and recyclates)	*EU Level*	*European Commission*	Uniform classifications of waste, PUR not listed as waste					
	National Level	*National government*			Strict recycling quotas			
	Regional level	*Regional government, municipalities*			Amount of PUR rigid foam to incinerators reduced		No PUR going to incinerators, but sent for recycling	

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KEY FACTOR	LEVEL	STAKEHOLDERS	TIME					
			Short term		Mid term		Long term	
			2028	2030	2035	2040	2045	2050
Financial incentive systems for collection	*EU Level*	*European Commission*			Creation of level playing field for sustainable products			
	National Level	*National government*			Attractive incentives (subsidies, tax incentives) for establishment of recycling companies			
	Regional level	*Regional government, municipalities*			Support for regional waste centres for collection of PUR rigid foams			
Price development of the primary production	*EU Level*	*European Commission (DG GROW), packaging industry, technical sectors, standards bodies*	Implementation of mandatory minimum recycled content targets (e.g. 25% in high-performance plastics by 2030)					
		European Commission, fossil fuel lobby, recycling industry, consumer groups			Gradual imposition of limits on the production of primary plastics from fossil sources			
		EU institutions, research bodies, NGOs, consumer watchdogs					Full prohibition of non-essential use of virgin plastics when high-quality recycled alternatives are available	
		European Commission (DG CLIMA, DG ENV), petrochemical industry, automotive sector, NGOs	Adjustment of harmonised carbon pricing mechanisms (including imports) for primary plastic production through the					

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KEY FACTOR	LEVEL	STAKEHOLDERS	TIME					
			Short term		Mid term		Long term	
			2028	2030	2035	2040	2045	2050
			extended Emissions Trading System (ETS)					
		Member States' governments, European Court of Auditors, industry			Harmonisation of carbon pricing mechanisms across Member States			
		Economy and business (EIB), chemical industry, national governments					Implementation of an integrated regulatory and financial framework promoting recycling processes and the high-end regranulation of technical plastics	
		National Fund for Environmental Protection, automotive, refrigerators and construction industries, chemical processing		Subsidies for manufacturers using high-grade recycled plastics, particularly in technical sectors such as automotive, construction, and chemical processing				
		Public Procurement Office, municipalities, material suppliers			Mandatory use of recycled plastics in publicly procured goods and infrastructure (Insulation boards PIR/PUR)			
		National Development Fund, National Bank, industrial producers, employer organizations			Establishment of a national transition fund to support the conversion of industrial			

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KEY FACTOR	LEVEL	STAKEHOLDERS	TIME					
			Short term		Mid term		Long term	
			2028	2030	2035	2040	2045	2050
					production lines from primary to recycled inputs			
	Regional level	*Local municipalities, research institutes, chemical plants*	Mapping of transformation potential for chemical plants and plastics processing facilities towards advanced recycling methods					
		Universities, regional tech parks, recycling companies			Establishment of a regional R&D centre for mechanical and chemical recycling of high-grade plastics			
		Municipal Governments, innovation clusters, research and industry partnerships					Positioning the region as a leading Central and Eastern European hub for advanced technical plastic recycling, integrating research, industry, and energy systems	
		Regional funds, SMEs, municipal governments, EU funding bodies	Grants for the modernisation of facilities that process recycled HPP					
		Regional government, tax authorities, energy-efficient firms			Introduction of regional tax incentives for companies using recyclates and implementing energy-efficient technologies			

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<tr><td></td><td></td><td>Environmental Inspectorate, industrial sector, labor unions, development agencies</td><td></td><td></td><td></td><td></td><td></td><td>Decommissioning of facilities relying exclusively on virgin material inputs, while recycled infrastructures are economically and technically viable</td></tr>
<tr><td rowspan="4">Viability of recycling-oriented business models</td><td rowspan="4">EU Level</td><td>European Commission (DG ENV, DG GROW), Eurostat, plastics producers, recyclers, trade associations (e.g., PlasticsEurope)</td><td colspan="2">Establishment of a full-cost transparency system across the plastics value chain</td><td></td><td></td><td></td><td></td></tr>
<tr><td>European Investment Bank (EIB), Horizon Europe, national promotional banks, SMEs, R&D institutions</td><td colspan="2">Pilot EU fund supporting recycling-oriented business models</td><td></td><td></td><td></td><td></td></tr>
<tr><td>European Parliament, PROs (producer responsibility organisations), packaging industry</td><td></td><td colspan="2">Introduction of eco-modulated EPR fees</td><td></td><td></td><td></td></tr>
<tr><td>Directorate-General for Competition, recyclers,</td><td></td><td></td><td colspan="4">Establishment of the European Observatory for Circular Business Viability</td></tr>
</table>

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KEY FACTOR	LEVEL	STAKEHOLDERS	TIME					
			Short term		Mid term		Long term	
			2028	2030	2035	2040	2045	2050
		environmental NGOs, audit bodies		Launch of a permanent EU subsidy scheme for high-quality recyclers				
		European Council, DG COMP, industry lobbies, NGOs					Introduction of EU-backed guarantees for long-term supply contracts	
	National Level	*Ministry of Climate and Environment, Statistics, producers, recyclers*	Creation of a national platform for plastics cost transparency					Full integration of subsidies into EU industrial competitiveness policy
			Seed grants and funding for circular business models					
		Ministry of Finance, tax authorities, manufacturers, chambers of commerce		Tax reform promoting recycled-content products				
		Ministry of Development Funds, public procurement offices, local governments, suppliers			Long-term public procurement contracts with recycled plastics			
		Private banks, recycling investors			National risk-guarantee fund for high-risk recycling investments			
		National Fund for Environmental Protection, academic partners, think tanks			National circular business model scoring system			

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KEY FACTOR	LEVEL	STAKEHOLDERS	TIME					
			Short term		Mid term		Long term	
			2028	*2030*	*2035*	*2040*	*2045*	*2050*
	Regional level	*Regional government, local development agencies, universities*	Baseline Development and Stakeholder Integration					Integration of circular business viability indicators into public funding and procurement
		Business support centres, universities, NGOs, regional chambers of commerce	Formation of a regional circularity coalition or industrial cluster				Inclusion of strategic recyclers in national industrial policy	
		Technology parks, incubators, R&D centres, small companies		Business incubation programme for technical plastics recyclers				
		Regional government, EIB regional instruments, local banks, cluster organisations			Creation of a regional circular economy investment fund			
		Public R&D institutions, industrial partners, technical universities			Development of demonstration and pilot facilities			
		Regional development agencies, innovation support funds, consulting firms			Co-financing of feasibility studies and life cycle analyses (LCA)			

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<tr><td rowspan="6"></td><td rowspan="6"></td><td>Regional policymakers, monitoring and evaluation units, funding institutions</td><td></td><td></td><td></td><td colspan="2">Operational subsidy scheme for key recyclers</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td>Continued adaptation of subsidies and monitoring frameworks</td></tr>
<tr><td>Regional administration, economic think tanks, university departments</td><td></td><td></td><td></td><td colspan="2">Regional benchmarking system for circular business models</td><td></td></tr>
<tr><td>Buyers (construction, producers), recyclers, public procurement offices, regional investment agencies</td><td></td><td></td><td></td><td colspan="3">Long-term supply agreements between recyclers and buyers</td></tr>
<tr><td>Regional government, local businesses, urban planning offices</td><td></td><td></td><td></td><td></td><td colspan="2">Designation of regions as “Circular Economy Zones”</td></tr>
<tr><td>Academic sector, NGOs, regional data centres, media</td><td></td><td></td><td></td><td></td><td></td><td>Establishment of a regional Circular Economy Observatory</td></tr>
<tr><td>Development of digital services</td><td>EU Level</td><td>European Commission</td><td></td><td colspan="3">Creation of pan-European environmental data platforms, e.g. for recycling</td><td></td><td></td></tr>
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KEY FACTOR	LEVEL	STAKEHOLDERS	TIME					
			Short term		Mid term		Long term	
			2028	2030	2035	2040	2045	2050
and data availability	*National Level*	*National ministries*	Creation of a circular economy data repository		Development of a national monitoring platform for the circular economy in real time			
	Regional level	*Regional authorities*	Creation of regional open-access data repositories and matchmaking tools for local stakeholders					
Global responsibility and coordination	*EU Level*	*European Commission*	Refine the strategy for mandatory ESG reporting throughout the supply chain (an extension of CSRD), while maintaining the reporting obligation for large entities and gradually introducing it to the SME sector					
		European Commission bodies; Certification and labelling organisations, e.g. EU Ecolabel Board	Harmonisation of environmental labelling schemes					
		EU legislative and regulatory bodies; Entrepreneurs and packaging manufacturers; consumer organisations		Mandatory display of carbon/ material footprint on packaging				

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			Short term		Mid term		Long term	
			2028	2030	2035	2040	2045	2050
	National Level	*Public administration; government and institutions implementing circular policies*	The launch of a central register of the carbon and material footprint of traded products is planned					
		Governmental bodies; academia	Integration of the national CE strategy with industrial and energy policy (specifically in Poland)					
		Governmental bodies			Introduction of tax preferences for products that are recycled and those with a reduced carbon footprint			
		Government institutions and public administration e.g. ministry of finance; ministry of environment			Economic incentives for circular consumer behaviour (e.g. VAT cuts)			
		Governmental and administrative bodies					Full integration of CE policies into education, vocational training, and urban planning systems	
	Regional level	*Local government units; Local waste collection companies and operators*	Local mapping of waste streams to support the development of regional CE Hubs					
		Local government units; Local waste collection companies and operators	Launch of eco-loyalty programs (e.g. for waste sorting)					

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		Local authorities; local companies and craftspeople		Establishment, development and improvement of CE hubs (repair cafés, exchange points, material libraries – all R strategies included)				
Awareness for circular economy	*EU Level*	*NGOs/ Municipalities*	Strengthening promotional and communication efforts regarding available information sources (portals, materials, publications) on the CE of HPP					
		European Commission, EU Parliament, European Environment Agency, EIT	Funding of educational campaigns and social projects on the CE of HPP through programs such as LIFE, Horizon Europe					
		European Commission, Producers, Universities, NGOs			Support for social research on consumer motivations and barriers to implementing the CE of HPP on the individual level			
			Standardization of product and packaging labels in terms of their environmental impact (e.g. 'eco-score' for plastics)					
		European Commission, Associations, Producers			Introduction of a mandatory requirement to disclose the carbon and material footprint of products (environmental labels)			
						Environmental labels indicating the carbon and material footprint of products		
						Coordination of labelling systems among EU Member States		

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			Short term		Mid term		Long term	
			2028	*2030*	*2035*	*2040*	*2045*	*2050*
							Mandatory reporting of social and environmental impacts by businesses	
							Full integration of CE and conscious consumption within the EU	
	National Level	*European Commission, Associations, Producers*	Information campaigns on the CE of HPP					
		National Ministries of Climate, Economy, Environment; Associations; NGOs; Media,	Continued information campaigns on the CE of HPP targeting businesses					
		National Ministries of Climate, Economy, Environment; Associations; NGOs; Media, Universities, Producers, Distributors, Associations; National media	Preparatory work for revising core curricula at the primary, secondary, and university levels to incorporate environmental education with a focus on CE					
		Ministry of National Education, Ministry of Science and Higher Education; Primary, secondary schools and universities representative			Implementation of core curriculum objectives for environmental education (primary, secondary and university education)			

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		(light houses, living labs); Producers					Environmental education - continuation	
			Development of university-level programs, including those offered within the framework of the Third Mission of Universities, aimed not only at students but also at the broader public — with a focus on strengthening key competencies aligned with the needs of CE, labor market, and society					
		Ministry of Science and Higher Education; Universities' representatives; Producers			Implementation of the third mission of universities			
							The third mission of universities - lasting changes in the education system and public awareness – generations oriented towards CE	
			Pilot implementation of incentive programs (e.g. loyalty points for waste separation in cities, deposit systems), specifically targeting HPP					

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<tr><td rowspan="4"></td><td rowspan="3"></td><td rowspan="2">National Ministries of Climate, Economy, Environment; Consumers; Associations (e.g. city, recycling); NGOs;</td><td></td><td></td><td colspan="2">Development of recovery and recycling infrastructure close to consumers, including deposit systems for plastics</td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="2">Introduction of economic incentives to encourage the purchase of recycled products (e.g. reduced VAT)</td><td></td><td></td></tr>
<tr><td>National Ministry of Finance; National Ministries of Climate, Economy, Environment; Associations (e.g. city, recycling); Producers;</td><td></td><td></td><td></td><td></td><td colspan="2">Implementation of economic incentives to the purchase of recycled products (e.g. reduced VAT)</td></tr>
<tr><td rowspan="2">Regional level</td><td>National Ministry of Finance; National Ministries of Climate, Economy, Environment; Associations (e.g. city, recycling); Producers;</td><td colspan="6">Continued information campaigns on the CE of HPP targeting businesses</td></tr>
<tr><td>Associations; NGOs; Local authorities; Producers; Local media; Universities;</td><td colspan="2">Preparatory work for revising core curricula in higher education institutions and lifelong learning centres with a focus on strengthening key competencies aligned with the needs of CE</td><td></td><td></td><td></td></tr>
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<tr><td rowspan="6"></td><td rowspan="6"></td><td rowspan="3">Primary, secondary schools and universities; Students; Teachers; Local authorities;</td><td colspan="2"></td><td colspan="2">Implementation of core curriculum objectives for environmental education in universities and lifelong learning centres</td><td colspan="2"></td></tr>
<tr><td colspan="2"></td><td colspan="2"></td><td colspan="2">Environmental education - continuation</td></tr>
<tr><td colspan="2">Testing of local reward programs for environmentally responsible behaviour (e.g. discounts on public transport tickets for returned waste).</td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td rowspan="3">Recycling centres; Local authorities; NGOs; Universities; Producers; Consumers;</td><td colspan="2"></td><td colspan="2">Local innovations – e.g. urban games and competitions focused on CE, waste separation, and sustainable consumption</td><td colspan="2"></td></tr>
<tr><td colspan="2"></td><td colspan="2"></td><td colspan="2">Permanent incentive mechanisms (e.g. integrated applications, local discounts, eco-loyalty points)</td></tr>
<tr><td colspan="2"></td><td colspan="4">Development of local exchange and repair hubs (e.g. Repair Cafés, CE points)</td></tr>
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<tr><td rowspan="3">Cooperation between companies along the value chain</td><td>EU Level</td><td>EU regulators, industry bodies</td><td colspan="2">EU regulations support transport of PUR rigid foam between countries</td><td></td><td></td><td colspan="2">PUR rigid foam flows seamlessly between collection / recycling companies, chemical processing, and back to manufacturers</td></tr>
<tr><td>National Level</td><td rowspan="2">Businesses</td><td colspan="2"></td><td colspan="2">Business associations in place and encourage cooperation and knowledge sharing between companies</td><td colspan="2">Full cooperation between producers and collection / recycling companies</td></tr>
<tr><td>Regional level</td><td colspan="2"></td><td colspan="2">Platform in place to identify regional collection hubs and companies</td><td></td><td></td></tr>
<tr><td rowspan="5">Importance of ecological transformation for companies</td><td rowspan="2">National level</td><td>Recycling centres; Local authorities; NGOs; Universities; Producers; Consumers</td><td colspan="2">Introduction of ecological transformation objectives in national industrial strategy</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Government / Ministries</td><td></td><td colspan="2">Public support programme for ecological business transformation for SMEs</td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Regional level</td><td>National innovation agencies</td><td colspan="3">Support for regional CE business incubators focused on ecological innovation</td><td></td><td></td><td></td></tr>
<tr><td>Regional authorities</td><td></td><td></td><td colspan="3">Co-financing of CE transformation audits in companies</td><td></td></tr>
<tr><td>EU level</td><td>Local governments, clusters</td><td></td><td colspan="3">Introduction of EU-wide funding instrument for ecological transformation</td><td></td><td></td></tr>
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<tr><td></td><td></td><td>European Commission, EIB</td><td></td><td></td><td></td><td colspan="3">Mandatory CE reporting standards in environmental performance reports</td></tr>
<tr><td rowspan="5">Design for Circularity (Refuse, Rethink/-design, Reduce)</td><td rowspan="3">EU Level</td><td rowspan="3">EU institutions, industry organizations, academic and research entities, NGOs and think tanks, industry</td><td colspan="2">Introduce ISO/EN standards for eco-design of HPP products (e.g., minimum requirements for ease of disassembly)</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="2">EU obligation to design HPP products with recycling in mind - e.g., ban on permanent combination with other materials</td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="4">Include “design for circularity” as a condition in product approvals (e.g., CE certificates) for products containing HPP</td></tr>
<tr><td rowspan="2">National Level</td><td>Public administration, industry, NGOs</td><td colspan="2">Industry education campaign on designing for HPP dismantling and recovery</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Public administration, industry, regulatory and control bodies</td><td></td><td colspan="3">Tax credits for companies implementing recyclable design</td><td></td><td></td></tr>
<tr><td></td><td colspan="3">Mandatory guidelines in public procurement to promote products designed for HPP recycling</td><td></td><td></td></tr>
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<tr><td></td><td>Regional level</td><td>Recycling and Waste Management Companies, Innovation and Research Centers, Local Manufacturers & Industry Clusters</td><td colspan="2">Eco-design workshops and training for local manufacturers (e.g., automotive, medical, home appliances)</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">Life cycle optimization and recycling technologies</td><td rowspan="2">EU Level</td><td rowspan="2">EU institutions, industry organizations, academic and research entities, NGOs and think tanks, industry</td><td colspan="2">EU R3-R9 strategy guidelines[3] for advanced materials, including HPP. Promote reuse and refurbishment as mandatory steps before recycling</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">Implement a European standard for identifying and labeling products containing HPPs to track them throughout their life cycle</td><td></td><td></td></tr>
<tr><td>National Level</td><td>Public administration, research institutes, industry, NGOs, regulatory and control bodies</td><td colspan="2">Develop a national strategy for HPP reuse and valorisation, including a hierarchy of activities from R3 to R9, and support for companies applying these strategies</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="3"></td><td></td><td></td><td colspan="3">Obligation of full recovery (R8, R9) of HPP-containing components in industry (transportation, electronics, medicine) as a requirement in the Green Deal and EU taxonomy</td></tr>
</table>

[3] The R-strategies are a set of 10 principles for waste management within a circular economy: R0 Refuse, R1 Rethink, R2 Reduce, R3 Reuse, R4 Repair, R5 Refurbish, R6 Remanufacture, R7 Repurpose, R8 Recycle and R9 Recover.

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<tr><td rowspan="2"></td><td></td><td></td><td></td><td colspan="5">Tax credits and national funds for investment in advanced HPP chemical recycling technologies</td></tr>
<tr><td>Regional level</td><td>Local authorities, educational and scientific units, entrepreneurs and clusters, municipal companies</td><td colspan="4">Initiating regional hubs for testing and implementing R3-R7 technologies for HPP waste (e.g., repair centres, pilot mechanical recycling lines)</td><td></td><td></td></tr>
<tr><td rowspan="4">Collection and sorting in the waste system</td><td rowspan="4">EU Level</td><td>Government</td><td colspan="2">Adjustment of EU waste framework directive on separate collection and classification of waste containing HPP</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">Government, Producers, Business</td><td></td><td></td><td colspan="4">Implementation of extended producer responsibility for products containing HPP</td></tr>
<tr><td></td><td></td><td colspan="2">Implement a common European system for HPP labelling and identification in the value chain (including in products that incorporate different materials)</td><td></td><td></td></tr>
<tr><td></td><td colspan="3">Implement support from EU funds for the development of advanced recycling centres</td><td colspan="2">Mandating HPP recycling levels for specific sectors (e.g., automotive, medical industry, manufacturers introducing products containing high-performance plastics)</td></tr>
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	National Level	*Government / Ministries*		Introduction of nationwide classification and labelling of waste containing high-performance plastics				
		Recycling companies and industry consortia Government			Providing subsidies for innovative technologies for sorting and recycling HPP. Mandatory reporting system for marketers of these materials			
		Producers/ Importers				Implement an EPR system covering HPP, mandatory recovery and recycling reporting		
	Regional level	*Regional waste management companies* *Municipal and province governments*			Implementation of regional programs for separate collection of waste containing HPP			
		Regional industry clusters / Local chamber of commerce				Integration with regional industry to collect and recycle industrial waste containing HPP		

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2.13 Challenges for Roadmap Implementation

The recommendations that address key developments needed to enable a CE for HPP by 2050 are context-sensitive and their implementation processes underlie several limitations and challenges that should be considered.

Firstly, **social factors** play a significant role in the success of the project, yet they are difficult to predict. These include in particular trust as well as attitudes, relations and rules of cooperation among stakeholders from industry, politics, research and development, and society. It is possible to investigate and establish strategies and approaches for stakeholder collaboration and governance structures, but these rely ultimately on the interpersonal dynamics and relations that are formed and need to be continuously fostered.

Consumer acceptance for recycled products and recycling technologies is another social factor that we have quantitatively and qualitatively analysed. We can, on the one hand, identify and investigate socio-economic trends and factors that affect circular solutions in the European market economy. This includes e.g., consumer surveys showing that price is a primary concern, considering the socio-economic base conditions and thus questioning the competitiveness of new business models for chemical recycling, or evaluating the need for targeted funding opportunities or financial support measures. On the other hand, socio-political conditions for the market economy evolve dynamically, as could be observed for the recent changes towards less and differentiated sustainability reporting obligations and standards on the EU level. Additionally, the project focused on a narrow category of waste that is often unknown or unrecognizable to consumers, such as insulation material hidden in household devices like refrigerators or building materials like insulation boards and sandwich panels. Consequently, awareness and interest in these specific waste materials are likely to remain lower compared to more familiar everyday items.

Many activities that determine the success of the project depend on the European Commission's (EC) activities, as many key factors – such as directives, recycling targets, and taxation of products – fall under its domain. While the EC provides an 'umbrella' for regional activities, these are often secondary to **EU-level actions**. To significantly drive the implementation of this project's results, the EU must engage more actively in these areas, as they could serve as the most important triggers for success.

Despite common EU policies and regulations, **national and regional peculiarities** create varied starting points and situations for developing the circular economy and establishing hubs for circularity. The three pilot regions differ not only in their techno-economic conditions but also in their socio-political characteristics, making a European "one-size-fits-all" circular economy challenging. Existing power relations, conflicts, and hierarchies are regionally different and historically embedded, further complicating the implementation of uniform strategies. This illustrates the need for the provision of framing EU activities that leave enough space for regional adaptation and implementation.

In **Poland**, for example, factors such as the polarized development vision of the Metropolis GZM, the lack of a decisive leader of change, and the deficits in support from decision-makers – coupled with the expectation that regulations will drive change – may pose substantial barriers to achieving the project's goals, especially considering that the GZM lacks legislative power.

While the region of **Greater Amsterdam** is much better equipped with prerequisites for circularity, it also faces challenges that are relevant to all three regions such as undocumented waste flows (lost e-waste), low public awareness or consumer return behavior that will not only be solved by regulatory action. The same is valid for the **German region**. However, these different contexts require varying

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modes of addressing these challenges. These have been discussed in depth in the regional scenario workshops and must be kept in mind. The roadmap presented focusses on common actions that apply to all three regions.

The developed roadmap steps primarily approach and express **optimistic future developments** in order to support circular solutions for high-performance plastics by 2050. At the same time, it is essential to acknowledge **countervailing trends**. The risks associated with the scenarios underlying the roadmap have been addressed in Deliverable 1.5.

On a more general level, positive trends may not be sufficient to offset current challenges. For instance, there is a growing political commitment to the circular economy. Still, stronger effort and further initiatives are needed to improve recycling rates and overcome existing obstacles. For now, chemical recycling is significantly less established compared to mechanical recycling and is sometimes viewed critically by environmental NGOs. It will be crucial to monitor how the **debate on the advantages and perceived risks of different recycling technologies** evolves. Environmental groups preferably advocate for binding zero-waste strategies, the substitution of plastic with bio-based products, and raise concerns especially regarding the sustainability score of chemical recycling processes. The European plastics market may become more diversified through innovations in bio-based plastics or the use of alternative product designs and materials.

Circular supply chains, either through closed-loop or reverse logistics approaches, could promote lifetime-related resource efficiency and durability, potentially reducing environmental impacts compared to frequent consumption and fast economic valorization of material/product cycles. Yet, this **collective effort** requires stakeholder collaborations along the whole value chain in a competitive plastics market with a high number of independent actors. Bringing them together in hubs for circularity could in particular foster circular solutions for challenging high-performance plastics, such as PUR, and in general create awareness for the opportunities and challenges of circular economy approaches, such as recycling technologies and business models.

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3 Collaboration and Governance

Governance and collaboration refer to distinct, yet complementary approaches in shaping transformation processes. ***Participatory governance*** focuses on democratic legitimacy and inclusivity, emphasizing the involvement of citizens and organized interests in decision-making through mechanisms such as citizen assemblies, roundtables, or participatory planning. These formats aim to improve both the effectiveness and legitimacy of political decisions—particularly by involving marginalized groups and ensuring local, decentralized engagement (Grothus et al., 2025; Fischer, 2012; Fung, 2003; Arnstein, 1969).

Collaboration refers to the cooperative interaction between organizations and social groups, often in networked, non-hierarchical structures. Rather than focusing on democratic legitimacy, collaboration emphasizes joint problem-solving and goal-oriented coordination among actors - public, private, and civil society - especially in complex, multi-stakeholder environments (Grothus et al., 2025; Ansell & Gash, 2008; Newig et al., 2018).

In short, we use the concept of collaboration as a mode of cooperation, and participatory governance as a structure for collective decision-making processes. **Transition management** (TM) is an example for a governing arrangement for coordinating change across multiple actors. TM is a prominent and empirically grounded framework for sustainable development, advocating for a governance approach rooted in complexity theory (Rotmans & Loorbach 2009). The authors argue that while top-down planning and market mechanisms contribute to societal change, they only address part of the whole picture. Network dynamics and reflexive behaviours also play crucial roles. Rotmans and Loorbach conclude that neither government intervention nor market forces alone are sufficient to achieve sustainable societal transformation. Although both remain essential, they emphasize the need for new governance strategies that foster better coordination, strengthen the effectiveness of existing institutions, and support informal networks that drive innovative policymaking. Building on this approach, we adapt the framework to suit the specific context and objectives of CIRCULAR FOAM in this chapter and show a step-by-step model for implementation.

The first step, known as the **establishment phase**, centres on engaging stakeholders and laying the groundwork for building trust within the core group. During this phase, the group collaboratively develops a shared vision and sets concrete goals, also described as transition agenda. Effective expectation management is achieved by mapping out the values and potential risks for each partner. Trust serves as the key success factor in this phase.

To set up a core group, the stakeholders need to be identified that are directly relevant and personally involved in the value chain. In Deliverable 1.2, relevant stakeholders for CIRCULAR FOAM have been defined and identified including an analysis based on an influence and interest map and a core-periphery map.

Rotmans and Loorbach (2009) recommend that there should be a limited number of frontrunners (10-15) from government, companies, NGOs, knowledge institutes, and intermediaries (e.g. consulting organizations, project organizations and mediators). They should be able to operate to a certain degree autonomously and participate on a personal basis rather than primarily representing their institution. Also, the core group stakeholders bring an “innovative” mindset, meaning that they are willing to work together with a range of other disciplines and are open to new ideas.

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The roles of the core group include strategic decisions, organization and facilitation of the process. The stakeholders involved take part in various thematic transformation arenas in which topics such as the legal framework and market conditions are addressed.

Guiding questions for defining a common vision and goals are:

- What is the shared vision that the group aspires to achieve?
- What specific, concrete goals can be established to realize this vision?
- What is the sphere of influence of each partner, and what responsibilities arise from this for each stakeholder?

The **growth phase** aims to expand the core group gradually over time. The circle is enlarged by inviting more members to the core group who have a direct connection to common goals and personal relations with the members of the core group. Regular meetings facilitate continuous exchange and collaboration. A key success factor during this phase is maintaining the relevance of the group's activities to the individual agendas of all partners.

The **experimenting phase** centres on practical application, with piloting and experimentation as its primary focus. During this stage, the shared vision and goals established in the initial phase are put into practice, allowing for trial and error. The key success factor in this phase is providing the freedom to experiment and explore new approaches.

The **final phase** is continuous, establishing long-term collaboration within the multi-stakeholder network that has been developed. Learning and evaluation are embedded throughout the process, enabling the group to regularly assess which goals have been achieved, identify emerging risks, and capture insights gained along the way. This iterative approach ensures ongoing improvement and adaptation in each phase.

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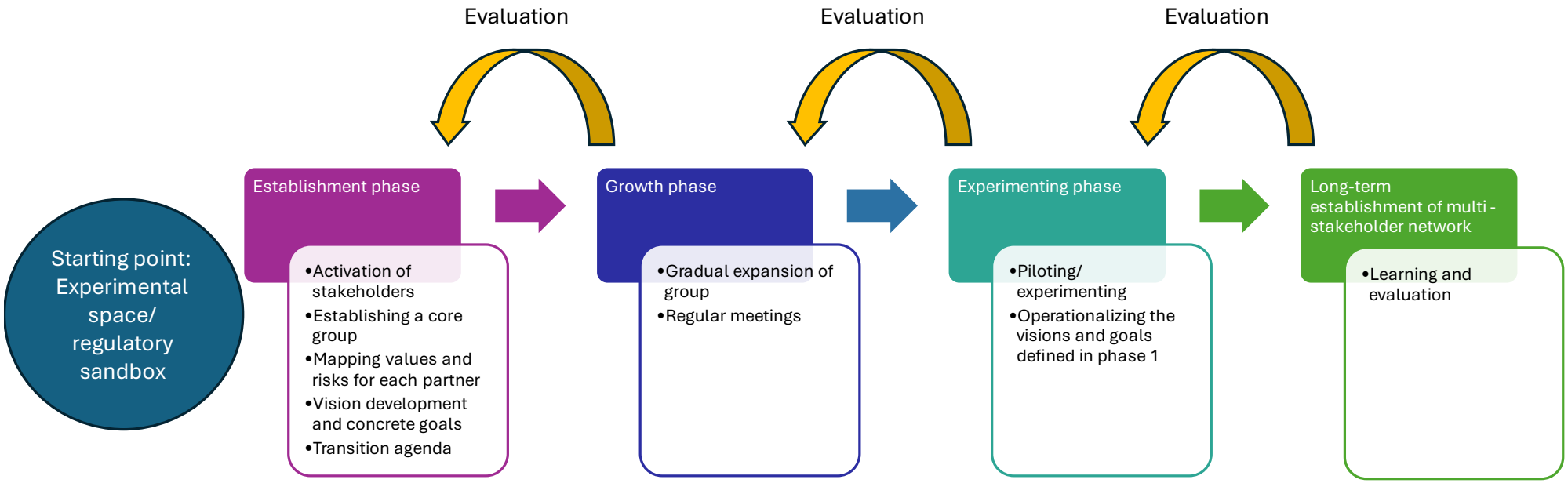

Figure 12: Own presentation based on Rotmans and Loorbach (2009)

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3.1 Regulatory Sandboxes

During the experimentation phase in particular, there is a need for a testing environment for innovation and regulation. One useful tool for this purpose is the concept of a regulatory sandbox.

According to the Policy Report on Regulatory Sandboxes by the European Technology and Innovation Platform Smart Networks for Energy Transition (European Commission 2023), a regulatory sandbox is a "general framework for innovators to test new products, services, and methodologies for a certain period" (p. 8). Regulatory sandboxes address the challenge of integrating innovation with existing systems, especially when new solutions are not compliant with current regulatory frameworks. They are considered a tool for future-proof regulation, allowing for the identification of advantages and disadvantages of an innovation before a permanent regulatory framework is developed. To this end, exemptions are granted from statutory or regulatory provisions that have been identified as obstacles.

European law plays an important role for regulatory sandboxes. In 2020, the Council of the European Union adopted conclusions on regulatory sandboxes and experimentation clauses. Regulatory sandboxes are also a key part of the EU innovation agenda, with the European Commission often tasked with improving their legal framework. Experimentation clauses and real-world labs are now included in various EU legal acts, for example in the Artificial Intelligence (AI) Regulation, the Net Zero Industry Act, the Industrial Emissions Directive and the Interoperable Europe Act (BMWE 2023).

Regulatory experimentation areas can be based on four forms of exceptions. An *exception to a prohibition* authorizes an authority to deviate from the specified legal regulations. In the case of *exceptions to an approval requirement*, the legislator waives the requirement for approval, a procedure or proof, thereby simplifying or eliminating work steps and bureaucratic processes for innovators. The legislator can also *waive requirements for proof and equipment* for the purpose of testing. Furthermore, *bundling and catch-all provisions* can also be used to regulate deviations from responsibility and formal requirements (e.g. between the federal and state governments) (own translation from BMWi 2019, p. 63).

Key questions concerning the implementation and management of regulatory sandboxes:

- What is the interest in knowledge about adaptation of regulations?
- How can the achievement of the objectives be made measurable?
- Which areas of law and which specific legal provisions are relevant for the implementation of the project?
- Which legal regulations hinder or prevent the introduction of the technology or business model?

3.2 Adapting the Transition Management Framework to CIRCULAR FOAM

Building on the general principles of transition management and regulatory sandboxes, we now illustrate how these concepts can be specifically adapted to the CIRCULAR FOAM project, with a focus on the collection and sorting steps in the insulation material value chain.

In particular, regulatory sandboxes offer a valuable tool for piloting innovative approaches within the value chain, such as enabling the cross-border transport of PUR waste from the Netherlands to Germany, facilitating on-site separation at demolition and construction sites, and testing the market acceptance of products containing recycled PUR.

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The transition management framework provides a structured, phased approach to achieving systemic change, emphasizing stakeholder engagement, vision-building, experimentation, and iterative learning. Regulatory sandboxes, on the other hand, offer a concrete mechanism for enabling experimentation within real-world regulatory environments, allowing stakeholders to test innovative solutions without being constrained by existing legal frameworks.

In the context of the CIRCULAR FOAM project, these two concepts are mutually reinforcing. By embedding regulatory sandboxes within the TM framework, the CIRCULAR FOAM project serves as a starting point for joint action systematically identifying, testing, and scaling innovative solutions for circularity in the PUR rigid foam value chain. TM provides the process and stakeholder governance, while sandboxes offer the practical means to overcome regulatory barriers and accelerate learning.

The current system already has a recycling infrastructure in place for cooling appliances while there is currently no infrastructure dedicated to the collection of insulation materials for recycling purposes in place (cf. Del. 7.8). For this reason, the focus here will be on the more challenging construction and demolition sector. With regard to cooling appliances, we briefly outline below the consumer-related challenges – particularly at the end-of-life and purchase stages – that can be mitigated by testing solutions within regulatory sandbox frameworks.

To operationalize the regulatory experiments, a core group should be established along the value chain of insulation boards, with clear governance structures and binding commitments for the trial period. Establishing this nucleus – or initial circularity hub for high-performance polymers – is a critical first step, given the wide range of challenges associated with closing material loops in the building and construction industry (cf. Chapter 1.2). The group agrees to set up a regulatory framework that allows for experimenting with new ways of collection and sorting for a certain time period. The members of the core group commit themselves to the full range of actions required for the circular system.

The binding agreements for this case could include the following aspects:

- Involved construction and demolition companies separate PUR waste on-site at demolition and construction sites.
- All PUR waste is transported to the same place: collection facilities, which act as secondary consolidation points, then to recovery and treatment facilities.
- PUR waste can be treated as raw material (including cross-border exceptions from e.g. Netherlands to Germany), ensuring reliable feedstock for recyclers.

These pilot conditions allow for learning and feedback to continuously inform future regulation and business models while demonstrating technical, logistical, and legal feasibility across European regions.

3.3 Financial and Operational Challenges

Insights from the project's work packages show that significant financial and operational barriers currently prevent circular practices from scaling.

The analysis in WP7 shows that value creation in the current system is unevenly distributed: collection, sorting, and pre-treatment involve high operational and capital expenditures, while most economic returns are realized at the end of the value chain. To address this imbalance, compensation mechanisms are needed.

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WP3 results indicate that establishing a new dismantling process requires significant investment—not only in machinery and facilities, but also in further research, as the dismantling process remains rough and only partially tested. Given uncertainties around output requirements for chemical recycling, this represents a financial risk for the recycling industry.

Risks also arise earlier in the value chain, particularly with feedstock collection. Without an effective collection system and incentives, single-variety collection is unlikely, making feedstock access challenging. However, if the value of processed PUR/PIR is high enough to cover collection and recycling costs, the market could self-regulate, similar to other valuable materials like copper.

These risks and inefficiencies make it difficult for stakeholders to invest in collection and sorting, treatment and recycling infrastructure - precisely the gap that regulatory sandboxes are designed to address. These challenges could be addressed by setting up a regulatory sandbox that allows specific stakeholders in the value chain to try out the required mechanisms and prevent the uncertainties defined above.

3.4 Concrete Applications: Insulation Waste and Refrigerators

Regulatory sandboxes can be adapted to different segments of the PUR rigid foam value chain. In the construction and demolition sector, sandboxes could enable:

- On-site separation of PUR insulation boards and sandwich panels.
- IT-supported documentation on-site across European regions, preventing complex mixed waste at demolition sites despite regulations for separate collection.
- Adjusted or new financial measures that support business models to become profitable or at least break even, especially for collection and sorting.
- Dedicated transport containers to collection facilities, followed by processing at recovery and treatment facilities into pellets and metal recovery.
- Automated sorting, to improve the quantity and quality of collected PUR rigid foam waste.
- Delivery of pellets to chemical processing facilities for catalytic pyrolysis and recovery.
- Developing and sharing of quality standards for recycled construction/insulation material to counter quality concerns in the industry.
- Financial incentives to prevent PUR waste going to recycling rather than incineration, e.g., coming from recyclate certificate trading systems.

In the appliance sector, sandbox pilots could support by addressing challenges at the end of the value chain:

- Testing of market acceptance for products containing recycled PUR.
- Ensure transparency in how products containing recycled materials are priced and marketed to avoid greenwashing and build consumer trust.
- Implementation of return incentives (e.g., vouchers for discarded refrigerators).
- Piloting innovative ownership models such as renting instead of buying, ensuring end-of-life return to producers.

These experiments provide critical insights into consumer behavior, logistics, material quality, and legal requirements.

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3.5 Synergies, Future Developments, and Legal Considerations

Looking ahead, exploiting synergies with other waste streams and leveraging technological advancements in sorting can further enhance the circularity of PUR rigid foam, provided that legal and regulatory frameworks are appropriately adapted.

3.5.1 Role of automation, robotics, and AI in sorting

Future advancements in automated sorting technologies – particularly those integrating robotics and artificial intelligence (AI) – are expected to play a pivotal role in transforming the efficiency, scalability, and precision of waste collection and sorting systems. These technologies offer the potential to overcome long-standing bottlenecks in material identification, contamination control, and manual labour dependency, especially in complex or mixed waste streams such as foams and composite plastics.

Robotic systems equipped with computer vision and real-time learning capabilities cannot only sort materials faster and more accurately than human operators but can also adapt to changing waste input compositions. AI-driven analytics further enable predictive maintenance, dynamic sorting route optimization, and feedback loops that enhance the overall circularity of materials by improving traceability and material yield.

In certain waste streams, such as polyethylene terephthalate (PET), polyethylene (PE), or expanded polystyrene (EPS), near-infrared (NIR) spectroscopy is already deployed with high levels of accuracy, allowing for the separation of polymers based on their chemical fingerprint. These technologies are viable and increasingly cost-effective today, but their broader adoption across less homogeneous waste types still faces technical and infrastructural challenges.

This is particularly relevant for PUR rigid foams, which present challenges due to their heterogeneous structure, complex formulations, and presence of additives and flame retardants. Efficient sorting of PUR rigid foam waste requires highly selective detection technologies that can distinguish PUR from other foams and contaminants. Once these technologies are mature and integrated into industrial settings, they could significantly improve the pre-processing phase of chemical recycling for PUR, enabling higher feedstock purity and process efficiency.

Ultimately, the convergence of AI, robotics, and advanced spectroscopy holds promise as a decisive lever in scaling up chemical recycling pathways. By improving upstream sorting accuracy, especially for difficult streams like PUR foam, these systems can deliver cleaner feedstocks, reduce processing costs, and increase the yield and quality of recycled outputs. These are all critical factors in making chemical recycling both economically viable and environmentally sound within circular economy strategies.

3.5.2 Synergies with other waste streams

Especially for the collection of waste material at demolition sites, there is potential for synergies with other waste streams, for example EPS (as explored, for example, in the Austrian research project EPSolutely[4]) and other insulation materials that are common and currently not sorted for recycling. Apart from insulation material, mattresses can serve as another example for potential synergies in

[4] https://epsolutely.at/

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collection and sorting as Covestro already explores this challenge in another research project (Foam Recycling Ecosystem Evolution[5]).

3.5.3 Legal requirements for demolition and waste reporting

Demolition in North-Rhine Westphalia currently requires only a notification (incl. disposal concept) for the demolition of buildings weighing over 500 tons (which corresponds to approx. a 3-4 family house). While smaller demolitions remain unregulated in this regard, these larger projects offer a clear opportunity for anticipation and planning.

For buildings exceeding 500 tons, the type, quantity and intended disposal of the resulting waste must be announced to the authorities. A building pollutant report can provide information on the presence of building materials containing pollutants. This way, building demolitions above a certain size can be anticipated and assessed according to the expected amount of PUR waste generated.

The chance here is that together with advancements in automation and synergetic treatment with other waste streams, the organization effort of collection and sorting at large demolition sites becomes more efficient and worthwhile so that a self-regulation of market dynamics becomes more likely. Because the presence and timing of large-scale demolitions are known in advance, demolition notifications can serve as a strategic trigger for launching efficient and scalable PUR waste recovery efforts.

3.6 Section Summary

The transformation towards a sustainable future state is highly dependent on contextual factors such as social acceptance, political will, technological readiness, infrastructure, and appropriate market mechanisms. In the case of advancing circularity in the PUR foam industry, much of the responsibility lies with the European Union and national governments. Legislative actions at the EU level – such as carbon pricing, directives on waste classification, and recycling thresholds – are central to enabling this shift. Regional entities appear limited in their influence, often reduced to logistical roles like establishing collection points.

In this context, Transition Management offers a pragmatic pathway forward. By empowering stakeholders beyond the traditional decision-making hierarchy and forming a transition arena, a collaborative and adaptive space emerges for building shared visions and experimenting with innovative solutions. This structured process, underpinned by trust-building and safe experimentation, e.g. using regulatory sandboxes, enables gradual progress even amid initial uncertainties.

Ultimately, the success of such a transition relies not only on top-down directives but also on inclusive, bottom-up engagement, tailored to local conditions and sustained through iterative learning and stakeholder commitment.

[5] https://www.covestro.com/press/consortium-develops-evolutionary-concept-for-recycling-of-end-of-life-polyurethane-mattress-foams/

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4 Conclusion

Chapter 1 established the foundational theoretical framework for the roadmap development, rooted in **transformation knowledge**, which builds upon previously gathered system and target knowledge from Deliverables 1.1-1.5. This approach aims to bridge the gap between plausible future scenarios and concrete, stakeholder-based actions until 2050. Insights from critical review studies on complex waste streams, such as WEEE and C&D waste, significantly informed the roadmap's development by offering transferable lessons for closing material loops. The overarching emphasis is on a **context-conscious and integrated strategy**, ensuring the roadmap is grounded in validated approaches for achieving systemic circularity.

Chapter 2 outlines a **roadmap for a circular system for high-performance plastics**, including PUR rigid foam, targeting achievements by 2050. It details key developments and steps for stakeholder actions across numerous interconnected factors. For each factor, the roadmap specifies long-term goals and concrete steps, further divided into short-term (to 2030), mid-term (to 2040), and long-term actions (to 2050) at EU, national, and regional levels. This structured approach is essential for guiding the concerted efforts required to achieve the ambitious goal of preventing PUR rigid foam waste from going to waste incinerators, and instead being chemically recycled in the EU.

Chapter 3 deals with the critical role of **collaboration and governance** in fostering systemic change for PUR rigid foam circularity. It differentiates between participatory governance, which emphasizes democratic legitimacy and inclusivity, and collaboration, focused on cooperative problem-solving among diverse public, private, and civil society stakeholders. A central framework for guiding this transformation is Transition Management, which advocates for new governance strategies to enhance coordination and strengthen networks for societal change. Crucially, the chapter highlights **regulatory sandboxes** as a practical tool within the TM framework, allowing for the systematic identification, testing, and scaling of innovative solutions – such as on-site separation or market acceptance for recycled content – by temporarily mitigating existing regulatory barriers and accelerating learning in real-world environments.

In summary, this Deliverable 1.6 builds upon prior system and target knowledge from WP1 to detail **actionable implementation elements** for a circular systemic solution for high-performance plastics, particularly PUR rigid foam. It establishes a structured roadmap with concrete, multi-level steps across regulatory, economic, and technological factors, emphasizing **participatory governance** and **collaboration** as crucial for forming **joint clusters** and driving systemic change. Ultimately, this deliverable serves as a **starting point for joint action**, integrating practical governance frameworks like **regulatory sandboxes** to address policy issues and accelerate the transition towards a **fully circular systemic solution** for PUR rigid foam.

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5 References

Agora Industrie, Systemiq (2023): *Resilienter Klimaschutz durch eine zirkuläre Wirtschaft: Perspektiven und Potenziale für energieintensive Grundstoffindustrien*. Available at: https://www.agora-industrie.de/fileadmin/Projekte/2022/2022-11_IND_Kreislaufwirtschaft/A-EW_309_Kreislaufwirtschaft_WEB.pdf.

Ansell, C., & Gash, A. (2008): Collaborative governance in theory and practice. *Journal of Public Administration Research and Theory*, 18(4), 543–571.

Arnstein, S. R. (1969): A ladder of citizen participation. *Journal of the American Planning Association*, 35(4), 216–224.

Brandao, R., Hosseini, an Macêdo, Melo, A.C., Martek, I. (2022): Public administration strategies that stimulate reverse logistics within the construction industry: a conceptual typology. *ENGINEERING CONSTRUCTION AND ARCHITECTURAL MANAGEMENT* 29, 2924–2949. https://doi.org/10.1108/ECAM-07-2020-0547.

Brandt, P., Ernst, A., Gralla, F., Luederitz, C., Lang, D.J., Newig, J., Reinert, F., Abson, D.J., Wehrden, H. von (2013): A review of transdisciplinary research in sustainability science. *Ecological Economics* 92, 1–15. https://doi.org/10.1016/j.ecolecon.2013.04.008.

Bundesministerium für Wirtschaft und Energie (BMWi) (2019): *Freiräume für Innovationen - Das Handbuch für Reallabore. Deutsches Bundesministerium für Wirtschaft und Energie*. Available at: www.bmwi.de/Redaktion/DE/Publikationen/Digitale-Welt/handbuch-fuer-reallabore.html (German)

Bundesministerium für Wirtschaft und Energie (BMWE) (2023): *Innovationspolitik. Reallabore – Testräume für Innovation und Regulierung*. Available at: https://www.bundeswirtschaftsministerium.de/Redaktion/DE/Dossier/reallabore-testraeume-fuer-innovation-und-regulierung.html (German)

Carbon Market Watch (2021): *How can the EU Emissions Trading System drive the plastics sector's zero-carbon transition?* Available at: https://carbonmarketwatch.org/wp-content/uploads/2021/04/How-can-the-EU-Emissions-Trading-System-drive-the-plastics-sectors-zero-carbon-transition.pdf.

de Geus, T., Silvestri, G. Wittmayer, J. (2022) : *Designing participatory transformative processes for just and climate-neutral cities.* Deliverable report. Brussels: TOMORROW. Download: https://www.citiesoftomorrow.eu/sites/default/files/documents/TOMORROW%20Methodological%20Guidelines%20for%20Using%20Transition%20Management.pdf

European Commission (2018): *Guidelines for the waste audits before demolition and renovation works of buildings: EU Construction and Demolition Waste Management*. Available at: https://ec.europa.eu/docsroom/documents/31521/attachments/1/translations/en/renditions/native

European Commission (2020): *A new Circular Economy Action Plan - For a cleaner and more competitive Europe*: COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS. COM 98, Brussels. https://eur-lex.europa.eu/resource.html?uri=cellar:9903b325-6388-11ea-b735-01aa75ed71a1.0017.02/DOC_1&format=PDF (accessed 7 June 2025).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101036854

European Commission (2023): WFD - Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Directive 2008/98/EC on waste.

European Commission: Directorate-General for Energy, ETIP SNET, Efthymiou, V., Hartz, N., McGranaghan, M. et al., *Regulatory sandboxes – Policy report drafted by WG5's regulatory sandboxes task force*, Publications Office of the European Union, 2023, https://data.europa.eu/doi/10.2833/676429

European Commission (2025): *Construction and demolition waste: EU rules aim to ensure that this waste is managed in an environmentally sound way, and to contribute to the circular economy*. Available at: https://environment.ec.europa.eu/topics/waste-and-recycling/construction-and-demolition-waste_en (accessed 2 June 2025).

Eurostat (2025): *Industrial producer price index overview*. Available at: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Industrial_producer_price_index_overview#Industrial_producer_price_index_-_sub-indices (accessed 29 July 2025).

Fischer, F. (2012): Participatory governance: From theory to practice. In D. Levi-Faur (Hrsg.), *The Oxford Handbook of Governance* (Online ed.). Oxford Academic. https://academic.oup.com/edited-volume/34384/chapter-abstract/291595271

Fung, A. (2003): Thinking about empowered participatory governance. In A. Fung & E. Wright (Hrsg.), *Deepening democracy* (Bd. 4, Issue 3, S. 1–42). Verso

Grothus, A., Kühnl, H., Kamlage, JH. (2025): Diversifizierung der Transformationsakteure – Zum Verhältnis von Beteiligung, Nachhaltigkeit und bürgerschaftlichen Innovationen im Strukturwandel des Rheinischen Reviers. In: Panreck, IC., Girnus, L., Partetzke, M. (eds) *Von der Krise zur Innovation*. Politische Bildung. Springer VS, Wiesbaden. https://doi.org/10.1007/978-3-658-47649-6_17

Guarnieri, P., Silva, L.C., Haleem, F., Bianchini, A., Rossi, J., Wæhrens, B.V., Farooq, S., Reyes, E., Reis, A.L., Vieira, B.D. (2023): How Can We Measure the Prioritization of Strategies for Transitioning to a Circular Economy at Macro Level? A New Approach. *Sustainability* 15. https://doi.org/10.3390/su15010680.

Hirsch Hadorn, G., Bradley, D., Pohl, C., Rist, S., Wiesmann, U. (2006): Implications of transdisciplinarity for sustainability research. Ecological Economics 60, 119–128. https://doi.org/10.1016/j.ecolecon.2005.12.002.

Kirchherr, J., Hartley, K. (2025): Is circular economy a failing sustainability paradigm? Not necessarily. *J of Industrial Ecology*, jiec.70055. https://doi.org/10.1111/jiec.70055.

Kirchherr, J., Reike, D., Hekkert, M. (2017): Conceptualizing the circular economy: An analysis of 114 definitions. In: *Resources, Conservation and Recycling* 127, 221–232. https://doi.org/10.1016/j.resconrec.2017.09.005.

Kirchherr, J., Yang, N.-H.N., Schulze-Spüntrup, F., Heerink, M.J., Hartley, K. (2023): *Conceptualizing the Circular Economy* (Revisited): An Analysis of 221 Definitions. Resources, Conservation and Recycling 194, 107001. https://doi.org/10.1016/j.resconrec.2023.107001.

Newig, J., et al. (2018): The environmental performance of participatory and collaborative governance: A framework of causal mechanisms. *Policy Studies Journal*, 46(2), 269–297.

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Oluleye, B.I., Chan, D.W., Antwi-Afari, P., Olawumi, T.O. (2023): Modeling the principal success factors for attaining systemic circularity in the building construction industry: An international survey of circular economy experts. In: *SUSTAINABLE PRODUCTION AND CONSUMPTION* 37, 268–283. https://doi.org/10.1016/j.spc.2023.03.008.

Piorunek et al. (2025): *Closing the Loop - Critical Review of Stakeholder Cooperation and Governance for the Circularity of Complex Waste Streams by the Example of CIRCULAR FOAM*. To be submitted.

ProClim (1997): *Forschung zu Nachhaltigkeit und Globalem Wandel - Wissenschaftspolitische Visionen der Schweizer Forschenden*, Bern.

Rotmans, J. and Loorbach, D. (2009): Complexity and Transition Management. *Journal of Industrial Ecology*. 13. P. 184 - 196. DOI: 10.1111/j.1530-9290.2009.00116.x

Sharpe, B., Hodgson, A., Leicester, G., Lyon, A., Fazey, I. (2016): Three horizons: a pathways practice for transformation. *E&S* 21. https://doi.org/10.5751/ES-08388-210247.

Wegener et al. (2025): Report on “Dialog-based format for implementation with partners in industry, science, administration”, D1.5. Ruhr University Bochum.

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