EU–CHINA
BRIDGE

Building Roadmaps to Industrial Decarbonisation and Green Economy through EU-China Cooperation

D3.3 – Scale-up paths of chemical recycling (EU)

WP3 – Technology demonstration, upscaling and roadmaps

https://www.eu-china-bridge.eu

Note: this version of the Deliverable is subject to the final approval of the European Commission

Funded by the European Union

Funded by UK Research and Innovation

Funded by the Ministry of Science and Technology of P.R. China

Version: 30.11.2025

Disclaimer

Funded by the European Union (EU), UK Research and Innovation UKRI (grant No 10132630), and the Ministry of Science and Technology of the People's Republic of China (PRC). Views and opinions expressed are those of the author(s) only and do not necessarily reflect those of the EU, the European Climate, Infrastructure and Environment Executive Agency (CINEA), UKRI, and the Ministry of Science and Technology of PRC. The EU, UK, the PRC, and the granting authorities cannot be held responsible for these views and opinions.

Copyright Message

Grant agreement number	101137971		**Acronym**	**EU-CHINA-BRIDGE**
Full title	Building Roadmaps to Industrial Decarbonisation and Green Economy through EU-China Cooperation			
Topic	HORIZON-CL5-2023-D1-02-01			
Funding scheme	HORIZON EUROPE, RIA – Research and Innovation Action			
Start date	April 2024	**Duration**		36 Months
Project URL	**https://www.eu-china-bridge.eu**			
EU project advisor	Pilar Roman			
Project coordinator	Wuppertal Institute – WI			
Deliverable	D3.3 – Scale-up paths of chemical recycling (EU)			
Work package	WP3 – Technology demonstration, upscaling and roadmaps			
Date of delivery	**Contractual**	*30/11/2025*	**Actual**	*30/11/2025*
Nature	Report	**Dissemination level**		Public
Lead beneficiary	Wuppertal Institut für Klima, Umwelt, Energie gGmbh			
Responsible author	Georg Holtz	**Email**		georg.holtz@wupperinst.org
	WI	**Phone**		+49 2492 202 301
Contributors	Georg Holtz, Charlotte Hullmann, Svenja Theisen, Chun Xia-Bauer [WI]			
Reviewer(s)	Lixue Lin-Siedler [ITE]			
Edited and submitted by	Chun Xia-Bauer [WI]			
Keywords	Technology Upscaling; EU; Chemical recycling; Pyrolysis			

Funded by the European Union

Funded by UK Research and Innovation

Funded by the Ministry of Science and Technology of P.R. China

EC Summary Requirements

1. Changes with respect to the Description of the Action (DoA)

No changes with respect to the work described in the DoA.

2. Dissemination and uptake

The deliverable will mostly be used within the project as a key input into roadmapping process in Task 3.6 and into a policy brief on decarbonising the chemicals sectors in the EU and China (D3.9). It can also be used outside the project to provide insights about the potential of pyrolysis in Europe, the main factors influencing its upscaling and policy measures for supporting the technology upscaling.

3. Short summary of results (<250 words)

Chemical recycling is an essential option to expand circularity in the plastics value and for the reduction of related scope-3 emissions. This Deliverable assesses the technical upscaling potential of pyrolysis for chemical recycling in the EU using existing models and knowledge on the technical capabilities of pyrolysis. It also analyses key barriers and drivers for its upscaling through a qualitative multi-dimensional analysis. Policy recommendations are derived based on this analysis and address the identified main gaps: public risk-sharing mechanisms could address a need for sustained technological experimentation; a clear organizational framework defining roles, standards and procedures across the (emerging) value chain is required to activate investments in the waste management sector and tackle the inaccessibility of high-quality plastic waste feedstock; the significant cost disparity relative to conventional virgin polymer production induces the need for mandatory recycled content quotas, consideration of recycling contents in public procurement or broader, systemic policy changes, like a fossil tax or extended producer responsibility (EPR) schemes; and the current lack of legal certainty must be overcome and a predictable and trustworthy policy environment be created.

4. Evidence of accomplishment

This report.

Funded by the European Union

Funded by UK Research and Innovation

Funded by the Ministry of Science and Technology of P.R. China

History of changes

Date/Version	Status	Changes
01.07.2025	*Draft v.0*	Creation of the document
30.10.2025	*Draft v.1*	Draft text for all sections
7.11.2025	*Draft v.2*	Consolidation of text across sections
10.11.2025	*Draft v.3*	Report sent for internal review
14.11.2025	*Draft v.3.1*	Executable summary added (and notification of reviewer)
25.11.2025	*Draft v.4*	Revision based on reviewer's comments
27.11.2025	*Deliverable*	Final editing and submission to the EC portal

Funded by the European Union

Funded by UK Research and Innovation

Funded by the Ministry of Science and Technology of P.R. China

Preface

EU-CHINA BRIDGE will support the transition to a climate-neutral and resilient society in both Europe and China by jointly advancing knowledge on technology innovations and roadmaps for decarbonising energy intensive industries, co-creating innovative modelling by combining cutting-edge bottom-up and integrated assessment modelling to quantify net-zero sustainable pathways, and developing the most updated and comprehensive emissions data. It will intensively engage relevant stakeholders from both regions, enhancing dialogues, and fostering mutual learning among policymakers, industries, and experts. It will deliver two open-source EU-China joint technology inventories of promising net-zero emission technology options for the iron & steel and chemical industries, two co-implemented demonstrations of promising technologies in China, and co-created scale-up paths and roadmaps of the selected industrial technologies in both regions. It will also develop the most up-to-date, high-resolution, multi-sectoral, national and regional GHG and short-lived climate pollutant emission inventories as well as dynamic monitoring of key emission sources at high spatiotemporal granularity. A state-of-the-art modelling framework will be developed, exploiting and advancing cutting-edge and established modelling tools for EU and China, using the latest emissions data, representing technology and policy options, enabling assessment of socioeconomic impacts, covering multiple economic sectors and regions, and offering high spatial and technology detail. The enhanced models will be used to co-produce net-zero pathways for the EU and China, explicitly assessing co-benefits and trade-offs of climate policies with other societal goals while exploring cooperation policies and governance to drive the global transformation and assessing the distributional and global-level implications of the two regions' decarbonisation. The pathways will be documented in new workspaces in the I²AM PARIS platform.

WI – Wuppertal Institut Fuer Klima, Umwelt, Energie gGmbH	DE
E3M – E3-Modelling AE	GR
IIASA – Internationales Institut fuer angewandte Systemanalyse	AT
UoB – The University of Birmingham	UK
ICCS – Institute of Communication and Computer Systems	GR
HOL – HOLISTIC IKE	GR
ITE – University of Kassel	DE
THU-SA – Tsinghua University	CN
THU-CE – Department of Chemical Engineering, Tsinghua University	CN
THU-DESS – Department of Earth System Science, Tsinghua University	CN
RUC – Renmin University of China	CN
SDU – Shandong University	CN
CHINACOAL – China National Coal Group Corporation	CN
BITARIM – Advanced Research Institute of Multidisciplinary Sciences, BIT	CN
FULONG – Inner Mongolia Fulong Heating Engineering Technology Co., LTD	CN
BIT-ME – School of Mechanical Engineering, Beijing Institute of Technology	CN

Funded by the European Union

Funded by UK Research and Innovation

Funded by the Ministry of Science and Technology of P.R. China

Executive Summary

The petrochemicals sector, which produces polymers from carbon-rich feedstock, is one of the most energy- and CO_2-intensive industrial sectors and features high scope-3 emissions. A transformation of the feedstock-basis of the petrochemicals sector towards renewables-based feedstock and increased circularity is therefore essential to achieve climate targets and for reducing environmental pressures from plastic waste.

Chemical recycling involves the decomposition of plastic waste into smaller hydrocarbon molecules which can be processed to polymers similar to primary feedstock. Chemical recycling is an essential option to expand circularity in the plastics value chain beyond what is possible via mechanical recycling. The establishment of chemical recycling necessitates the construction of a completely novel value chain and requires the coordination of actors who were not previously interconnected partners within a shared supply network. The core actors are petrochemical incumbents and recycling technology developers, typically pursuing joint ventures and equity investments. Their activities need alignment with both, upstream sourcing of feedstock (plastic waste) as well as end-users of polymers, who produce consumer products from them. Pyrolysis is currently the most implemented and expanding chemical recycling technology in the industry. During pyrolysis, plastic waste is cracked at high temperatures and in the absence of oxygen.

Against this backdrop this Deliverable analyses upscaling pathways for pyrolysis for chemical recycling and addresses three main research questions:

- What is the technical upscaling potential of pyrolysis for chemical recycling?
- What are the key barriers and drivers for its upscaling?
- Which policies would effectively facilitate the upscaling?

Technical potential

The technical potential is assessed using existing models and knowledge on the technical capabilities of pyrolysis. The technical potential of plastic waste pyrolysis is defined by the volume of suitable plastic waste considering that all waste fractions suitable for mechanical recycling should be directed to mechanical facilities. Today, the remaining fraction, including rejects from mechanical recycling, is typically landfilled or incinerated and represents the pool potentially available for chemical recycling. It is projected that until 2050 landfilling is eliminated entirely, and only 10% of polymer fractions are unsuitable for recycling and subject to incineration. The waste potential specifically designated for pyrolysis technologies constitutes approximately 88% of the total chemical recycling potential of 2030 and 70% in 2050. The projected waste potential for pyrolysis of 26 M t in 2050 in the EU could result in the production of roughly 7.8 M t of pyrolysis oil for use as a steam cracker feedstock and could contribute around 13% to the total high value chemicals production in the EU.

Barriers and drivers

Barriers and drivers are explored in a multi-dimensional, qualitative analysis. The analysis takes a deliberately broad perspective and dimensions of the qualitative analysis include: 1) technical challenges, 2) R&D and knowledge diffusion, 3) financial and human capital, 4) feedstock availability, 5) market formation and business models, 6) legitimation and 7) political framework conditions and targets. Data was collected through desk research, semi-structured interviews and a stakeholder workshop. While the ambition of the analysis was to

Funded by the European Union

Funded by UK Research and Innovation

Funded by the Ministry of Science and Technology of P.R. China

draw conclusions that are applicable to the European level and a broad range of member states, the data collection focused on two countries: Germany and The Netherlands, both of which have a leading role for chemical recycling in Europe.

Technical challenges

The technology for the pyrolysis of plastic waste is generally considered established. Currently, numerous pyrolysis projects are being planned or are operational across Europe, though most are still at the pilot scale. Experts observe a shift in focus from purely technical development toward technology demonstration and the construction of the initial commercial-scale plants. The successful industrial deployment of pyrolysis technology is contingent upon meeting several critical technical requirements: the ability to process complex, lower-quality waste fractions that are unsuitable for mechanical recycling; achieving a significant improvement in efficiency (carbon yields of up to 95%); meeting stringent quality specifications for the resulting pyrolysis oil.

R&D and knowledge diffusion

Collaboration between startup-like chemical recycling firms and larger petrochemical incumbents constitutes a key mode for successful pilot projects and subsequent scaling. These collaborations allow niche actors to gain access to the established value chain and provide a critical pathway for knowledge diffusion. Despite being mature, the process requires ongoing R&D due to uncertainty regarding which specific chemical recycling technologies will ultimately prevail. Scaling is hampered by the fragmentation of project-specific collaborations and a reluctance to share operational knowledge. Industry growth depends on institutional platforms and multi-stakeholder consortia to coordinate the value chain, accelerate knowledge diffusion, and establish unified regulatory frameworks.

Financial and human capital

Investment constraints remain a significant barrier to the expansion of chemical recycling within the current crisis in the European chemical sector, where new projects must demonstrate clear financial viability to attract capital. Chemical recycling companies generally pursue hybrid financing models that combine equity and debt instruments. Funding depends on cross-actor collaboration and involvement of downstream brand owners through off-take agreements or direct equity contributions. Challenges to securing investments, however, arise from uncertain market and policy conditions as well as limited availability of government subsidies. Furthermore, chemical recycling startups struggle with a shortage of experienced chemical engineers. The latter challenge is best overcome through partnerships with established chemical companies that can provide the necessary expertise.

Feedstock availability

Accessibility, quality, and price of plastic waste feedstock are central determinants for the successful upscaling of pyrolysis. New and additional volumes of plastic waste need to be made accessible for recycling – beyond volumes that are mechanically recycled. Achieving the necessary feedstock quality and volume requires substantial investments in waste management for better sorting and cleaning, alongside clear separation from fractions destined for mechanical recycling. Overcoming these barriers demands deeper engagement from waste management companies, logistical improvements, and the establishment of a clear organizational framework defining roles and responsibilities across the emerging value chain.

Funded by the European Union
Funded by UK Research and Innovation
Funded by the Ministry of Science and Technology of P.R. China

Market formation and business models

The emerging market for chemical recyclates is primarily driven by the demand from sectors like food packaging and automotive whose quality requirements cannot be met by mechanical recycling. The market is still in its nascent stage and mostly established through bilateral cooperations, with Original Equipment Manufacturers (OEMs) and brand owners possessing significant leverage to orchestrate and shape value chains by setting stringent requirements for price, performance, and safety. A clear, scalable business model is not yet established. A key reason is the significant cost disparity relative to conventional virgin polymer production with cleaned pyrolysis oil being approximately three times more costly than naphtha. Upscaling pyrolysis for chemical recycling requires that all actors along the value chain identify viable business models but it remains uncertain how engaged actors can monetise their contributions to chemical recycling. The necessary scaling is furthermore structurally impeded by resistance from established actors (e.g., mechanical recyclers and brands invested in mechanical recycling), who fear losing feedstock access and market share. To create the enabling conditions for market formation regulatory mandates are required.

Legitimation

Despite consumer interest and the emerging market demand for recycled content, chemical recycling suffers from a lack of legitimacy and mistrust within public discourse, particularly among civil society and NGOs. To overcome this scepticism and establish "credibility", the industry views the implementation of mass balance accounting as a critical measure. This system is intended to transparently track and calculate the recycled content in products along the value chain.

Political framework conditions and targets

Policies that specifically set mandatory recycling targets in market segments for sensitive applications like food-contact plastics where mechanical recycling struggles are key to creating a predictable demand for high-quality recyclates from chemical recycling –even if chemically recycled material is currently more expensive, compared to material from virgin feedstock. The Packaging and Packaging Waste Regulation (PPWR) and the Directive on End-of-Life Vehicles (ELV) are the two most important policies in that regard. However, concerns exist that the delayed effective date of targets (e.g., PPWR in 2030) may result in an insufficient build-up of infrastructure and an undersupply of recyclates. Introducing broader systemic measures like a fossil tax might be an alternative approach that targets the underlying economics instead of particular market segments.

Policy gaps and recommendations

- The industry currently faces a need for sustained experimentation and uncertainty regarding which specific chemical recycling technologies will ultimately prevail. Public risk-sharing mechanisms could be beneficial to facilitate investments under such uncertain conditions.
- Sufficient volumes of high-quality plastic waste feedstock are currently inaccessible to market participants. Achieving the necessary feedstock quality and volume requires substantial investments in waste management and overcoming these barriers demands deeper engagement from waste management companies. A clear organizational framework defining roles, standards and procedures across the (emerging) value chain is required.
- Given the significant cost disparity relative to conventional virgin polymer production there are few incentives for upscaling chemical recycling at scale. Clear regulatory and market frameworks are thus required that convert integration of chemical recycling into tangible strategic or economic benefits. Mandatory recycled content quotas, consideration of recycling contents in public procurement or

Funded by the European Union
Funded by UK Research and Innovation
Funded by the Ministry of Science and Technology of P.R. China

broader, systemic policy changes, like a fossil tax or extended producer responsibility (EPR) schemes, are required to establish and secure markets for chemical recycling.

- The current lack of legal certainty must be overcome and a predictable and trustworthy policy environment with clear, stable, and consistently applied legal frameworks is required to secure investments. Regulations and procedures that increase transparency and accountability are required to address lacking legitimacy within the public discourse.

Funded by the European Union

Funded by UK Research and Innovation

Funded by the Ministry of Science and Technology of P.R. China

Contents

Figures

Tables

Funded by the European Union
Funded by UK Research and Innovation
Funded by the Ministry of Science and Technology of P.R. China

1 Introduction

1.1 Background

The petrochemicals sector, which produces polymers from carbon-rich feedstock, is one of the most energy- and CO_2-intensive industrial sectors. Moreover, it features high scope-3 emissions, due to the fact that the carbon contained in its products is eventually released into the atmosphere (Bauer et al., 2022). A transformation of the feedstock-basis of the petrochemicals sector towards renewables-based feedstock and increased circularity is therefore essential to achieve European and global climate targets and for reducing environmental pressures from plastic waste. Yet, the transformation pathway for the petrochemicals sector is still uncertain, from today's perspective and existing scenarios feature a large bandwidth of feedstocks, technologies and mixes thereof (Kloo et al., 2024). Orientation is thus urgently needed to foster the transformation of the European petrochemicals industry.

The work reported in this Deliverable is the middle step of a three-step approach underlying the work conducted in Workpackage 4 (WP 4) of the EU-CHINA BRIDGE project (see Figure 1). This three-step approach started from an overview of existing low-carbon technologies in technology inventories (reported in Deliverable 3.1) and will eventually lead to Roadmaps for the European Petrochemicals industry – to be reported in Deliverable 3.11. The intermediate step reported in this Deliverable consists of the analysis of upscaling pathways for a single, key technology: pyrolysis for chemical recycling (see below). The upscaling analysis takes a deliberately broad perspective on the technical potential of and barriers and drivers for upscaling, identifies the most significant gaps and derives suggestions for policy measures for fostering the upscaling pathway. Through this it provides valuable insights and paves the way towards the Roadmapping.

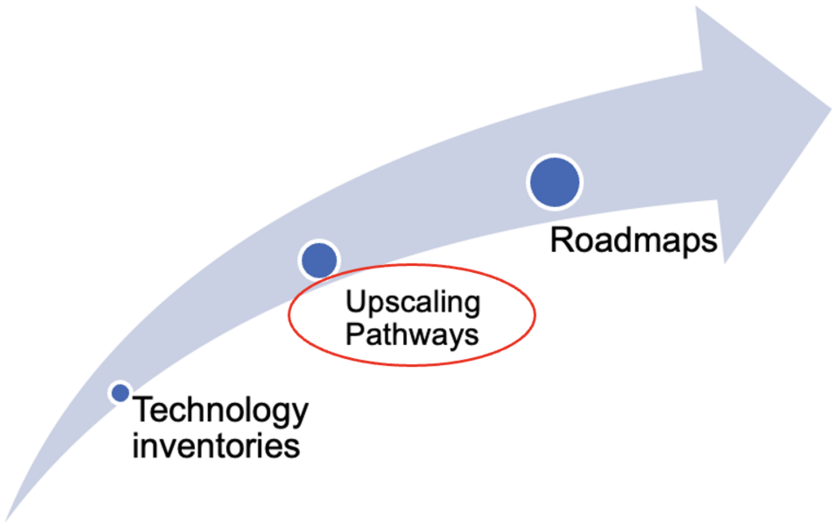

Figure 1: Three-step approach used in Work Package 4 of the EU-CHINA BRIDGE project

Chemical recycling of plastic wastes is chosen as a topic for the upscaling analysis. Chemical recycling involves the decomposition of plastic waste into smaller hydrocarbon molecules which can be processed similar to primary feedstock. Chemical recycling is an essential option to expand circularity in the plastics value chain beyond what is possible via mechanical recycling – which is limited to selected polymers and comparably clean waste streams. Moreover, in contrast to mechanical recycling, chemical recycling allows products which are

Funded by the European Union
Funded by UK Research and Innovation
Funded by the Ministry of Science and Technology of P.R. China

equally clean to those produced from primary feedstocks and therefore allows expanding the markets for recycled products to manufacturing industries which produce high-quality, contact-sensitive materials – such as products and packaging for the food and medical sectors. Chemical recycling thus increases the potential to keep carbon in the loop and to reduce the amounts of plastic waste being landfilled or burnt and associated CO_2 emissions and environmental impacts (Davidson et al., 2021; Jeswani et al., 2021). It is also key for reducing the need for fossil feedstocks of the petrochemicals industry, complementing CO_2-based and biogenic feedstocks.

There are various technological approaches to chemical recycling of plastic wastes with pyrolysis, gasification and solvolysis being the main ones. This upscaling analysis focuses on pyrolysis. Pyrolysis allows to recycle large shares of the carbon contained in the waste feedstock (Lange et al., 2024). It is currently the most implemented and expanding chemical recycling technology in the industry and can easily be integrated into the established petrochemical value chain. During pyrolysis, plastic waste is cracked into small molecules at high temperatures and in the absence of oxygen. The primary product of this process is a crude pyrolysis oil – a secondary raw material that can replace fossil feedstocks in steam crackers. This requires the crude pyrolysis oil to be upgraded through hydrogenation with the addition of hydrogen in a separate hydrogenation plant.

1.2 Research questions

Against this backdrop, this study seeks to address three main research questions:

- What is the technical upscaling potential of pyrolysis for chemical recycling?
- What are the key barriers and drivers for its upscaling?
- Which policies would effectively facilitate the upscaling?

Funded by the European Union
Funded by UK Research and Innovation
Funded by the Ministry of Science and Technology of P.R. China

2 Approach and methods

The upscaling analysis reported in this Deliverable builds on but goes beyond the description of techno-economic factors in the technology inventories reported in Deliverable 3.1. It takes a deliberately broad perspective covering technical, socio-technical and economic aspects to address the above research questions. The technical potential is assessed using existing models and knowledge on the technical capabilities of pyrolysis. Barriers and drivers are explored in a multi-dimensional, qualitative analysis, based on which main gaps are identified and policy measures are suggested.

2.1 Estimate of the technical potential

The technical potential for pyrolysis for chemical recycling is estimated using the EU Material Flow Analysis (MFA) Model, developed by the Wuppertal Institute (Wuppertal Institute, 2025). This MFA tracks the stock and flows of polymers across various sectors from 2020 to 2050. Following production, plastics remain in the product stock until their designated product lifetime ends and they become waste. The annual generated plastic waste exhibits diverse polymer compositions, sectoral origins, mixtures, and characteristics. The capability of pyrolysis to treat these various plastic waste streams (Karlsruhe Institute of Technology, 2024) is used to calculate the amount of plastic waste that can be processed by pyrolysis from a technical point of view.

2.2 Multi-dimensional analysis of barriers and drivers

A multi-dimensional analysis is conducted to analyse barriers and drivers for the upscaling of pyrolysis for chemical recycling. Barriers are obstacles or constraints that prevent or hinder the implementation of pyrolysis for chemical recycling and which need to be overcome for a successful upscaling. Drivers are factors or forces that push or motivate companies to adopt it and that hence work in favour of the upscaling process.

The multi-dimensional analysis includes a qualitative assessment along various dimensions, which were identified and defined based on the literature on technological innovation systems (TIS) and on insights from explorative desktop research. TIS analyses view technological systems as "Network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion and utilization of technology" (Carlsson & Stankiewicz, 1991, as cited in Markard & Truffer, 2008). In this context, "institutions" is to be understood in the sociological meaning of the term, as "rules of the game", including formal regulations (e.g. laws, technical standards), informal elements (e.g. best practices, behavioural norms) and psychological factors (e.g. paradigms). The TIS perspective thus does not focus on the technology itself, but on the socio-technical system that underlies its development and upscaling. One stream of the TIS literature follows a "functional" approach that focuses on what this socio-technical system does, rather than putting the elements of which it is composed at centre stage (Bergek et al. 2008; Hekkert et al. 2007; Jacobsson & Bergek, 2011; Kivimaa & Virkamäki, 2014). This functional perspective defines sub-functions of the system that are required to fulfill its main function (i.e., generation and diffusion of a technology). Such sub-functions suggested by the TIS literature therefore cover aspects that are required for upscaling technologies and thus provide a valuable starting point for defining a framework for the analysis of barriers and drivers. Various authors have suggested slightly different lists of such sub-functions (see Markard & Truffer 2008 for a comparison).

Most of the multiple dimensions of the analysis for the upscaling of pyrolysis displayed in Table 1 were defined based on sub-functions from the TIS literature. In order to cover technical and material aspects as well, the

Funded by the European Union
Funded by UK Research and Innovation
Funded by the Ministry of Science and Technology of P.R. China

dimension "technical challenges" was added, as well as "feedstock availability". As guidelines for the analysis along the various dimensions, guiding sub-questions were defined for each dimension, which are also included in Table 1. In order to facilitate the multi-dimensional analysis, the socio-technical system is briefly outlined at the beginning of section 4.

Table 1: Dimensions of the multi-dimensional analysis and guiding sub-questions

Dimension	Guiding sub-questions
Technical challenges	What key knowledge has been gained for critical technical aspects essential for upscaling? What gaps still exist? What are key performance requirements for new technologies to be successful in the future decarbonising markets and potential lead markets? What are the requirements at sites for first large-scale implementation?
R&D and knowledge diffusion	Who are the main actors involved in pyrolysis? How effective are the current R&D efforts in addressing the critical knowledge gaps necessary for scaling up pyrolysis technology? How sufficient are the existing knowledge exchange and dissemination activities in promoting widespread understanding and adoption of this technology?
Financial and human capital	Which sources provide financial capital? Which expertise is required and how is it provided?
Feedstock availability	Which feedstock is required for pyrolysis? Which factors influence availability of suitable feedstock?
Market formation and business models	Which market segments are susceptible for products from pyrolysis? Which factors influence the size of these market segments? Which business models exist for actors along the value chain?
Legitimation	Which societal debates exist around chemical recycling? Is pyrolysis socially accepted? Does pyrolysis fit into the existing regulatory structure?
Political framework conditions and targets	Which policies and regulations foster and hinder the upscaling of pyrolysis? Which targets exist?

2.3 Data collection

The data for the multi-dimensional analysis was collected through various channels. To address the various sub-questions listed in Table 1, data collection involved desk research, including data retrieval from previous research and exploring literature. In Scopus and the Web of Science, the search string *("chemical recycling" AND policy) AND ("European Union" OR Europe OR "EU" OR Germany OR Netherlands)* provided a total of 14 articles of which 5 proved relevant for this study. In addition, 6 semi-structured interviews of 1.5 hours lengths, each, were conducted with 2 interviewees from the chemical industry, 2 interviewees from an industry association, 1 from an NGO, and 1 from a regulatory authority. The questionnaires for the interviews were designed in line with the dimensions of the multi-dimensional analysis and partly tailored towards the expertise of the

Funded by the European Union
Funded by UK Research and Innovation
Funded by the Ministry of Science and Technology of P.R. China

interviewees. While the ambition of the analysis was to draw conclusions that are applicable to the European level and a broad range of member states, the data collection focussed on two countries for reasons of resource availability and practicality: Germany and The Netherlands, both of which have a leading role for chemical recycling in Europe (Fraunhofer UMSICHT, 2025).

Preliminary findings from the analysis were presented, discussed and validated at an online stakeholder workshop of 2 hour length. The workshop focussed on aspects that were identified as being critical to the upscaling during the analysis: closing the cost-gap to conventional production, mass balance approaches and developing the market for chemically recycled polymers (see Deliverable 1.2 for a more extensive report from the workshop).

Funded by the European Union
Funded by UK Research and Innovation
Funded by the Ministry of Science and Technology of P.R. China

3 Technical potential

The technical potential of plastic waste pyrolysis is defined by the volume of suitable plastic waste, assuming that there is no limit to the use side as the polymers produced from pyrolysis oil are identical to those produced from fossil feedstock (For more details on technical aspects of pyrolysis plants, see Section 4.1.). The EU Material Flow Analysis (MFA) Model developed by the Wuppertal Institute was used to project the future generated plastic waste and its composition, sectoral origins, mixtures, and characteristics (Wuppertal Institute, 2025).

The overall waste potential for chemical recycling is projected to increase over time. This increase is predicated on the model's assumptions of improved future collection and sorting rates, which enhance the available feedstock for both chemical and mechanical recycling. The model assumes that generated waste (50.6 M t in 2030, 64.7 M t in 2050) is first collected and sorted according to predefined collection and sorting rates. Within this sorted stock (49.6 M t in 2030, 63.5 M t in 2050), all fractions suitable for mechanical recycling are directed to mechanical facilities. For 2030, this stream will account for 18.5 Mt or 37% of the total collected waste, while in 2050, 29 M t or 46% is sent to mechanical recycling.
The residual fraction is not suitable for mechanical recycling due to contamination, additives, different types of materials like multi-layer foils, or downgraded polymers as a result of repeated mechanical recycling (Tang, 2025).

This fraction currently is typically landfilled or incinerated and represents the pool potentially available for chemical recycling. For 2030, 40% of the total collected waste is considered chemically recyclable (44% in 2050). The remainder is assumed to be incinerated. The resulting technical waste potential for chemical recycling of 20 M t in 2030 and 28 M t in 2050 is illustrated in Figure 2.
Furthermore, rejects from the mechanical recycling process are also added to this potential. These rejected waste fractions are particularly well-suited for chemical recycling as they have already undergone initial sorting and cleaning. These mechanical recycling losses suitable for chemical recycling include 6 M t in 2030 and 9 M t in 2050 and are added to the chemical recycling waste potential, as shown in Figure 2.
By the year 2050, the system is projected to eliminate landfilling entirely, and only a small fraction (10%, e.g. thermoplastics) of polymer fractions which are unsuitable for recycling are subject to incineration.

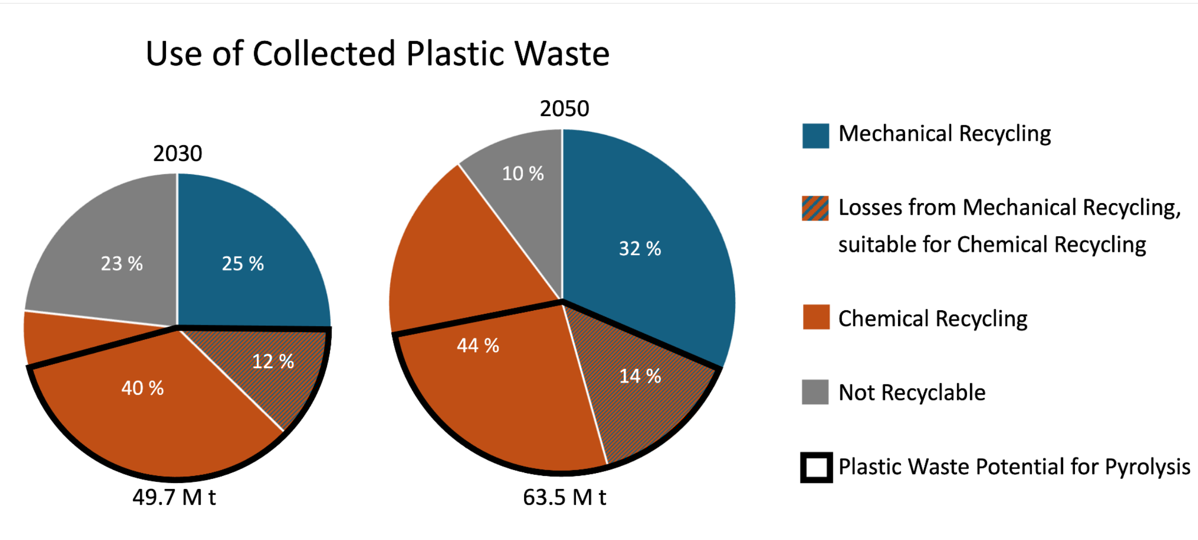

Figure 2: Use of Collected Plastic Waste in 2030 and 2050 according to the EU MFA Model by the Wuppertal Institute

Funded by the European Union
Funded by UK Research and Innovation
Funded by the Ministry of Science and Technology of P.R. China

This plastic waste stream designated for chemical recycling is suitable for various chemical recycling technologies based on its characteristics. Most fractions are compatible with both pyrolysis and gasification, while only specific, pure polymer streams (PMMA, PET, PU, PA) are suitable for solvolysis technologies. Some fractions are – because of their quality – only suitable for gasification and not pyrolysis. The waste potential specifically designated for pyrolysis technologies constitutes approximately 88% of the total chemical recycling potential of 2030 and 70% in 2050 and is marked in Figure 2.

Assuming an average conversion rate of 1 t of plastic waste yielding approximately 0.3 t of pyrolysis oil, the projected waste potential for pyrolysis of 26 M t in 2050 could result in the production of roughly 7.8 M t of pyrolysis oil for use as a steam cracker feedstock in the EU. For context: the current European petrochemical industry consumes approximately 46 M t of fossil naphtha as steam cracker feedstock. The High Value Chemical (HVC) yield of pyrolysis oil cracking differs from naphtha cracking, as no aromatics are produced from pyrolysis oil. By 2050, the use of pyrolysis oil in steamcrackers could contribute around 13% to the total high value chemicals production (Scholz et al., 2025).

In conclusion, chemical recycling via pyrolysis demonstrates a significant technical potential which is mostly dependent on future available plastic waste volumes. This positions the technology as a central building block for a sustainable, circular European petrochemical industry.

Funded by the European Union

Funded by UK Research and Innovation

Funded by the Ministry of Science and Technology of P.R. China

4 Barriers and drivers for upscaling pyrolysis

This section discusses key barriers and drivers influencing the scaling up of plastic waste pyrolysis along seven dimensions, as introduced in Section 2.2. In order to facilitate the analysis, the socio-technical system that underlies the development and upscaling of pyrolysis is briefly outlined.

4.1 Outlining the value chain of pyrolysis

Chemical recycling includes several steps of the value chain that need to be aligned, from waste management over the chemical recycling process itself to the manufacturing of polymers and their uptake in the market (Figure 3): Waste management activities include the collection, sorting and pre-treating of plastic waste and ensure plastics waste feedstock volume, quality and logistics. Chemical recycling technology providers develop and/or deploy conversion technologies (e.g., pyrolysis) that turn waste into feedstock (pyrolysis oil) for producing plastics. These technologies are used in the chemical recycling step of the value chain to convert sorted and treated plastic waste into feedstock (pyrolysis oil) for the petrochemicals industry which uses it for polymer production. End-users of polymers, including original equipment manufacturers (OEMs) and brand owners incorporate the recycled plastics into final plastic products.

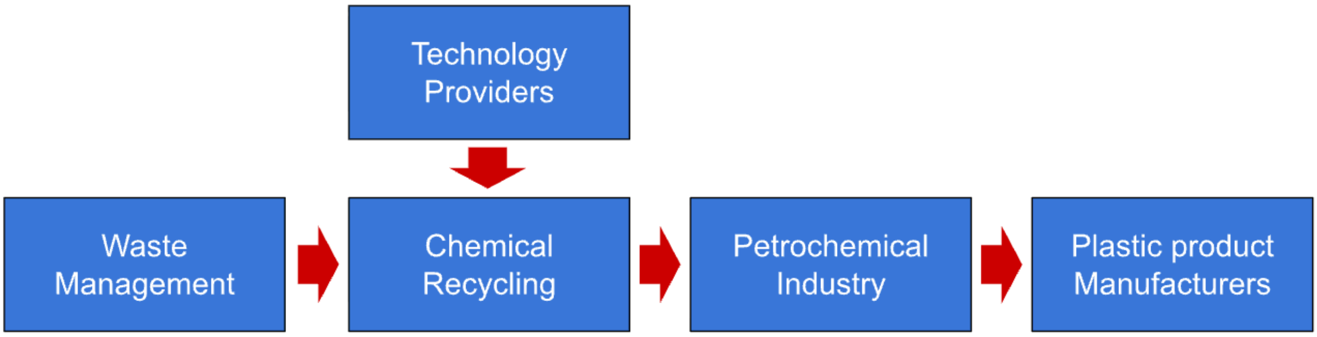

Figure 3: Outline of the value chain of chemical recycling

The core actors are petrochemical incumbents and recycling technology developers, typically pursuing joint ventures and equity investments. Their activities need alignment with both upstream sourcing of feedstock (plastic waste) as well as end-users of polymers, who produce consumer products from them. As such, chemical recycling establishes a new value chain—linking waste management to chemical companies and their customers. The upscaling of chemical recyclates hence introduces new customers to the recycling market, namely the base chemistry (e.g., BASF, Lanxess, Covestro, Evonik) where chemically recycled raw material would directly be processed. A key motivation for the chemical industry's engagement in chemical recycling lies in the desire to preserve existing assets and maintain the continuity of supply chains amid ongoing industrial crises and the shifting dynamics of globalisation. These producers have largely been outside of the recycling market before and lack experience in establishing themselves in the value chain.

The establishment of chemical recycling necessitates the construction of a completely novel value chain and requires the coordination of actors who were not previously interconnected partners within a shared supply network. Currently, the form of overarching coordination for this value chain remains unclear, as does which actor or actors can or will assume this central coordinating role. Furthermore, participants at different stages of the value chain possess divergent interests and requirements for chemical recycling. These interests and requirements manifest across all considered TIS dimensions and will be detailed in the following sections.

Funded by the European Union
Funded by UK Research and Innovation
Funded by the Ministry of Science and Technology of P.R. China

Within this new, highly complex value chain, crucial information (such as technical specifications) and market signals must be efficiently communicated and allowed to propagate across all participating actors to ensure successful scaling and operation.

Table 1 presents the key actors currently active in chemical recycling across Germany and the Netherlands, spanning the entire value chain. The integration along the value chain differs between the two exemplary countries that were analysed:

In Germany, the chemical recycling ecosystem already encompasses actors from across the entire value chain, with increasing alignment between upstream waste management, midstream conversion and petrochemical processing, and downstream end users. Two waste management companies have entered joint ventures and strategic partnerships with petrochemical producers, thereby linking feedstock sorting and preparation directly with conversion and cracker integration (OMV, 2023; Evonik, 2023). End-user engagement in Germany also extends beyond conventional business-to-business (B2B) purchase agreements. In one case, an end user has invested directly in chemical recycling capacity to secure long-term access to circular feedstock (Suedpack, 2024). Across the German landscape, petrochemical companies, often also major plastics manufacturers, and chemical recycling technology providers remain the most active participants. Both groups demonstrate a high level of engagement through pyrolysis-oil offtake contracts, strategic partnerships, and joint venture investments.

In the Netherlands, waste management companies have so far played a limited role in chemical recycling. A recent example of growing vertical integration is a recycler's acquisition of a specialised waste collection company, establishing an integrated collection and feedstock-supply capability for end-of-life plastics (Linnenkoper, 2025). In terms of downstream participation, brand owners and end users in the Netherlands remain mainly engaged through B2B purchase agreements, without significant direct investment in conversion capacity. Licensing is found as a business model: Recycling technology providers adopt the capital-light licensing strategy to replicate their technology, thereby potentially enabling scalability without the need for direct asset ownership. In addition, a recent case in the Netherlands involves a large engineering services company investing in chemical recycling technology to provide fully integrated plastic-recycling lines, a development that further supports the scale-up of advanced recycling capacity (Sulzer, 2023).

Table 2: Key actors in the chemical recycling value chain in Germany and the Netherlands

Actors on the value chain	Active in DE	Active in NL
Waste management companies	REMONDIS, Interzero	
Chemical recycling technology providers	ARCUS, CARBOLIQ, Plastic Energy, Pyrum Innovations AG	BioBTX, Xycle, Fuenix Ecogy, BlueAlp, Circtec
Petrochemical producers and polymer manufacturers	BASF, Evonik, INEOS Olefins & Polymers, OMV, LyondellBasell	Dow, SABIC, Shell
End users, including brand owners	SÜDPACK, AUDI	Unilever
Engineering services companies		Sulzer

Funded by the European Union
Funded by UK Research and Innovation
Funded by the Ministry of Science and Technology of P.R. China

These various actors along the value chain engage through diverse forms of cooperation and business models. The following types of business models and collaboration forms were identified in the case study countries (Table 2): business-to-business (B2B) of pyrolysis oil, B2B of recycled plastics, licensing, investment in technology providers, strategic partnership, and Joint Venture (JV).

Table 3: Forms of cooperation along the chemical recycling value chain in Germany and the Netherlands

Actors on the value chain	DE	NL
Waste management companies	strategic partnership, JV	
Chemical recycling technology providers	B2B of pyrolysis oil, invested by large petrochemical producers and engineering services, strategic partnership, JV	B2B of pyrolysis oil, Licensing, invested by large petrochemical producers and engineering services, JV
Petrochemical producers and polymer manufacturers	B2B of pyrolysis oil, investment in technology providers, strategic partnership, JV	B2B, investment in technology providers, JV
End users, including brand owners	B2B of recycled plastics, investment in technology providers	B2B of recycled plastics
Engineering services companies		investment in technology providers

4.2 Technical challenges

The technology for the pyrolysis of plastic waste is generally considered established (IN4CLIMATE.NRW, 2020; Participant 2, personal communication, 2025). However, the large-scale implementation of this technology within the industrial system remains incomplete. Currently, numerous pyrolysis projects are being planned or are operational across Europe, though most are still at the pilot scale (Zelt et al., 2025).

Experts now observe a shift in focus from purely technical development toward technology demonstration and the construction of the initial commercial-scale plants (Participant 2, personal communication, 2025; Participant 3, personal communication, 2025). Most companies engaged in pyrolysis projects are currently erecting or commissioning their first commercial assets, with very few possessing multiple operational commercial units (Participant 2, personal communication, 2025). This progression extends the focus beyond technical feasibility to include the viability of business models, market development, infrastructure, and policy frameworks (see the following sections).

Despite its maturity, several technical aspects of the pyrolysis process require further optimization. The crucial step in the pyrolysis process is the introduction of heat to facilitate the thermal decomposition of the waste. This is a significant technical challenge because most plastics are poor heat conductors, leading to slow heat penetration and large temperature gradients within the reactor's feedstock. In an industrial context, this poor heat transfer can cause the material to melt and agglomerate, further reducing the effective surface area for

Funded by the European Union
Funded by UK Research and Innovation
Funded by the Ministry of Science and Technology of P.R. China

heating. If the heating is non-uniform, it results in undesired secondary reactions that reduce the quality and yield of the pyrolysis oil (Al-Salem et al., 2017).

Various solutions exist to enhance heat transfer, leading to distinct pyrolysis technologies, such as conventional pyrolysis, catalytic pyrolysis, fluidized bed pyrolysis, and hydrothermal pyrolysis, among others (Dai et al., 2022; Participant 2, personal communication, 2025). However, a major technical difficulty remains in scaling up reactor sizes. Increasing the reactor's volume significantly decreases the surface-area-to-volume ratio, fundamentally limiting how quickly and uniformly the entire mass can be heated. (Orozco et al., 2022; Participant 2, personal communication, 2025).

Another central technical challenge involves improving the process yield. Current pilot and demonstration plants can achieve carbon yields of up to 85% (Participant 2, personal communication, 2025). However, to be economically viable within the highly optimized chemical industry, yields approaching 95% are necessary. One strategy for improving yields is the utilization of process off-gases by capturing and decarbonising them. The aim is to use these off-gases as secondary raw materials rather than simply combusting them. This approach enhances the overall carbon efficiency of the technology, leading to a higher carbon conversion rate and reduced emissions (Participant 6, personal communication, 2025).

The quality of the plastic waste feedstock continues to pose a significant challenge (see Section 4.5). Since chemical recycling targets waste fractions unsuitable for mechanical recycling, these inputs often contain undesirable contaminants (e.g., metals, chlorine). Feedstock quality directly impacts the plant's performance and the resulting oil quality; cleaner and more polyolefin-rich waste yields better output (Schade et al., 2024; Participant 2, personal communication, 2025). Low quality of feedstocks necessitates either the cleaning of the plastic waste prior to the pyrolysis process (front-end solution), or the upgrading of the produced pyrolysis oil in a separate, downstream facility (back-end solution) (Participant 2, personal communication, 2025). In the Netherlands, significant investments in upgrading facilities have been made by Shell and Sabic to enable the use of pyrolysis oil in their steam crackers (Participant 4, personal communication, 2025). Research is also underway to stabilize pyrolysis oil — specifically by removing free radicals to prevent re-polymerization and using additives to inhibit wax formation, thereby ensuring the pyrolysis oil remains pumpable (Participant 6, personal communication, 2025).

For the initial large-scale deployment of pyrolysis technology, specific requirements regarding site selection and infrastructure must be met. The location of the pyrolysis plant must ensure a viable logistical supply of the waste feedstock. Similarly, the shipment of the produced pyrolysis oil to upgrading facilities and steam cracker sites must be feasible. A key consideration is the integration of the pyrolysis plant into a chemical park or Verbund site, which allows processes to leverage existing structures, such as using a refinery unit for pyrolysis oil upgrading. However, the complex product flows in such integrated sites pose new challenges concerning the mass balance approach (see Section 4.7).

In summary, the successful industrial deployment of pyrolysis technology is contingent upon meeting several critical technical requirements. Fundamentally, the technology must possess the ability to process complex, lower-quality waste fractions that are (currently) unsuitable for mechanical recycling. The process must achieve a significant improvement in efficiency, specifically by achieving carbon yields of up to 95% to ensure economic viability. Furthermore, the resulting pyrolysis oil must either meet the stringent quality specifications for direct processing in existing steam crackers or be paired with upgrading technology.

Funded by the European Union
Funded by UK Research and Innovation
Funded by the Ministry of Science and Technology of P.R. China

4.3 R&D and knowledge diffusion

Collaboration between startup-like chemical recycling firms and larger petrochemical incumbents constitutes a key mode for successful pilot projects and subsequent scaling. New pyrolysis technologies for plastic waste processing are frequently developed by smaller, often startup-like companies operating in specialized niches. These niche actors commonly enter into partnerships with larger chemical companies that possess established experience across the petrochemical value chain. These collaborations allow niche actors to gain access to the established value chain and provide a critical pathway for knowledge diffusion. The partnerships are leveraged for piloting development concepts, accessing partner expertise, and tailoring the produced pyrolysis oil to meet customer specifications. Crucially, the larger petrochemical companies often provide the essential financial and technical support required for the smaller pyrolysis firms to advance their technology (Participant 2, personal communication, 2025).

Despite the technology being long-established and numerous pilot and demonstration projects being underway, a continued need for focused R&D activities persists. As noted in Section 4.2, a variety of different pyrolysis technologies exist. The industry currently faces uncertainty regarding which specific chemical recycling technologies will ultimately prevail, suggesting a need for sustained experimentation and potential industry consolidation. Moreover, continuous development linked to business models remains necessary (Participant 2, personal communication, 2025; see also Section 4.6).

The R&D process underscores the essential role of coordinating actors along the value chain for effective knowledge diffusion and support. When considering the broader value chain, the integration of chemical recycling into an emerging circular economy necessitates engagement with new stakeholders to shape its systemic development. Companies and industrial clusters committed to reducing their environmental impact must acquire knowledge, coordinate efforts, and collaborate across entire value chains (Kloo et al., 2024).

However, the sharing of knowledge, particularly concerning potential operational challenges, can inadvertently limit business opportunities by hindering the ability to secure investment. Consequently, the reluctance to share specific operational knowledge may constitute a barrier to the expansion of chemical recycling. Further constraints on knowledge sharing are imposed by confidentiality and competitiveness concerns.

A further barrier arises from the fragmented and bilateral nature of the existing projects. The majority of collaborations remain project-specific, lacking multi-party coordination or cross-sector governance. This fragmentation hampers knowledge sharing and limits scalability. There is a clear shortage of multi-stakeholder consortia that integrate upstream, midstream, and downstream actors under a common governance structure, shared performance metrics, and transparent risk-sharing mechanisms (Participant 2, personal communication, 2025).

Institutional collaboration platforms are instrumental in mitigating informational and regulatory barriers to the industrial scaling of chemical recycling. These structures facilitate the diffusion of critical knowledge across the value chain. Associations are crucial for establishing the necessary pre-competitive technical and regulatory frameworks. Groups like "Chemical Recycling Europe" and the "European Coalition for Chemical Recycling" work to develop clear, uniform definitions and scope for these technologies (Chemical Recycling Europe, n.d., European Coalition for Chemical Recycling, n.d.). This effort is critical for securing regulatory alignment and fostering investment confidence. Additionally, these associations communicate their stand on chemical recycling in high-profile position papers and are key in advocating for methodologies such as the Mass Balance approach (CEFIC, 2022a, VCI & Plastics Europe, 2022).

Funded by the European Union
Funded by UK Research and Innovation
Funded by the Ministry of Science and Technology of P.R. China

Beyond policy, platforms serve as formal mechanisms for technical knowledge transfer and coordination among diverse stakeholders. These platforms systematically gather experts from across the entire system—including waste management, technology providers, and petrochemical users—to exchange non-competitive technical data and best practices related to process optimization, feedstock preparation, and the quality assurance of pyrolysis oil. Specific national initiatives, such as the Netherlands' "Acceleration Table on Chemical Recycling" and the broader "Plastic Table," exemplify high-level platforms dedicated to National Deployment Coordination. These tables bring together industry, government, and civil society to coordinate strategic actions, share regulatory insights, and formulate collective policy recommendations necessary for accelerating domestic deployment and securing crucial investment (Participant 4, personal communication, 2025; VTCR, 2023; THINKTANK Industrielle Ressourcenstrategien, n.d.; IN4CLIMATE.NRW, 2021).

In summary, development of new plastic pyrolysis technologies is often led by small, specialized firms that partner with larger petrochemical companies to access established value chains, gain support, and tailor products. Despite being mature, the process requires ongoing R&D due to technological uncertainty, but scaling is hampered by the fragmentation of project-specific collaborations and a reluctance to share operational knowledge. Industry growth depends on institutional platforms and multi-stakeholder consortia to coordinate the value chain, accelerate knowledge diffusion, and establish unified regulatory frameworks.

4.4 Financial and human capital

Investment constraints remain a significant barrier to the expansion of chemical recycling. Industry actors are actively seeking partners and public co-financing to support plant construction. A notable investment holdback has emerged: despite earlier declarations of strong commitment, such as the EUR 8 billion investment intention projected by Plastics Europe and CEFIC in 2021–2022, current developments suggest a more cautious or delayed investment posture, reflecting growing frustration with uncertain market and policy conditions (Participant 6, personal communication, 2025).

The limited availability of government subsidies and public-risk sharing mechanisms substantially complicates project financing, particularly within the current crisis in the European chemical sector, where new projects must demonstrate clear financial viability to attract capital (Participant 3, personal communication, 2025). The EU Innovation Fund is one of the principal public funding mechanisms at the EU level supporting chemical-recycling projects in Europe, with examples such as LyondellBasell Industries receiving around €40 million (Santos, 2024), and GreenDot Advanced Recycling being selected for a large-scale integrated pre-treatment and chemical-recycling plant for mixed plastic waste (European Commission, 2025).

Chemical recycling companies generally pursue hybrid financing models that combine equity and debt instruments. Funding depends on cross-actor collaboration and the ability to leverage demand from downstream brand owners. End-user participation, either through offtake agreements or direct equity contributions, can play a critical role in enhancing the bankability of early-stage projects (Participant 6, personal communication, 2025). Moreover, mobilisation of equity from a diversified investor base adds further strength. A compelling example of this systemic integration is Xycle B.V. A consortium comprising industrial and financial partners including Dow Inc., ING Bank N.V., Invest-NL, Vopak N.V. and Polestar Capital secured hybrid funding (equity from upstream and downstream actors and senior debt) to build a flagship chemical-recycling facility in the Port of Rotterdam (Port of Rotterdam, 2025).

A challenge to securing investments, however, is the lack of "Rechtssicherheit" (legal certainty). Multiple legislative changes are expected to affect the policy landscape of chemical recycling, including the Omnibus

Funded by the European Union
Funded by UK Research and Innovation
Funded by the Ministry of Science and Technology of P.R. China

procedures and the adoption of the Single Use Plastics Directive, introducing rules for calculating, verifying and reporting recycled content in single-use plastic (SUP) beverage bottles. These rules will include mass balance. Participant 6 stated that "only when this is through do we know what we are getting into" (personal communication, 2025). This suggests that the lack of clarity in regulatory conditions is a major barrier to investment, regardless of specific financial support measures.

Regarding the requisite expertise for technological development, experts indicate that many chemical recycling startups face challenges due to a critical shortage of experienced chemical engineers needed to operate complex plants (Participant 2, personal communication, 2025; Lee et al., 2021). This highlights the vital role of collaborations with established chemical companies (see Section 4.3) in providing technical assistance, given their deep understanding of complex chemical processes (Participant 2, personal communication, 2025). It can, however, be observed and concluded that a lack of fundamental technical knowledge is not a primary barrier to pyrolysis technology development, provided that effective cooperation along the value chain is in place.

In summary, the expansion of chemical recycling faces significant barriers due to investment constraints and a cautious investment posture, stemming from uncertain market and policy conditions as well as limited availability of government subsidies. Companies typically pursue hybrid financing models, which rely heavily on cross-actor collaboration and involvement of downstream brand owners through offtake agreements or direct equity contributions (e.g., the Xycle B.V. consortium). Furthermore, chemical recycling startups struggle with a shortage of experienced chemical engineers. This challenge is best overcome through partnerships with established chemical companies that can provide the necessary expertise.

4.5 Feedstock availability

The plastic waste feedstock is a central determinant for the successful upscaling of pyrolysis technology, with its accessibility, quality, and price being critical parameters. According to industry experts, sufficient volumes of suitable plastic waste feedstock are currently inaccessible to key market participants (Participant 3, personal communication, 2025; Stallkamp et al., 2024).

Beyond the required quantities, feedstock quality is a primary concern for chemical recycling due to its significant impact on the resultant pyrolysis oil quality. These constraints are compounded by the fact that the engagement of waste management companies in the nascent chemical recycling value chain has thus far been limited, which restricts the efficient sourcing and quality control of the necessary feedstocks (Participant 2, personal communication, 2025; Stallkamp et al., 2024).

The existing plastic waste infrastructure is primarily tailored to the mechanical recycling value chain, which must be preserved. Chemical recycling is fundamentally viewed as complementary to mechanical recycling; fractions suitable for mechanical recycling should preferentially utilize that pathway, as its life-cycle energy consumption is significantly lower than that of pyrolysis (Official Journal of the European Union, 2008; Participant 3, personal communication, 2025).

Therefore, the upscaling of chemical recycling necessitates making new and additional volumes of plastic waste accessible for recycling. These targeted streams are currently directed toward waste incineration plants or landfills. The key challenge is routing these volumes toward chemical recycling, which often requires different waste handling and pre-treatment than is currently applied for incineration and landfilling. However, interests diverge: chemical parks demand high-quality feedstock, whereas waste incinerators focus on the calorific value

Funded by the European Union
Funded by UK Research and Innovation
Funded by the Ministry of Science and Technology of P.R. China

of plastic waste (Participant 1, personal communication, 2025). Additionally, reject streams from mechanical recycling processes are highly suitable for chemical recycling, as they are already pre-treated (see Section 3). Making them available for chemical recycling also requires the establishment of new handling routines.

Achieving the required feedstock volumes and qualities demands investments and improvements in the waste management sector. Waste requires more thorough sorting and cleaning, while maintaining a clear separation between fractions destined for mechanical and chemical recycling. The involvement of multiple actors in the waste management chain contributes to the feedstock cost, exacerbating the cost gap between pyrolysis oil and conventional fossil naphtha (see also Section 4.6).

Access to feedstock with the proper quality and volume as well as at acceptable costs remains hence one of the most critical barriers to scaling chemical recycling. This challenge is further exacerbated by the limited engagement of waste management companies in the value chain. Without their deeper participation, improvements in sorting, pre-treatment, and material traceability remain constrained. The case of REMONDIS – which is positioned not merely as a logistics or waste-supply provider but as an equal strategic partner in a partnership with Neste – showcases the feasibility of achieving such deeper participation for enhancing feedstock quality and reliability (Neste, 2019).

In addition to waste management improvements, the logistics of plastic waste feedstock must be optimized. When planning a pyrolysis facility, the decision between a decentralized location (near waste sources) and centralized integration within an existing chemical park is crucial. Experts suggest that as long as pyrolysis oil is not directly usable in crackers (without upgrading), locating plants near waste sources is preferable. The logistics of shipping waste differ fundamentally from shipping oil; leveraging existing, well-developed logistic corridors (e.g., channels, major transport routes) is key for cost-effective material transport over distances up to 500 km in regions like the Netherlands, Germany, and France (Participant 2, personal communication, 2025).

A challenge arises from the mismatch between waste generation and waste processing capacity of EU member states, necessitating the cross-border movement of waste as a raw material. The trade and transport of plastic waste are complex, particularly concerning the need to ensure a transparent and credible supply chain. Defining the legal transition point—when waste ceases to be waste and becomes an industrial pre-product—is critical (Participant 5, personal communication, 2025). Furthermore, under the German Federal Immission Control Act (BImSchG), pyrolysis plants are classified as waste treatment facilities. There is a significant need for regulatory clarification on when pyrolysis oil loses its waste status and is considered a product, as chemical production plants are typically not permitted to accept waste (Participant 5, personal communication, 2025). The ambiguity regarding the processes' formal recognition and the high threshold established by concurrent stringent regulatory and compliance standards is impeding the upscaling of chemical recycling (Kubiczek et al., 2023). Experts call for pragmatic approaches to define and document this transition from waste to raw material status (Participant 3, personal communication, 2025).

Addressing the challenges surrounding plastic waste feedstock and its corresponding infrastructure requires a clear definition of roles and responsibilities among various value chain actors. Key players include the waste management sector, recycling companies (both mechanical and chemical), and large chemical companies (with financial strength, know-how, and the ability to connect smaller actors). Effective coordination is crucial, as better-sorted input waste directly translates to higher yields and quality. But, as chemical recycling establishes a completely new value chain—linking waste management to chemical companies—responsibilities remain unclear.

Funded by the European Union
Funded by UK Research and Innovation
Funded by the Ministry of Science and Technology of P.R. China

Moreover, currently, conflicts exist between stakeholder groups regarding the most suitable recycling method for specific materials and the assignment of responsibility. Illustrative examples of these disputes highlight the inherent tension between petrochemical companies and the feedstock market: These companies require relevant volumes of pyrolysis oil as feedstock for their high-capacity steam crackers (see Section 3) while simultaneously demanding high quality waste that necessitates minimal post-processing (see Section 4.2). Crucially, due to the currently high production costs of pyrolysis oil, their willingness to pay high prices for waste purchasing is limited (see Section 4.6). Conversely, mechanical recyclers fear competition over clean and well-sorted waste fractions. Since waste streams suitable for mechanical recycling are also particularly attractive for chemical recycling (owing to better output yields), mechanical recyclers advance the argument that chemical recycling jeopardizes their established business area. These disputes and the resulting organizational friction impede efficient collaboration and slow down the scaling of chemical recycling. A clear framework for collaboration and the assignment of responsibilities is essential to overcome these challenges (Participant 1, personal communication, 2025; Participant 3, personal communication, 2025).

In summary, the upscaling of pyrolysis is constrained by the inaccessibility of sufficient volumes of high-quality plastic waste feedstock, which is currently channelled to incineration or landfilling. Achieving the necessary feedstock quality and volume requires substantial investments in waste management for better sorting and cleaning, alongside clear separation from fractions destined for mechanical recycling. Overcoming these barriers demands deeper engagement from waste management companies, logistical optimization, and the establishment of a clear organizational framework defining roles and responsibilities across the emerging value chain.

4.6 Market formation and business models

The demand for chemical recyclates is driven by a mix of market segment needs, the technical feasibility of incorporating recycled content into specific products, and increasingly, by regulatory mandates. High-quality and sensitive markets (e.g., food packaging, automotive industry) often require advanced recycling solutions to avoid quality compromises (Participant 2, personal communication, 2025). Increasing consumer awareness, coupled with sustainability commitments from global Consumer Packaged Goods (CPG) companies, packaging manufacturers, and retailers, is fuelling the growing demand for recycled polymers (Saxena, 2025).

Today, the market for chemical recyclates is still in its nascent stage. In this stage, the market is mostly established through bilateral cooperation (Participant 1, personal communication, 2025; Participant 6, personal communication, 2025). These close end-to-end cooperation across the value chain is highlighted as enabler for increasing recycling of plastics, as these partnerships secure a consistent feedstock supply and demand (Saxena, 2025; Kloo et al., 2024). For example, the case of the packaging manufacturer SüdPack's investment in recycling companies illustrates a proactive downstream strategy, whereby end users invest directly in chemical recycling capacity to ensure supply security and compliance with emerging recycled-content regulations. Original Equipment Manufacturers (OEMs) and brand owners (e.g., BMW) possess significant leverage to orchestrate and shape value chains by setting stringent requirements for price, performance, and safety. Their influence serves as a catalyst for collaboration, innovation, and continuous improvement among value-chain partners (Participant 8, personal communication, 2025).

The development of a more open commodity market largely depends on the marketing strategies of brand owners (Participant 2, personal communication, 2025), the availability of capacities, and financing for investments. Marketing strategies, capacities and financing are currently lacking (Participant 3, personal communication, 2025; Participant 6, personal communication, 2025). The engagement of end users and brand

Funded by the European Union
Funded by UK Research and Innovation
Funded by the Ministry of Science and Technology of P.R. China

owners is currently limited. Despite growing awareness of circular economy principles, there remain few institutionalised mechanisms or external pressures that incentivise brands to integrate chemically recycled products at scale. These actors require clear regulatory and market frameworks that define how their contributions generate measurable value along the supply chain, and how such efforts are formally recognised and converted into tangible strategic or economic benefits (Participant 2, personal communication, 2025; Participant 3, personal communication, 2025).

While sustainability is within the interest of customers, the market is ruled by costs. Participant 2 raised scepticism about whether this prioritisation will change (personal communication, 2025). While current demand for pyrolysis oil is high and extends beyond the packaging industry, "no one is currently buying." (Participant 1, personal communication, 2025; Participant 3, personal communication, 2025). The lack of purchases is due to the high costs of pyrolysis oil, which is not competitive with virgin, nor mechanically recycled feedstock (Participant 2, personal communication, 2025; Participant 6, personal communication, 2025; Goyal, 2023; VDI ZRE, 2023).

The commercial upscaling of plastic waste pyrolysis is fundamentally impeded by a significant cost disparity relative to conventional virgin polymer production. While established steam cracking benefits from decades of optimization, depreciation, and inexpensive, high-quality fossil feedstock (representing approximately 70% of its cost), the large-scale implementation of pyrolysis is perceived as a high-risk venture, requiring a 15-20 year development pathway to realize the necessary economies of scale (Zelt et al., 2025). Critically, the elevated price of pyrolysis oil is heavily influenced by the high cost of waste inputs, directly reducing its competitiveness relative to virgin feedstock.

The total cost of cleaned pyrolysis oil is estimated at approximately 2000€/t, compared to 500-700 €/t for naphtha. This high figure is structurally divided: one-quarter is allocated to intensive sorting and cleaning of heterogeneous waste feedstock, a process that mitigates impurities that otherwise create disposal and oil clean-up costs, thus offsetting the traditional waste 'gate fee' value. Another quarter is dedicated to the necessary upgrading of the crude pyrolysis oil to remove contaminants and meet the specifications required for safe integration into existing steam cracker infrastructure (Participant 2, personal communication, 2025).

The remaining half of the cost is attributed to the unoptimized pyrolysis installation itself. This cost is exacerbated by the necessity for small-scale logistics (which can account for up to one-quarter of the total cost) for typical 10-20 kt plants. Furthermore, while upgrading can occur in existing refineries, this often results in valuable molecules being diverted into fuels, negatively impacting mass balance credit for recycled content, a critical factor in a market currently unwilling to pay a sufficient voluntary premium for recycled material (Participant 2, personal communication, 2025).

Market competition between mechanical and chemical recyclers should be avoided, ensuring that chemical recycling makes use of the waste streams that are currently unusable for mechanical recyclers. With the upscaling of chemical recycling, plastic waste as a feedstock may become a valuable and potentially scarce resource, leading to competition among companies for its availability and associated high prices. In the context of the proposed PPWR policy implementation (see Section 4.8), experts note that large companies are already securing considerable plastic waste volumes for 2030 and beyond to achieve their recycling targets. This could potentially disadvantage competitors, particularly smaller firms, in achieving their targets. Given that pyrolysis technology can potentially process higher-quality waste streams currently utilised by mechanical recycling, and due to the large volumes of pyrolysis oil needed for full-capacity steam cracker operation, there is a risk that all available plastic waste streams could be secured by chemical recycling actors, thereby undermining mechanical

Funded by the European Union

Funded by UK Research and Innovation

Funded by the Ministry of Science and Technology of P.R. China

recycling (Participant 7, personal communication, 2025). This outcome is undesirable, as mechanical recycling should remain the preferred option whenever technically feasible (Official Journal of the European Union, 2008). This anticipated market competition is the primary reason why mechanical recyclers often oppose chemical recycling, despite its potential to utilise their reject waste fractions. Facing economic challenges, illustrated by recent closures of mechanical recycling facilities in the Netherlands (Participant 4, personal communication, 2025), these established actors fear a loss of market share. This situation creates blockages that necessitate their stronger involvement in the process (Participant 1, personal communication, 2025).

Challenges also exist in spreading market signals and incentives along the value chain due to established actors (e.g., mechanical recyclers, "Frosch"-like brands) who are invested in mechanical recycling and resisting chemical recycling (Participant 1, personal communication, 2025). These actors make use of their market position and influence to protect their existing investments and supply chains. Thereby, these actors function as structural barriers against the adoption and scaling of chemical recycling.

Besides the formation of markets for chemical recyclates, upscaling pyrolysis for chemical recycling requires that all actors along the value chain (see Section 4.1) identify viable business models. The following types of business models and collaboration forms were identified in the case study countries (Table 2 in Section 4.1): business-to-business (B2B) of pyrolysis oil, B2B of recycled plastics, licensing, investment in technology providers, and strategic partnership, and Joint Venture (JV). Key features of these business models and examples are provided in Annex 1. While OEMs and brand owners are ascribed to be the drivers for the value chain, these companies struggle to monetise their contribution to chemical recycling due to a lack of clear mechanisms or sufficient external pressure to recognize the "benefit" (Participant 3, personal communication, 2025).

To create the enabling conditions for market formation, business models and trigger investment, regulatory mandates and regulatory certainty are required (Participant 2, personal communication, 2025; Participant 3, personal communication, 2025; Participant 6, personal communication, 2025; Stallkamp et al., 2024). More information on the regulatory landscape is presented in the sub-section on "Political Framework Conditions and Targets" below.

In summary, the emerging market for chemical recyclates is primarily driven by the demand from high-quality sectors (like food packaging and automotive), increasing consumer awareness, and mandatory regulations, often facilitated through initial bilateral cooperation and end-to-end partnerships that secure feedstock supply and demand. However, a clear, scalable business model is not yet established, and it remains uncertain how engaged actors can consistently monetise their contributions to chemical recycling. The uncertainty is increased by a lack of legal certainty (*Rechtssicherheit in German*) regarding impending legislative changes and the regulatory classification of processes like pyrolysis, directly blocking large-scale investments. Furthermore, the high cost of pyrolysis oil makes it uncompetitive with virgin or mechanically recycled feedstock, and the lack of robust marketing strategies, capacity, and financing is hindering the transition to an open commodity market. The necessary scaling is structurally impeded by resistance from established actors (e.g., mechanical recyclers and brands invested in mechanical recycling), who fear losing feedstock access and market share, despite chemical recycling's potential to process unusable waste. The market's development and the incentivisation of key actors like Original Equipment Manufacturers (OEMs) and brand owners, who have the leverage to shape value chains, depend heavily on the introduction of clear regulatory mandates and market frameworks that quantify and reward their contributions to chemical recycling.

Funded by the European Union
Funded by UK Research and Innovation
Funded by the Ministry of Science and Technology of P.R. China

4.7 Legitimation

While consumer awareness may be driving the demand for recyclates, Zepa et al. (2024) come to the conclusion that the legitimacy of chemical recycling is actually lacking within public discourse. Some interviewees stated that chemical recycling would currently be perceived as equal to waste burning, which would harm society's acceptance (Participant 2, personal communication, 2025; Participant 3, personal communication, 2025), while another interviewee stated that attitudes from civil society and NGOs towards chemical recycling are mixed, with significant mistrust from some associations (Participant 1, personal communication, 2025; VDI ZRE, 2023). Even though the contribution of chemical recycling to sustainability goals may be questioned by civil society and NGOs, OEMs/brand owners' sustainability goals and demand for recycled content are perceived to be the primary drivers for moving the entire value chain (Participant 6, personal communication, 2025; Saxena, 2025). CEFIC, being one of the most prominent lobbying associations in the EU according to Fagan-Watson et al. (2015), acts as an enabler for accepting chemical recycling as an integral solution for managing plastics waste (CEFIC 2022b).

Mass balance accounting is seen as a measure to increase transparency and accountability by transparently tracking recycled content, and thereby creating public "credibility" (Participant 1, personal communication, 2025; Participant 3, personal communication, 2025). The mass balance process implies a calculation of the recycled content of plastics in products (Cefic 2023), transparently integrating renewable and recycled plastics feedstock, and ensuring the tracking of feedstock sources throughout the production chain (Galan-Sanchez et al., 2023). To enable an increase in recyclate content over time, clear thresholds and benchmarks are required (Participant 1, personal communication, 2025; CEFIC 2022b).

In summary, despite consumer interest and the market demand for recycled content, chemical recycling suffers from a lack of legitimacy and mistrust within public discourse, particularly among civil society and NGOs. To overcome this scepticism and establish "credibility", the industry views the implementation of mass balance accounting as a critical measure. This system is intended to transparently track and calculate the recycled content in products, supporting sustainability goals and demonstrating accountability.

4.8 Political framework conditions and targets

Pressure to discover and implement circular solutions is created by a range of policies including the EU Commission's proposal of a 90% CO_2 reduction target for 2040 (in comparison to 1990) (Participant 3, personal communication, 2025; VDI ZRE, 2023). Policies that specifically address market segments have been highlighted by our interviewees to be the most successful in attracting investments into chemical recycling. A range of policies exist that shape the recycling landscape (please find the overview in Annex 2). The Packaging and Packaging Waste Regulation (PPWR) and the Directive on End-of-Life Vehicles (ELV) are crucial as they establish mandatory recycling targets in specific market segments (Participant 2, personal communication, 2025; Participant 6, personal communication, 2025). In 2022, packaging was the largest market segment creating 39% of plastics demand in Europe and the automotive industry created another 8% of plastics demand (PlasticsEurope, 2023). These policies create a predictable demand for circular plastics and encourage downstream investment.

Funded by the European Union
Funded by UK Research and Innovation
Funded by the Ministry of Science and Technology of P.R. China

The PPWR sets targets that will force the inclusion of recycling content, which is seen as a powerful driver, as it is perceived to create demand even if recycled material is currently more expensive. While chemical recycling is not clearly stated as the technology to meet recycling targets, the regulation includes targets on contact-sensitive plastics materials for food contact with high quality requirements that mechanical recycling struggles to meet. The demand for chemical recyclates is expected to be scaled by its ability to be considered for such sensitive applications (like food and pharma contact) (Participant 2, personal communication, 2025; Participant 6, personal communication, 2025).

Similarly, the ELV Directive lays down recycled content quotas. Automotive applications will create a demand for high quality recyclates. Nevertheless, one interviewee questioned whether the addressed market segments are significant enough in size to create enough demand for the upscaling of the pyrolysis technology (Participant 2, personal communication, 2025).

The Waste Framework Directive also plays an important role in the policy landscape enabling chemical recycling. It introduces the Waste Hierarchy to guide waste management (VDI ZRE, 2023). Chemical recycling, explicitly mentioned here are gasification and pyrolysis, are valued as a form of "recovery" and "recycling" depending on the use of outputs. Consequently, if chemical recycling allows for "outlets" for difficult-to-recycle plastics (especially for sensitive applications like food contact, as mentioned in the context of PPWR), then scaling will not be a problem. This suggests that fitting chemical recycling appropriately into the hierarchy (e.g., as similar to mechanical recycling) is key (Participant 2, personal communication, 2025; Participant 3, personal communication, 2025).

Nevertheless, concerns are voiced concerning the date that targets for plastics recycling take effect. For example, the targets of the PPWR are to come into force in the year 2030. Until 2030 demand is expected to remain low, while the demand is expected to steeply increase by the date of target enforcement. This may lead to an undersupply in 2030, and investments in chemical recycling to remain insufficient to build up the infrastructure to meet the targets in 2030 (Participant 7, personal communication, 2025). The Landfill Directive, which allows landfilling of waste suitable for recycling and other forms of recovery until 2030 may also undermine early investments in chemical recycling (Participant 7, personal communication, 2025).

While these just mentioned policies' purpose is to stimulate demand for recycled plastics, it is questioned how long such measures would need to be continued and how much they need to be extended if the underlying economics do not change. This points to a fundamental issue of the overall approach to establishing an enabling policy landscape: broader, systemic policy changes, like a fossil tax, may be more effective for long-term investment support than just targeted measures (Participant 1, personal communication, 2025).

In summary, policies setting mandatory recycling targets in market segments (e.g. for sensitive food-contact plastics, where mechanical recycling is technically limited) are key to creating predictable demand for high-quality recyclates. This is necessary to overcome current economic barriers where chemically recycled material remains more expensive compared to virgin feedstock. The Packaging and Packaging Waste Regulation (PPWR) and the Directive on End-of-Life Vehicles (ELV) are crucial policies in that regard. However, the delayed effective date of targets (e.g., PPWR in 2030) creates significant concerns. The lag may inhibit the necessary infrastructure build-up, leading to an eventual undersupply of recyclates. As a complement or alternative to segment-specific mandates, broader systemic measures like a fossil tax could be introduced. This approach directly addresses the underlying cost differential, targeting the economics of virgin materials and recyclates instead of particular market segments.

Funded by the European Union
Funded by UK Research and Innovation
Funded by the Ministry of Science and Technology of P.R. China

5 Policy gaps and recommendations

Pyrolysis for chemical recycling demonstrates a significant technical potential which is mostly dependent on future available plastic waste volumes. While the technology for the pyrolysis of plastic waste is generally considered established, several technical aspects of the pyrolysis process require further optimization and competing designs to address technical challenges exist. The industry currently requires **ongoing and comprehensive experimentation** and faces uncertainty regarding which specific chemical recycling technologies will ultimately prevail. Within the current crisis in the European chemical sector, where new projects must demonstrate clear financial viability to attract capital, **public risk-sharing mechanisms** could be beneficial to facilitate investments under uncertain conditions.

The key bottlenecks for upscaling, however, no longer reside in the technological domain, but rather in the broader system. **Sufficient volumes of high-quality plastic waste feedstock are currently inaccessible** to market participants. Instead, plastic waste feedstock is currently channelled to incineration or landfilling. Achieving the necessary feedstock quality and volume requires substantial investments in waste management for better sorting and cleaning, alongside clear separation from fractions destined for mechanical recycling. Overcoming these barriers demands deeper engagement from waste management companies and recyclers, while partly diverging interests impede collaboration. A **clear organizational framework defining governance and mandates** across the (emerging) value chain is required, that also defines and documents the transition from waste to raw material status. Market competition between mechanical and chemical recyclers should be avoided, ensuring that chemical recycling makes use of the waste streams that are currently unusable for mechanical recyclers.

Today, the market for chemical recyclates is still in its nascent stage. Original Equipment Manufacturers (OEMs) and brand owners are perceived to be the primary drivers for moving the entire value chain. However, **there are few incentives for these actors to integrate chemically recycled products at scale**. While sustainability is within the interest of customers, the market is ruled by costs. The significant cost disparity relative to conventional virgin polymer production renders pyrolysis oil uncompetitive with virgin and mechanically recycled feedstock. Clear regulatory and market frameworks are thus required that formally recognise and convert integration of chemical recycling into **tangible strategic or economic benefits**. For specific market segments and volumes, such clear benefits are created by policies that establish mandatory recycling targets in these market segments such as the Packaging and Packaging Waste Regulation (PPWR) and the Directive on End-of-Life Vehicles (ELV). While these policies stimulate demand for recycled plastics, further, complementary **mandatory recycled content quotas** for other market segments, consideration of recycling contents in **public procurement** or **broader, systemic policy changes, like a fossil tax or extended producer responsibility (EPR) schemes**, would be required to establish and secure markets for chemical recycling in the long-term.

Another barrier to securing investments and upscaling is the **lack of legal certainty**, including unclear definitions and procedures. Moreover, multiple legislative changes are expected to affect the policy landscape of chemical recycling. The industry needs a **predictable and trustworthy policy environment** with clear, stable, and consistently applied legal frameworks.

Legitimacy of chemical recycling is currently lacking within public discourse. Policy should thus collaborate with industry and trusted third-party actors for the creation of regulations and procedures that **increase transparency and accountability**. The mass balance approach is a first step in that direction.

Funded by the European Union

Funded by UK Research and Innovation

Funded by the Ministry of Science and Technology of P.R. China

ANNEX

Annex 1: Business models along the value chain of Chemical Recycling

Business models or cooperation	Key Features	Examples
B2B of pyrolysis oil	The company sells pyrolysis oil to petrochemical producers under a purchase agreement.	BASF and ARCUS signed agreement on the procurement of pyrolysis oil from mixed plastic waste. BASF will use the oil in its production plants as a feedstock for the production of Ccycled™ products. Agreement foresees take-up of up to 100,000 tons of pyrolysis oil per year. [1]
B2B of recycled plastics	The company sells recycled plastics to end users under a purchase agreement.	SABIC supplies Unilever with certified circular plastics for use in Unilever's packaging of specific products.[2] LyondellBasell and Audi conducted a pilot project using chemically recycled plastics to produce seatbelt-buckle covers.[3]
Licensing	A technology provider granting rights (via license contract) to third parties to implement, operate, or commercialise its chemical recycling process.	BioBTX's major competence lies in its proprietary Integrated Cascading Catalytic Pyrolysis (ICCP) and markets licensing as one key path for technology. [4]
Investment in technology providers	Actors from elsewhere in the value chain invest equity, joint development funds, or acquisitions in chemical recycling technology firms.	SÜDPACK, a manufacturer of flexible films, invested significantly and now holds a majority stake in CARBOLIQ, thereby securing direct access to chemical recycling capacity.[5] BASF invested €16 million into Pyrum Innovations AG, which is specialized in the pyrolysis of end-of-life tires, to support the expansion of Pyrum's pyrolysis plant in Dillingen[6] Sulzer, a global leader of industrial engineering, acquired a strategic stake in Fuenix Ecogy in 2023 to enable offers of fully integrated plastic recycling lines.[7] Shell invested in BlueAlp, a chemical recycling technology innovator, to develop and deploy its chemical recycling

[1] https://www.basf.com/global/en/media/news-releases/2022/09/p-22-328
[2] https://www.unilever.com/news/news-search/2022/were-making-the-switch-to-recycled-food-packaging-heres-how
[3] https://www.lyondellbasell.com/en/who-we-are/updates-events/products--technology-news/lyondellbasell-and-audi-create-first-automotive-plastic-parts-from-mixed-automotive-plastic-waste/
[4] https://biobtx.com/technology/
[5] https://www.packagingstrategies.com/articles/103484-suedpack-and-clean-cycle-investments-make-investment-in-chemical-recycling-technology-carbolq
[6] https://www.ellenmacarthurfoundation.org/global-commitment-2021/signatory-reports/rmpncp/basf
[7] https://www.sulzer.com/en/shared/news/230217-sulzer-acquires-stake-in-fuenix-ecogy
Fuenix filed for bankruptcy in 2025.

Funded by the European Union
Funded by UK Research and Innovation
Funded by the Ministry of Science and Technology of P.R. China

		technology.[8] Dow, which invested in Xycle, a Rotterdam-based chemical recycling company, will be an off-taker of Xycle's circular feedstock. [9] UK recycler Circtec Group is building the world's biggest tyre recycling plant in Delfzijl. It acquired a Dutch tyre collector company Granuband.[10]
Strategic partnership	Collaborations in which actors align their capabilities without necessarily merging or forming full joint ventures.	Plastic Energy, a leading company in chemical recycling, and INEOS Olefins & Polymers signed agreement to construct a chemical recycling plant in Cologne, Germany.[11] Evonik, a specialty chemicals leader, and REMONDIS, a major recycling and waste services company, have partnered to develop a circular value chain for polyurethane foams: REMONDIS sources and supplies end-of-life mattress foam of consistent quality, while Evonik applies its hydrolysis chemical recycling process.[12]
Joint Venture (JV)	A formalised cooperative arrangement in which two or more independent actors jointly own, finance, and operate a defined segment of the value chain, or collectively integrate different segments	Plastic Energy operates a JV advanced recycling plant with SABIC in Geleen, Netherland. [13] OMV, an integrated energy and chemical company, and Interzero, a leading innovator in plastics recycling with Europe's largest sorting capacity, established a JV to construct and operate a large-scale waste-sorting facility in Germany, designed to secure high-quality feedstock for OMV's chemical recycling operations.[14] LyondellBasell, one of the world's largest polyolefin producers, and 23 Oaks Investments, a Germany-based investment firm specialising in circular economy ventures, formed a joint venture called Source One Plastics, which will sort and recycle difficult plastics waste and supply a major share of the feedstock for LyondellBasell's upcoming chemical recycling facility in Germany.[15]

[8] https://www.shell.com/business-customers/chemicals/media-releases/2021-media-releases/shell-invests-in-plastic-waste-to-chemicals-technology-company-bluealp.html
[9] https://corporate.dow.com/en-us/news/press-releases/dow-boosts-access-to-circular-feedstocks-with-strategic-investment.html
[10] https://recyclinginternational.com/business/innovation/circtec-counting-down-to-opening-of-tyre-pyrolysis-hub/61523/
[11] https://www.ineos.com/news/shared-news/ineos-signs-agreement-with-plastic-energy-for-its-largest-plant-to-produce-100000-tonnes-of-raw-materials-from-plastic-waste/
[12] https://www.evonik.com/en/news/press-releases/2023/09/evonik-cooperates-with-remondis-on-sustainable-polyurethane-recy.html
[13] https://plasticenergy.com/plastic-energy-produces-first-recycled-oil-at-dutch-advanced-recycling-plant/
[14] https://www.omv.com/en/media/press-releases/2023/omv-and-interzero-establish-joint-venture-to-build-and-operate-europe-s-largest-sorting-facility-for-chemical-recycling
[15] https://www.lyondellbasell.com/en/who-we-are/updates-events/products--technology-news/source-one-plastics-starts-operations-at-plastic-waste-sorting-and-recycling-facility/

Funded by the European Union

Funded by UK Research and Innovation

Funded by the Ministry of Science and Technology of P.R. China

Annex 2: Policy Landscape for Chemical Recycling

Table A2-1: European Policy Landscape

Year	Policy	Description
2008	Waste Framework Directive (WFD)	Establishes Extended Producer Responsibility (EPR) that holds producers financially accountable for a product's life cycle. Moreover, it introduces the Waste Hierarchy to guide waste management: gasification and pyrolysis are understood as a form of "recovery" and as "recycling" depending on the use of outputs.
1996	Packaging and Packaging Waste Regulation (PPWR)	Its purpose is to minimise packaging waste and reduce the use of raw materials. It aims to foster a circular, sustainable, and competitive economy. It implicitly recognises chemical recycling by highlighting the importance of "high-quality recycling" and requiring recycled materials of equivalent or higher quality than original. Chemical recycling is a technology with the potential to provide sufficient quantities of high-purity recycled material. It introduces recyclate targets By 1 January 2030: - 30% for contact-sensitive PET packaging - 10% for other contact-sensitive plastic packaging - 30% single-use plastics beverage bottles - 35% for other plastic packaging By 1 January 2040 - 50% for contact-sensitive PET packaging - 25% for other contact-sensitive plastic packaging - 65% for single-use plastic beverage bottles - 65% for other plastic packaging Furthermore, it builds on the EPR of the WFD by defining the EPR for the packaging and packaging waste segment and suggesting modulation of fees based on recycled content, durability, reparability, reusability and recyclability. The PPWR also requires the European Commission to define clear sustainability criteria for recycling technologies. This ensures that the recycling processes are environmentally sound and consistently produce high-quality recyclates, thereby preventing "greenwashing" and building a reliable market for recycled content.

Funded by the European Union
Funded by UK Research and Innovation
Funded by the Ministry of Science and Technology of P.R. China

2000	End-of-Life Vehicles Directive (ELV Directive)	Reuse and Recovery Target: By 2015, a minimum of 95% of a vehicle's weight must be reused or recovered. (Recovery includes recycling and energy recovery/incineration with energy generation). Reuse and Recycling Target: By 2015, a minimum of 85% of a vehicle's weight must be reused or recycled.
1999	Landfill Directive	It introduces restrictions on landfilling of waste that can be recycled or recovered for material or energy from 2030 onwards.

Table A2-2: Dutch Policy Landscape

Year	Policy	Description
2014	Packaging Management Decree (Besluit Beheer Verpakkingen)	Transposes the European PPWR into national law: Legally binding targets of recycling rate for plastic packaging 2025: 50%. 2030: 55%
2019	Dutch Plastic Pact (Plastic Pact NL)	Transposes the European PPWR into national law: Commitment by 2025: • Ensure 100% recyclability of single-use plastic products and packaging. • Achieve a 70% recycling rate for single-use plastics • Incorporate at least 35% recycled plastic into single-use products

Table A2-3: German Policy Landscape

Year	Policy	Description
2019	Packaging Act (Verpackungsgesetz)	Transposes the European PPWR into national law: Legally binding targets of recycling rate for plastic packaging 2025: 50%. 2030: 55% Commitment by 2025: • Ensure 100% recyclability of single-use plastic

Funded by the European Union
Funded by UK Research and Innovation
Funded by the Ministry of Science and Technology of P.R. China

		products and packaging. • Achieve a 70% recycling rate for single-use plastics • Incorporate at least 35% recycled plastic into single-use products
2012	Circular Economy Law (Kreislaufwirtschaftsgesetz)	Transposes the European WFD waste hierarchy into national law

Funded by the European Union

Funded by UK Research and Innovation

Funded by the Ministry of Science and Technology of P.R. China

Bibliography

Al-Salem, S. M., Antelava, A., Constantinou, A., Manos, G., & Dutta, A. (2017). A review on thermal and catalytic pyrolysis of plastic solid waste (PSW). Journal of Environmental Management, 197, 177–198. https://doi.org/10.1016/j.jenvman.2017.03.084

Bauer, F., Kulionis, V., Oberschelp, C., Pfister, S., Tilsted, J. P., Finkill, G. D., & Fjäll, S. (2022). Petrochemicals and climate change: Tracing globally growing emissions and key blind spots in a fossil-based industry. IMES/EESS report, 126, Lund University.

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., & Rickne, A. (2008). "Analyzing the functional dynamics of technological innovation systems: A scheme of analysis." Research Policy, 37(3), 407-429.

Chemical Recycling Europe. (n.d.). Retrieved November 6, 2025, from https://chemicalrecyclingeurope.eu/

Dai, L., Zhou, N., Lv, Y., Cheng, Y., Wang, Y., Liu, Y., Cobb, K., Chen, P., Lei, H., & Ruan, R. (2022). Pyrolysis technology for plastic waste recycling: A state-of-the-art review. Progress in Energy and Combustion Science, 93, 101021. https://doi.org/10.1016/j.pecs.2022.101021

Davidson, M. G., Furlong, R. A., & McManus, M. C. (2021). Developments in the life cycle assessment of chemical recycling of plastic waste–A review. Journal of Cleaner Production, 293, 126163.

European Chemical Industry Council (Cefic). (2022a). Chemical recycling: Enabling plastic waste to become a valuable resource. https://cefic.org/app/uploads/2024/05/Cefic-position-paper-on-Chemical-Recycling.pdf

European Chemical Industry Council (Cefic). (2022b). Chemical Recycling: Delivering recycled content to meet the EU's circular economy ambitions – the Single Use Plastics Directive Implementing Act and the Packaging and Packaging Waste Directive revision. Position paper. Retrieved November 6, 2025, from https://cefic.org/resources/cefic-position-paper-on-chemical-recycling-delivering-recycled-content-to-meet-the-eus-circular-economy-ambitions-the-single-use-plastics-directive-implementing-act-and-the-packagi/

European Chemical Industry Council (Cefic). (2023, January 10). The recognition of the Mass Balance Chain of Custody is key to accelerating chemical recycling and meeting the EU's climate and circularity targets. https://cefic.org/news/the-recognition-of-the-mass-balance-chain-of-custody-is-key-to-accelerating-chemical-recycling-and-meeting-the-eus-climate-and-circularity-targets

European Coalition for Chemical Recycling. (n.d.). Retrieved November 6, 2025, from https://www.coalition-chemical-recycling.eu/

European Commission. (2025). LARS: First European large-scale integrated pre-treatment and chemical recycling plant for mixed plastic waste to generate pyrolysis oil as an alternative raw material for fossil-based raw materials. https://ec.europa.eu/assets/cinea/project_fiches/innovation_fund/101191215.pdf

Funded by the European Union

Funded by UK Research and Innovation

Funded by the Ministry of Science and Technology of P.R. China

Evonik. (20.09.2023). Evonik cooperates with REMONDIS on sustainable polyurethane recycling. Retrieved November 21, 2025, from https://www.evonik.com/en/news/press-releases/2023/09/evonik-cooperates-with-remondis-on-sustainable-polyurethane-recy.html

Fagan-Watson, B., Elliott, B., & Watson, T. (2015). Lobbying by trade associations on EU climate policy. London University of Westminster. https://westminsterresearch.westminster.ac.uk/item/98xz3/lobbying-by-trade-associations-on-eu-climate-policy

Fraunhofer UMSICHT (Sulzbach-Rosenberg). (2025). Advanced and Chemical Recycling Facilities in Europe. Retrieved November 20, 2025, from https://websites.fraunhofer.de/suro1/crmap/chemrec_map_interactive_Online_Alt_Map.html

Galan-Sanchez, L., Dittrich, C., van Zijl, A., Housmans, T., Soliman, M., & Kuijpers, F. (2023). Chemical recycling of mixed plastic waste for the production of aromatics and olefins as monomers for circular polyolefins and polycarbonate. SABIC TRUCIRCLE™. Industrial Arene Chemistry, 4, 2143–2162. https://doi.org/10.1002/9783527827992.ch68

Goyal, J. (2023, May 14-15). Investing in new value creation: A sustainable transformation - Plastic recycling and circular economy. 12th GPCA Plastic Conference. Chemical Market Analytics by OPIS, Al Khobar, Saudi Arabia.

Hekkert, M.P., Suurs, R.A.A., Negro, S.O., Kuhlmann, S., & Smits, R.E.H.M. (2007). "Functions of innovation systems: A new approach for analysing technological change." Technological Forecasting and Social Change, 74(4), 413-432.

IN4climate.NRW (Hrsg.). (2020). Chemisches Kunststoffrecycling – Potenziale und Entwicklungsperspektiven. Ein Beitrag zur Defossilisierung der chemischen und kunststoffverarbeitenden Industrie in NRW. Ein Diskussionspapier der Arbeitsgruppe Circular Economy. https://www.energy4climate.nrw/fileadmin/Service/Publikationen/Ergebnisse_IN4climate.NRW/2020/in4climatenrw-diskussionspapier-chemisches-kunststoffrecycling-web.pdf

IN4climate.NRW (Hrsg.). (2021). Chemisches Recycling – Eine Einordnung. Positionspapier von IN4climate.NRW. https://www.energy4climate.nrw/fileadmin/Service/Publikationen/Ergebnisse_IN4climate.NRW/2021/in4climate.nrw-positionspapier-chemisches-recycling-de.pdf

Jacobsson, S., & Bergek, A. (2011). "Innovation system dynamics and sustainability transitions: Tensions and complementarities in the function approach." In: Energy Policy, 39(2), 1039–1049.

Jeswani, H., Krüger, C., Russ, M., Horlacher, M., Antony, F., Hann, S., & Azapagic, A. (2021). Life cycle environmental impacts of chemical recycling via pyrolysis of mixed plastic waste in comparison with mechanical recycling and energy recovery. Science of the Total Environment, 769, 144483.

Karlsruhe Institute of Technology, 2024 (unpublished). Waste composition analysis and use in different chemical recycling technologies as part of the research project Green Feedstock for a Sustainable Chemistry – Energiewende und Ressourceneffizienz im Kontext der dritten

Funded by the European Union
Funded by UK Research and Innovation
Funded by the Ministry of Science and Technology of P.R. China

Feedstock-Transformation der chemischen Industrie (GreenFeed).

Kivimaa, P., & Virkamäki, V. (2014). "Policy mixes, policy interplay and low carbon transitions: The case of passenger transport in Finland." Environmental Innovation and Societal Transitions, 12, 52–67.

Kloo, Y., Nilsson, L. J., & Palm, E. (2024). Reaching net-zero in the chemical industry - A study of roadmaps for industrial decarbonisation. Renewable and Sustainable Energy Transition, 5, 100075. https://doi.org/10.1016/j.rset.2023.100075

Kubiczek, J., Derej, W., Hadasik, B., & Matuszewska, A. (2023). Chemical recycling of plastic waste as a means to implement the circular economy model in the European Union. Journal of Cleaner Production, 406, 136951. https://doi.org/10.1016/j.jclepro.2023.136951

Lange, J. P., Kersten, S. R., De Meester, S., van Eijk, M. C., & Ragaert, K. (2024). Plastic recycling stripped naked–from circular product to circular industry with recycling cascade. ChemSusChem, 17(12), e202301320.

Lee, R. P., Tschoepe, M., & Voss, R. (2021). Perception of chemical recycling and its role in the transition towards a circular carbon economy: A case study in Germany. Waste Management, 125, 280–292. https://doi.org/10.1016/j.wasman.2021.02.041

Linnenkoper, K. (08.08.2025). Circtec counting down to opening of tyre pyrolysis hub. Retrieved November 21, 2025, from https://recyclinginternational.com/business/innovation/circtec-counting-down-to-opening-of-tyre-pyrolysis-hub/61523/

Markard, J., & Truffer, B. (2008). Technological innovation systems and the multi-level perspective: Towards an integrated framework. Research policy, 37(4), 596-615.

Neste. (2019, October 23). REMONDIS and Neste into partnership to develop chemical recycling of plastic waste. https://www.neste.com/news/remondis-and-neste-into-partnership-to-develop-chemical-recycling-of-plastic-waste

Official Journal of the European Union. (2008). Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008L0098

OMV. (31.10.2023). OMV and Interzero establish joint venture to build and operate Europe's largest sorting facility for chemical recycling. Retrieved November 21, 2025, from https://www.omv.com/en/media/press-releases/2023/omv-and-interzero-establish-joint-venture-to-build-and-operate-europe-s-largest-sorting-facility-for-chemical-recycling

Orozco, S., Lopez, G., Suarez, M. A., Artetxe, M., Alvarez, J., Bilbao, J., & Olazar, M. (2022). Oxidative fast pyrolysis of high-density polyethylene on a spent fluid catalytic cracking catalyst in a fountain confined conical spouted bed reactor. ACS Sustainable Chemistry & Engineering, 10 (48), 15791–15801. https://doi.org/10.1021/acssuschemeng.2c04552

Funded by the European Union
Funded by UK Research and Innovation
Funded by the Ministry of Science and Technology of P.R. China

PlasticsEurope (PEMRG). (2023, October). Distribution of plastic converters demand in Europe in 2022, by segment. https://www.statista.com/statistics/869554/plastics-converter-demand-european-union/

Port of Rotterdam. (2025, March 14). Financing for first plant of Rotterdam-based chemical recycling company Xycle. https://www.portofrotterdam.com/en/news-and-press-releases/financing-first-plant-rotterdam-based-chemical-recycling-company-xycle

Santos, B. (2024, January 03). LyondellBasell's chemical recycling project to receive 40 million in EU funds. https://www.plasticsnews.com/news/lyondellbasells-chemical-recycling-project-receive-eu40-million-eu-funds/

Saxena, S. (2025). Pyrolysis and beyond: Sustainable valorization of plastic waste. Applications in Energy and Combustion Science, 21, 100311. https://doi.org/10.1016/j.jaecs.2024.100311

Schade, A., Melzer, M., Zimmermann, S., Schwarz, T., Stoewe, K., & Kuhn, H. (2024). Plastic waste recycling – A chemical recycling perspective. ACS Sustainable Chemistry & Engineering, 12(33), 12270–12288. https://doi.org/10.1021/acssuschemeng.4c02551

Scholz, A., Kloo, Y., Theisen, S., Saurat, M., Schneider, C., Meisel, K., Röder, L., Dögnitz, N., Cyffka, K.-F., Stapf, D., & Reeves, A. (2025). Unsicherheiten überwinden, grüne Märkte erschließen: Kompass zur Defossilisierung der Petrochemie in Deutschland; Ergebnisse aus dem Forschungsprojekt "Green Feedstock for a Sustainable Chemistry." https://doi.org/10.48506/opus-8856

Stallkamp, C., Hennig, M., Volk, R., Stapf, D., & Schultmann, F. (2024). Pyrolysis of mixed engineering plastics: Economic challenges for automotive plastic waste. Waste Management, 176, 105–116. https://doi.org/10.1016/j.wasman.2024.01.035

Suedpack. (03.01.2024). SÜDPACK erweitert sein Engagement in CARBOLIQ. Retrieved November 21, 2025, from https://www.suedpack.com/de/suedpack-gruppe/news/detailansicht/suedpack-erweitert-sein-engagement-in-carboliq

Sulzer. (17.02.2023). Sulzer acquires stake in Fuenix Ecogy and completes portfolio for plastic waste reduction. Retrieved November 21, 2025, from https://www.sulzer.com/en/shared/news/230217-sulzer-acquires-stake-in-fuenix-ecogy

Tang KHD. An Overview of Circular Economy Approaches for Plastics. Recent Progress in Materials 2025; 7(3): 011; doi:10.21926/rpm.2503011.

THINKTANK Industrielle Ressourcenstrategien. (n.d.). Retrieved November 6, 2025, from https://www.thinktank-irs.de/

VDI Zentrum Ressourceneffizienz (VDI ZRE) (2023). Ökologische und ökonomische Bewertung des Ressourcenaufwands: Einsatz von rezyklierten Kunststoffen in Verpackungsmaterialien. https://www.ressource-deutschland.de/fileadmin/user_upload/1_Themen/h_Publikationen/Studien/VDI_ZRE_Studie_Recyclingkunststoffe_komplett_BF_C1.pdf

Funded by the European Union

Funded by UK Research and Innovation

Funded by the Ministry of Science and Technology of P.R. China

Verband der chemischen Industrie (VCI) & Plastics Europe. (2022). Chemical recycling as a building block of a circular economy. https://www.vci.de/ergaenzende-downloads/vci-ped-position-chemical-recycling-as-a-building-block-of-a-circular-economy.pdf

Versnellingstafel Chemische Recycling van Kunststoffen (VTCR). (2023). Whitepaper Chemische Recycling. https://www.vno-ncw.nl/sites/default/files/whitepaper_vtcr_nl_27_juni_2023.pdf

Wuppertal Institute. (2025). EDM-stock plastics model: Application in the GreenFeed project. https://bitbucket.org/wupperinst/edm-stock_plastics_greenfeed/src/master/

Zelt, O., Jülich, A., Kloo, Y., Theisen, S., & Kong, H. (2025). EU-CHINA BRIDGE: D3.1 – Two EU-China technology inventories on promising low-emission technology options for EIIs (v0.9) [Data set]. Wuppertal Institut für Klima, Umwelt, Energie gGmbH. https://doi.org/10.5281/zenodo.15324420

Zepa, I., Grudde, V. Z., & Bening, C. R. (2024). Legitimising technologies for a circular economy: Contested discourses on innovation for plastics recycling in Europe. Environmental Innovation and Societal Transitions, 50, 100811. https://doi.org/10.1016/j.eist.2024.100811

Funded by the European Union

Funded by UK Research and Innovation

Funded by the Ministry of Science and Technology of P.R. China