Netherlands

Chemical Recycling in circular perspective

From vision to action: How Chemical Recycling steers the transition towards a circular and carbon neutral chemical industry


Source: Unsplash

Content

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Vivianne Heijnen

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State Secretary for Infrastructure and Water Management

Chemical Recycling: Pioneering the circular future

The ambitions of the Netherlands towards a sustainable future are clear: by 2050 we want to be fully circular and climate-neutral. To get there, innovative solutions in all sectors are crucial.

Amongst these, chemical recycling is a very promising path. It can transform plastic waste and organic residues into base chemicals and plastic feedstocks. In addition to mechanical recycling, chemical recycling plays a pivotal role in closing the loop of plastics and textiles recycling. It ensures a perspective that no plastics need to be incinerated or landfilled in the future.

The Netherlands has a strong and innovative chemical industry and wants to be a frontrunner in chemical recycling. With the ambitious goal of using 10 percent of domestic plastics production from chemical recycling by 2030, we are defying the boundaries of circular innovation in Europe. Complemented by a tailored policy and regulatory framework, our National Chemical Recycling Platform brings together various stakeholders, laying the groundwork for achieving our 2050 circular goals.

Leaders in this sector are clustering around ecosystems like the Ports of Rotterdam and Moerdijk, Chemport Europe, Chemelot and the chemical cluster in the North Sea Port and West Brabant area.

With this brochure on chemical recycling, we are sharing our insights, lessons learned and best practices from entrepreneurs, public authorities, and knowledge institutes. We invite you to delve into all the possibilities that chemical recycling offers. We hope to inspire and accelerate development towards a more sustainable, resource-efficient, and regenerative world.

"The Netherlands has a unique starting advantage to become a frontrunner in chemical recycling, with a strategic geographical position and a large chemical industry."

Jacqueline Vaessen

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Chair Top Sector ChemistryNL

The Dutch journey towards Chemical Recycling

Our society is addicted to plastic. We cannot imagine a world without plastic because it is inseparable with our everyday life; in the clothes we wear, the furniture we sit on, our smartphones and computers we work with, the food we pack it in to keep it fresh, and so on.

We all know by now that the downside of using so much plastic is that it leads to a lot of waste which is incinerated or landfilled, thereby contributing to global warming. Moreover, the chemical industry needs to shift from fossil carbon to circular carbon as a raw material. To reach our goals to be fully circular in 2050 this plastic waste needs to be reused. This challenge asks for innovative solutions, and this brochure gives you an insight of what is already happening in The Netherlands.

The Netherlands has a strong chemical sector. A total of 2% of the worldwide production of chemical products comes from the Netherlands, while only 0,2% of the world's population lives in our country. A major part of the chemical products produced are plastics. Chemical recycling can play an important role in the re-use of plastic waste, thus contributing to a circular economy, but also reducing the amount of CO_2 emissions.

Chemical recycling is a collection of emerging innovative technologies that transform plastic waste and organic residues into base chemicals, monomers, and feedstocks. This approach complements mechanical recycling, bridging the gap between waste management and the petrochemical industry. I was very pleased to read so many concrete examples in this booklet on what is already in practice. It is not a moonshot anymore; we have landed among the stars.

The Netherlands has a unique starting advantage to become a frontrunner in chemical recycling, with a strategic geographical position and a large chemical industry. Leaders in the sector are clustering around ecosystems like Chemport Europe, Chemelot, Rotterdam Port, Moerdijk, North Sea Ports and West Brabant, where their pioneering R&D efforts significantly contribute to a stronger chemical industry in the Netherlands.

Furthermore, Chemical recycling is part of the unique Dutch public private partnership program Circular Plastics NL.

The Netherlands is not alone in this endeavour. Together with the trilateral region of Netherlands-Flanders-North Rhine Westphalia, it holds significant potential with immense opportunities for cooperation and progress. Thanks to our collaborative culture, ingenuity, and innovative spirit, we are fostering change at home and abroad while creating new avenues for collaboration and experimentation in this crucial industry.

By sharing insights and lessons learnt, we hope to inspire and accelerate development towards a sustainable and sensible direction. This brochure on Chemical Recycling, which features the best practices and insights from entrepreneurs, public authorities and knowledge institutes in the Netherlands, will be helpful to create a learning environment from which we all benefit.

I hope you enjoy reading this brochure as much as I did and that you will be inspired by the many examples given.

Introduction and context

This brochure shares the latest best practices from entrepreneurs and insights and lessons learnt from public authorities and knowledge institutes from the Netherlands on chemical recycling.

This publication is an initiative of a public-private coalition consisting of Holland Circular Hotspot, the Network Chemical Recycling of the Circular Biobased Delta, The Netherlands Ministry of Infrastructure and Water Management, Chemport Europe, Chemelot Circular Hub, ChemistryNL, TNO and Infinity Recycling. The coalition would like to stimulate cooperation at international level and exploit potential synergies and partnerships between government, knowledge institutions, and businesses in chemical recycling that help us to accelerate towards an economy that is circular and climate neutral within the boundaries of the planet.

Chemical recycling or advanced recycling is a term for a set of emerging innovative technologies that turn plastic waste and/or organic residues into base chemicals, monomers and feedstocks. Chemical recycling provides additional options and should be seen as complementary to mechanical recycling. It bridges the world of waste management and the petrochemical industry.

Why a brochure on chemical recycling?

To ensure that everyone is fed, and necessary goods such as clothing and appliances are available by 2050, our economy must transition to a circular model. Ambitious goals have already been established: Europe aims to become a climate-neutral continent by 2050, while the Netherlands has set a target to achieve circularity by the same year. Moreover, by 2030, the Netherlands plans to reduce the consumption of primary raw materials such as minerals, fossils, and metals by 50%.

According to the Circularity Gap Report 2023 by the Circle Economy think tank, the current global circularity rate stands at only 7.2%. It means that we are still primarily operating within a linear economy, resulting in the loss of valuable raw materials. This urges us to work on global solutions. Firstly, how can we prevent waste, and secondly, how can we extract more value out of this inevitable waste?

In all this, chemical recycling or advanced recycling has become a hot topic. Some hope it is the cure to all diseases and can help to create a climate-neutral chemical industry where the ‘c’ molecule comes from waste plastics and organics and the ‘h’ molecule from green hydrogen. NGOs, however, warn about greenwashing and see chemical recycling as an excuse to prolong a linear economy with low-value products without transitioning to a real circular economy. In this brochure we will present you with a nuanced view on the contribution of chemical recycling to a climate neutral chemical industry.

An important momentum was created in June 2023. Delegates from 180 nations at the Intergovernmental Negotiating Committee for Plastics in Paris[1] set out a pathway to a binding global agreement on tackling plastic pollution as soon as 2025. It is described as the most important green deal since the 2015 international climate agreement.

This brochure aims to showcase the current state, needed and possible developments in a fact-based and objective manner to stimulate debate. We approach chemical recycling from economical, environmental, innovation and financing perspectives and place it in the context of a fully circular economy strategy. Multiple Dutch cases, toolboxes and approaches will illustrate how chemical recycling can be put into practice.

The last chapter shows a pathway and action agenda. What can regulators do, how can entrepreneurs collaborate towards sensible chemical recycling models, how can the financial sector kick-start development, and how can knowledge institutes support and strengthen the developments? We conclude with a number of future visions on the market.

By publishing this brochure, the authors hope to share views as well as stimulate debate and action. By sharing lessons internationally, others can accelerate development in a sensible direction and avoid pitfalls.

Source: CURE

Chapter 1

Chemical Recycling challenges & opportunities

This chapter examines chemical recycling role in industries like cement, steel, and chemicals within modern economies. It emphasizes the shift towards a circular economy and the demand for renewable carbon sources. It also discusses global material circularity, waste management infrastructure, and the potential for growing green economy markets and employment implications.

1. Setting the scene for chemical recycling

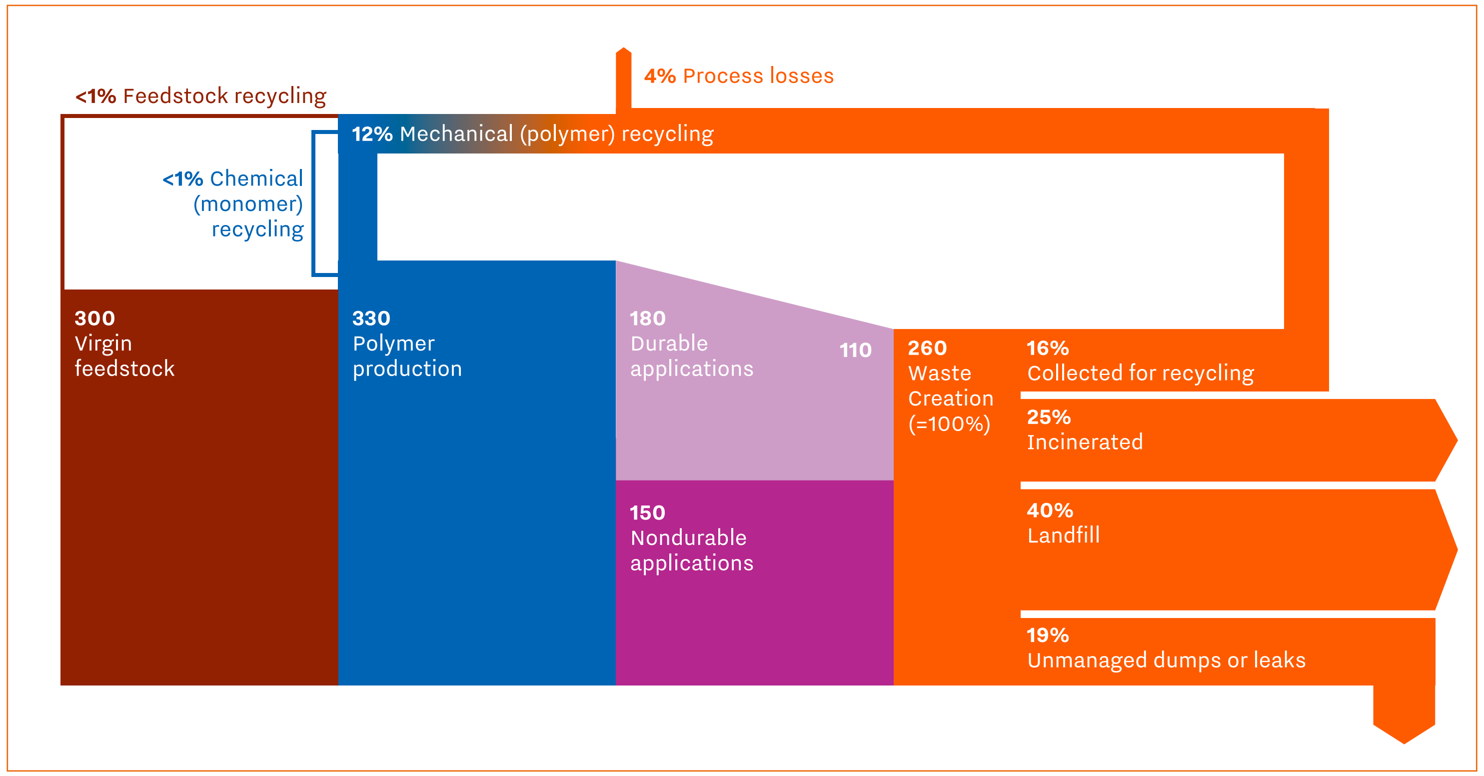
The cement, iron & steel, and chemicals & petrochemicals industries are the backbones of modern economies, providing materials for our houses, mobility, safety, health and day-to-day products. The petrochemical sector is the third-largest emitter of CO_2, following the cement and steel industry, contributing 14% of all industrial emissions[2]. This puts the sector under pressure to rapidly become more sustainable and ultimately climate and carbon-neutral. Achieving this goal will require a significant shift away from the currently used fossil feedstock and energy carriers (coal, oil, and gas).

Until now, most emphasis has been on executing renewable energy projects based on wind, sun or geothermal sources, in combination with the electrification of processes, integrating and exchanging heat 'industry to industry' and 'industry to cities'. This focus on energy is logical since humans consume carbon for many different purposes, with energy being the largest, accounting for approximately 7,600 million tonnes in 2020 (data by Nova Institute)[3]. On the other hand, materials and chemicals 'only' consume 1,200 million tonnes of carbon (10% of total carbon demand). It is of the utmost importance that industry, science, governments, politics and society begin executing the feedstock transition.

The supply of renewable carbon needed for the feedstock transition can come only from three sources: biomass, CO_2 use (CCU) and recycling of carbon-based materials (like waste plastics). This requires creating a circular economy with low carbon losses, resulting in a **circular and net zero carbon economy.**

Currently, we are far from achieving a circular economy, as evidenced by the recent McKinsey study titled 'Climate impact of plastics' (2022). According to the latter, the plastic industry represents the largest flow of carbon-based materials globally. Chapter 2 will delve into the developments in waste volumes, which could serve as a potential source of renewable carbon. It will also examine the demand for renewable carbon in chemical and materials sectors and the implications this has for the potential of mechanical and chemical recycling.

Figure 1: Global state of circularity for commodity and engineering plastics (2020)

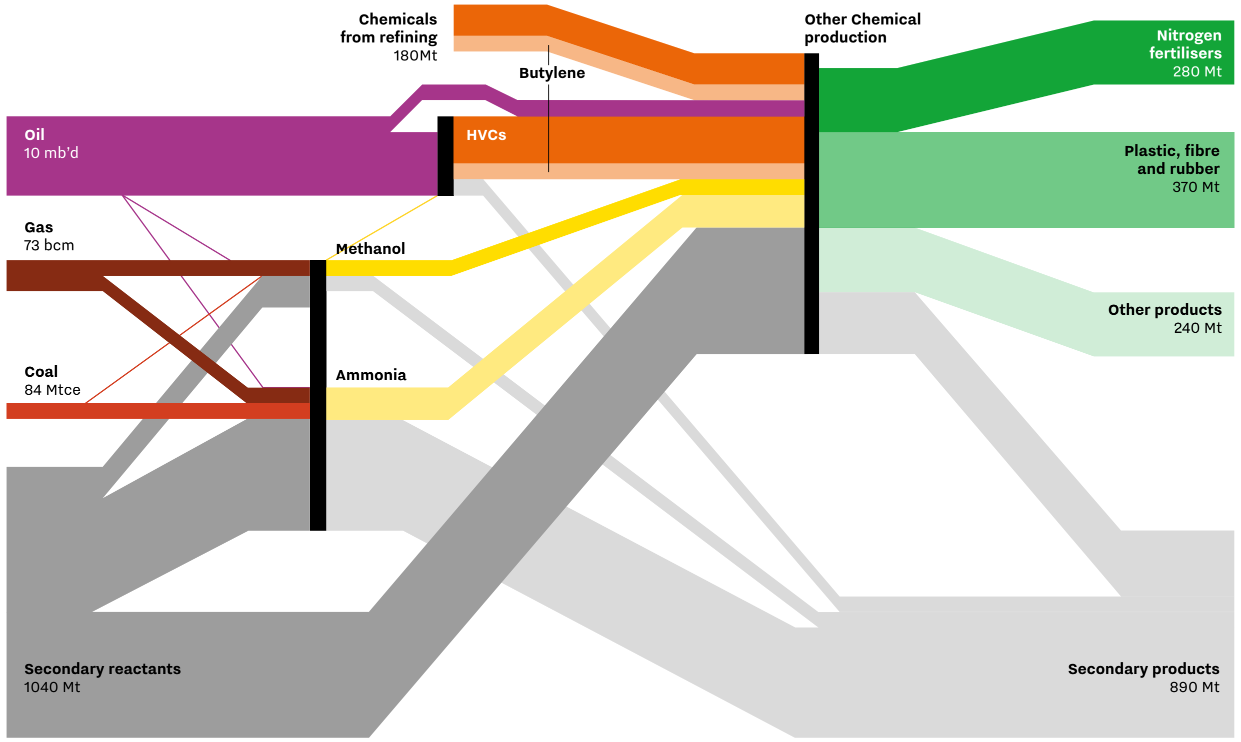


Source: McKinsey plastic waste stream mode. (2020)[4]

2. Demand for renewable carbon

In the mapping 'From Energy to Chemical Products[5]' below, the magnitude of the Fossil Fuel Feedstocks to Chemical Products can be seen.

Figure 2: Energy to chemical products (2015)



Source: IEA (2018). From energy to chemicals (IEA).

It is crucial to recognize the enormous scale of the renewable carbon feedstock transition required for the chemistry and materials industry. The demand magnitude alone, reaching 10 million barrels (1.6 million m³) per day of oil for high-value chemicals (HVC), is truly mind-boggling. Additionally, the natural gas demand of 73 billion m³ for ammonia (fertilisers) and methanol (HVC) production is also substantial.

Therefore, the feedstock transition deserves as much attention and commitment as the energy transition, and ideally, both should be fully integrated.

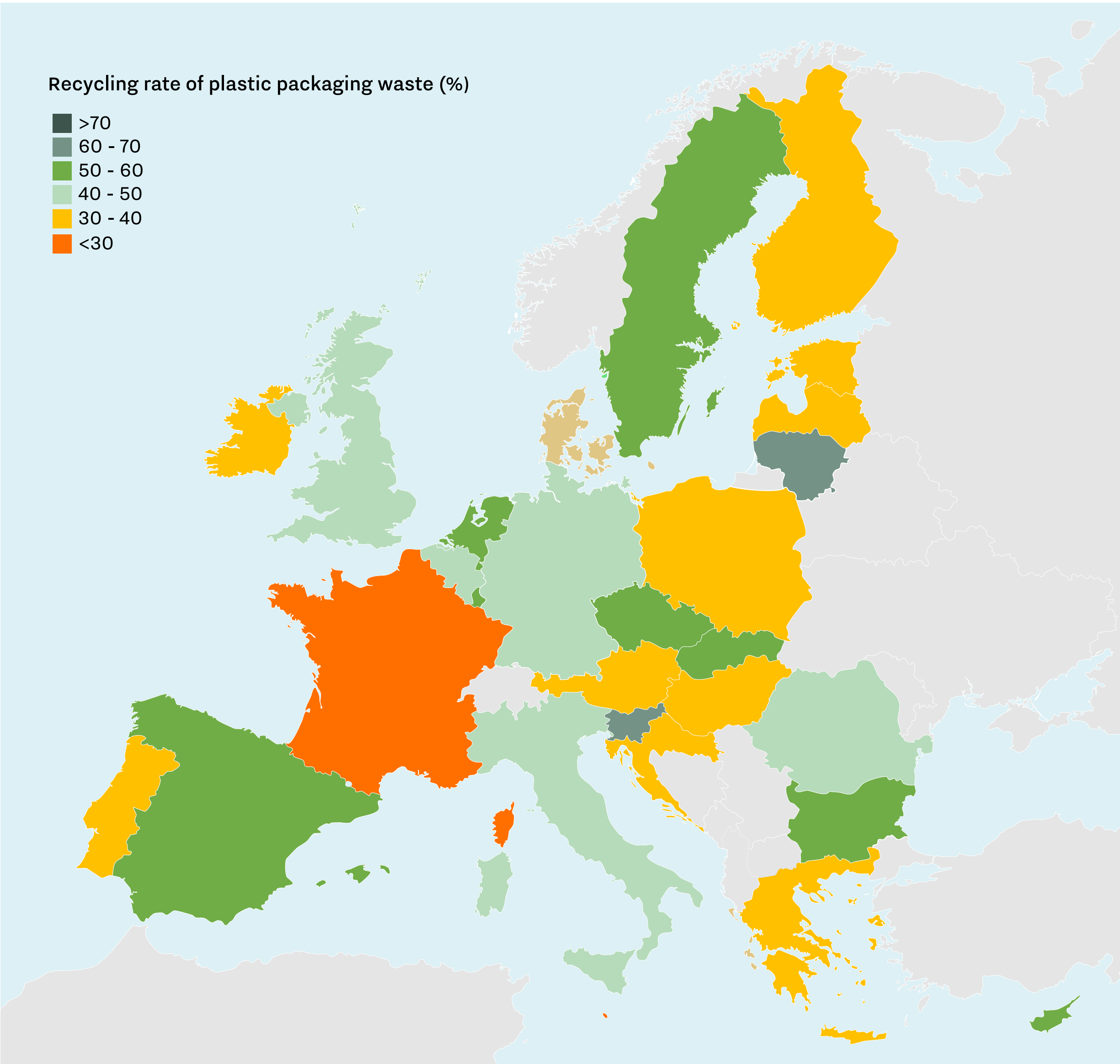
By exploring scenarios that involve a transition away from fossil oil and gas towards a renewable future for materials and everyday products, we can estimate the embedded carbon demand in the materials and chemicals sector.

3. Point of departure: Global waste outlook and recycling and circularity rates in Europe

In recent years, waste production has grown substantially. In 2016, an estimated 2.01 billion tonnes of municipal solid waste was generated, and thus the number is projected to rise to 3.40 billion tonnes by 2050 if the current business-as-usual scenario continues. It is anticipated that waste production in 2050 will be 70% higher than in 2020. The situation is particularly concerning in low-income countries, where the total quantity of waste is expected to increase by more than three times by 2050. This trend is partly driven by the rising levels of production and consumption in these countries.[6]

There are substantial disparities in recycling and circularity practices among different regions of the world. These disparities are closely related to the presence or absence of adequate waste management infrastructure (collection and recycling) in the respective regions. While Europe, America, Japan, and Australia have well-developed waste management systems, major parts of Asia, Africa, and the Middle East lack such infrastructure. Even within the well-developed region of Europe, there are notable differences between countries, as evidenced by the 2018 Eurostat data on the EU Plastic Packaging Recycling Rate[7]. Packaging accounts for 40% of all plastic usage and is a critical area that requires reshaping and redesigning as a post-consumer material stream. Key elements to achieve greater sustainability through circularity include reducing packaging, eliminating single-use packaging, designing for recycling, and adopting advanced recycling methods for food contact materials.

Figure 3: EU plastic packaging recycling (2018)[7]



Source: European Parlament. (2023). Plastic waste and recycling in the EU: facts and figures.

4. Global outlook for mechanical and chemical recycling

What is the global future outlook for mechanical and chemical recycling? We have combined data from various sources and consulted experts on the growth of plastic production, the supply and demand of plastic waste, and the expected preferential treatment method.

Currently, landfilling (and leakage into nature) is widely considered the predominant scenario for plastic waste globally. We combined data from different sources and experts on the growth in plastic production, plastic waste supply and demand and its expected preferential treatment method. Today, landfilling is globally seen as the dominant treatment method for plastic waste. However, this is expected to change as governments begin implementing policies to curtail plastic waste and transform it into a new raw material for the chemical industry. It could be utilised as an energy carrier or, preferably, as a feedstock, or even a combination of both.

What is the magnitude of the global market for chemical recycling in a world that is currently predominantly landfilling-dominated?

To get an indication of the global perspective for chemical recycling, we combined data from the following sources:

- Global embedded carbon demand for chemicals & derived materials from Nova Institute[7]. Based on recycling, this adds up to 632 million tonnes for chemicals & derived materials. For plastics only this amounts to 350 million tonnes (55%);
- Global waste recycling supply data 2020 from McKinsey (Figure 1), from Nexant and Technip Energies for 2020, 2040 and 2060 (see Figure 4) with 420 million tonnes plastic waste in 2040[8] and supported by OECD Global Plastic waste outlook 2060 with two scenarios: business as usual (BAU) and Global Ambition (GA)[9];
- In the BAU-scenario we have used the Nexant -Technip supply data with an optimistic chemical recycling outlook (CR>MR);
- In the GA scenario, we have used a more realistic chemical recycling outlook (MR>CR);

Figure 4: Plastic recycling outlook Nexant/Technip Energies[10]

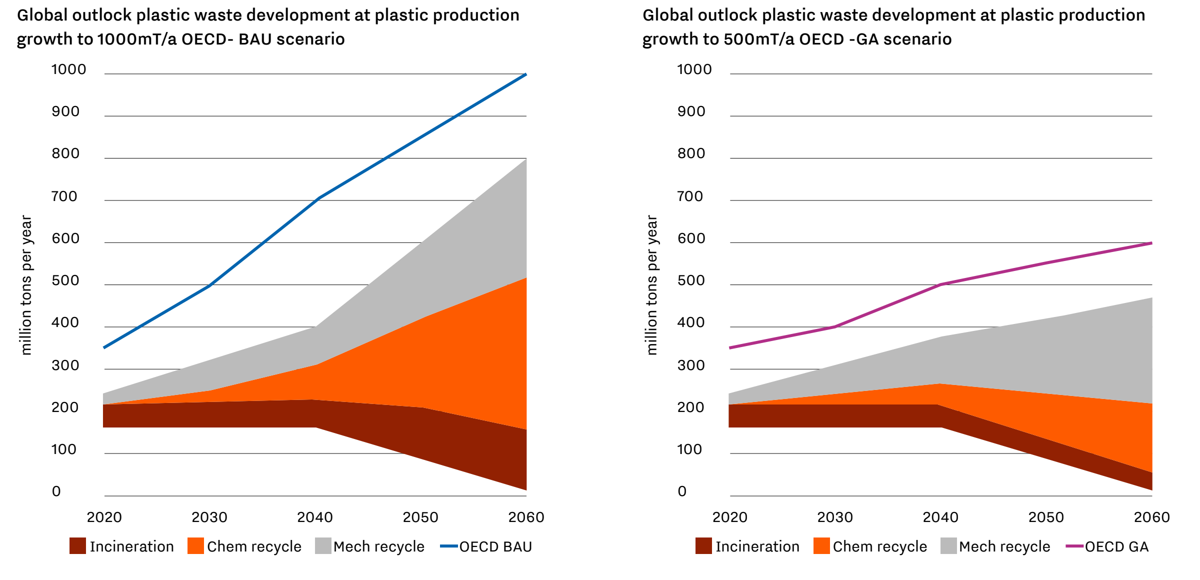
Combining this data, the following outlook can be presented for the development of waste in the period 2020-2060, including waste applications like mechanical and chemical recycling, as well as incineration in two OECD scenarios: Business As Usual (BAU) and Global Ambition (GA), see Figure 5. Mechanical and Chemical recycling growth will be largely enabled by discontinuing landfilling, which we foresee to occur after 2040 due to the realisation of waste management and infrastructure in low-income countries.

This data demonstrates an outlook that underpins the significant global growth opportunities for mechanical and chemical recycling, especially in the longer term (2040-2060). This is independent of the BAU scenario, which involves a tripling of plastic production and plastic waste, or a much lower growth scenario (GA) for plastic production and plastic waste (GA).

We assume that this coincides with significant participation from Asia, where it will require time to develop the necessary waste infrastructure for enabling waste collection, sorting, cleaning, and separation.

Chemical recycling, particularly in the current decade, is predominantly taking place in Europe, North America, and Japan.

Figure 5: Global plastic waste development and growth of MR & CR (2020 - 2060)

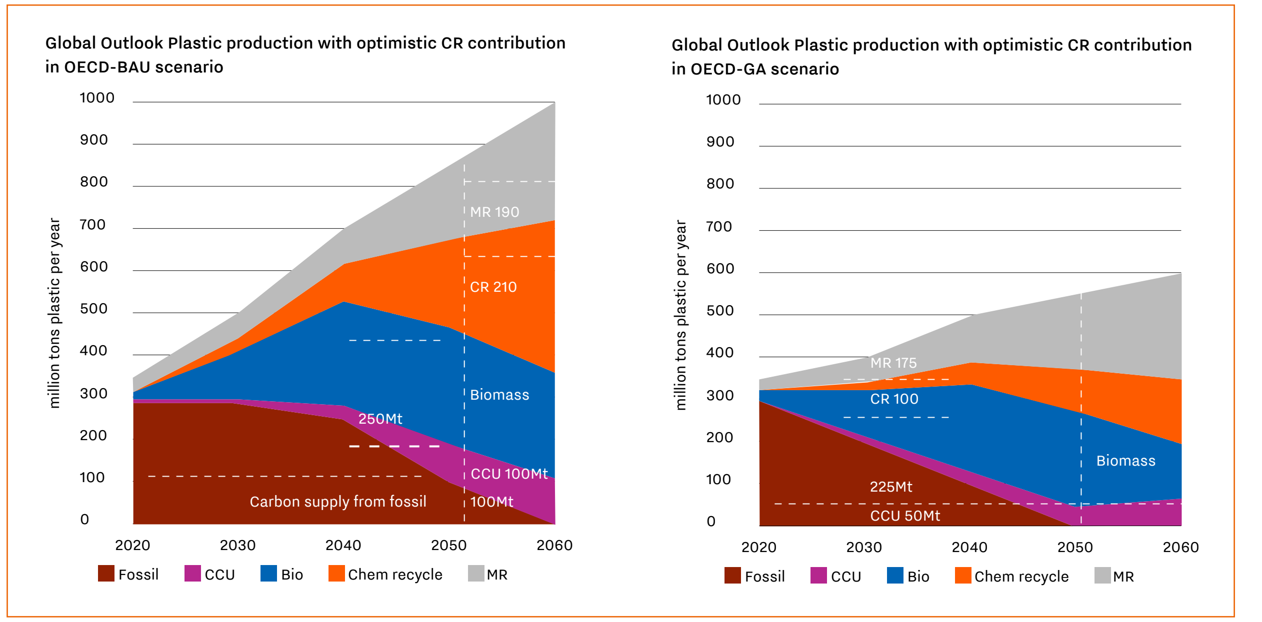


Source: Analysis by expert team Circular Biobased Delta

5. Feedstock for future plastic production

Using the circular and renewable carbon extracted from mixed plastic waste, we can now analyse the composition of virgin feedstock used in plastic production and the contribution of mechanical recycling to plastic production. We repeat this analysis for the two OECD scenarios, Business As Usual (BAU) and Global Ambition (GA), and the results are illustrated in Figure 6 below.

Figure 6: Renewable and circular carbon development for plastics production



Source: Analysis by expert team Circular Biobased Delta

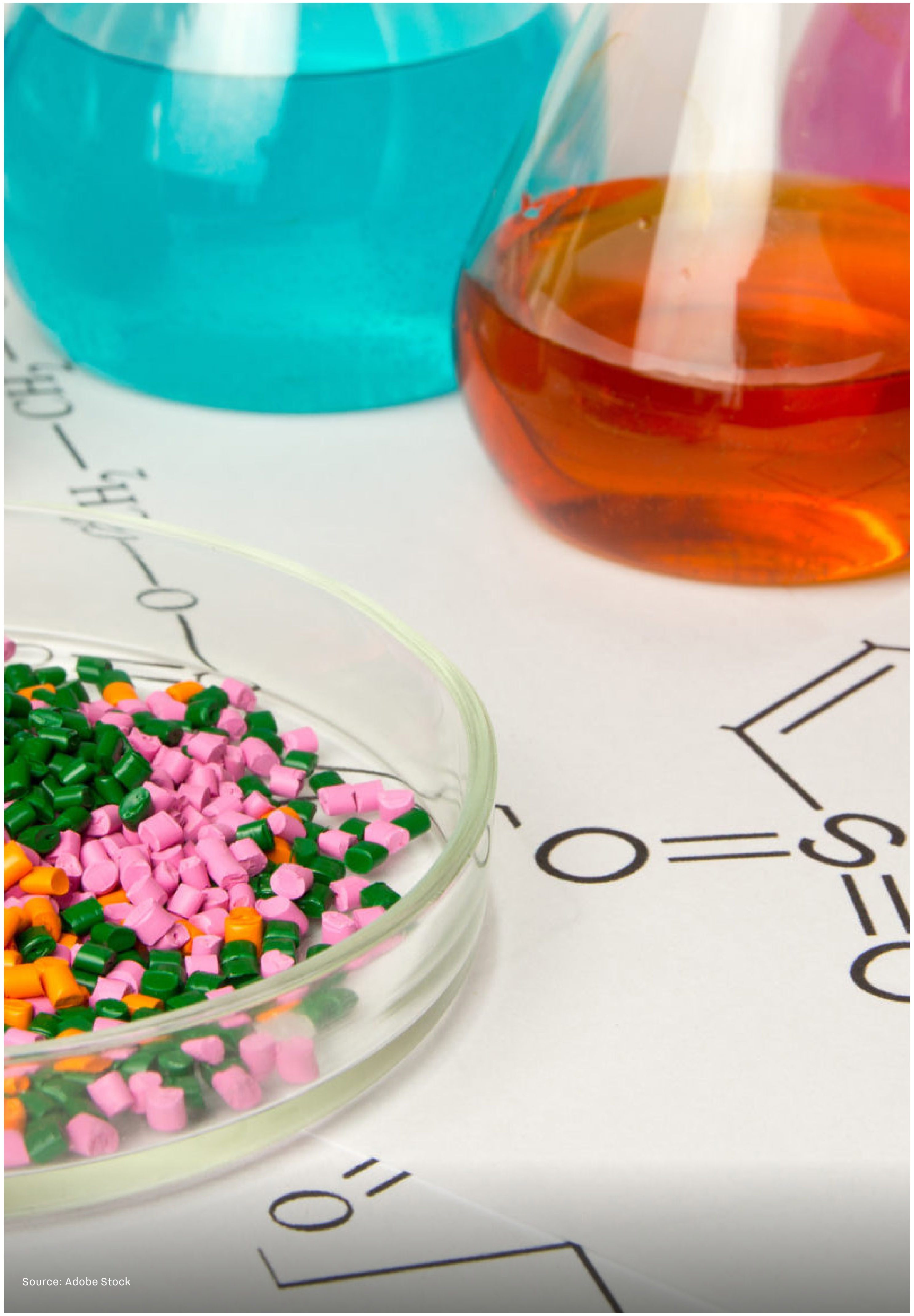
As experts in the field of chemical recycling, we draw the conclusion that regardless of the scenario we consider, mechanical recycling (MR) has the potential to reach 250 million tonnes by 2060, presenting a revenue opportunity of $300-400 billion in today's terms.
At the same time, chemical recycling (CR) is projected to grow to 150-360 million tonnes, offering a revenue opportunity that is roughly comparable to that of MR.

Human resources implications

The chemical transition has significant implications for employment and the labour market. As the industry evolves, there will be a rising demand for skilled workers capable of developing, implementing, and maintaining new technologies and processes. The recycling sector, encompassing sorting and processing facilities, waste-to-energy plants, and resource recovery centres, is expected to expand with the increasing importance of waste reduction and recycling.

Moreover, there will be a surge in employment opportunities for consulting businesses and specialised environmental service providers as the demand for environmental assessments, environmentally friendly business methods, and regulatory compliance grows. Finally, there will be a need for professionals in green chemistry, process engineering, and sustainability assessment to drive the adoption of greener chemical processes and technologies.

Plastic waste. Source: Unsplash



Source: Adobe Stock

Chapter 2

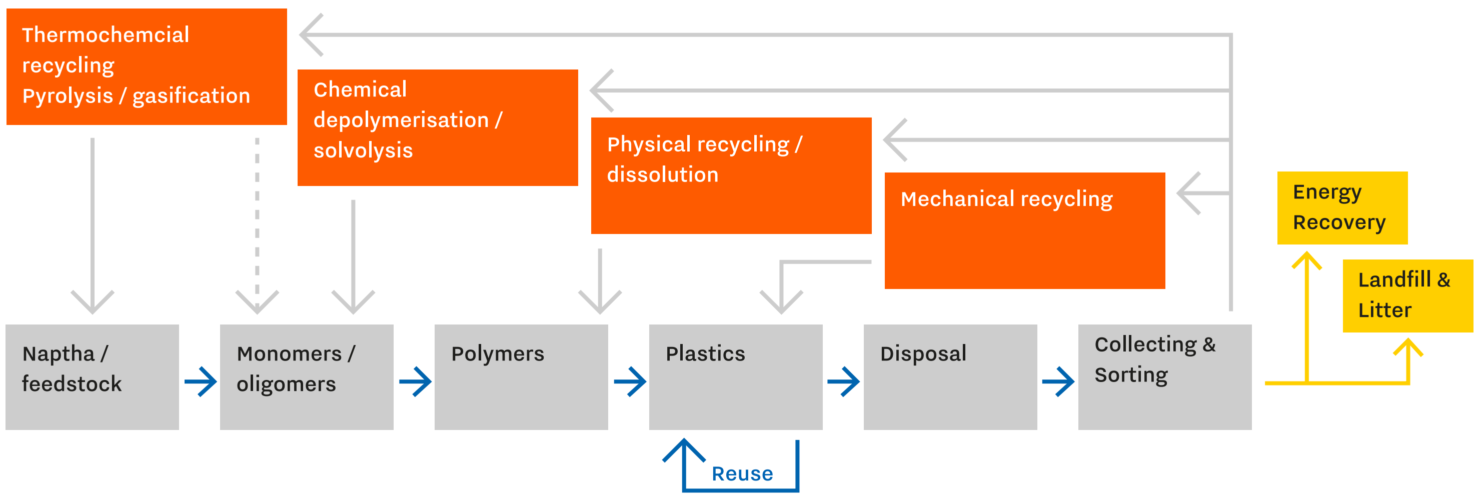
Chemical Recycling in a Circular Economy

In this chapter we will go into chemical recycling in more detail. We will discuss the different technologies, business development aspects and environmental and sustainability aspects.

1. Chemical Recycling and technologies

Chemical recycling of plastic waste refers to a process in which the polymer chains are converted into oligomers, monomers or other basic chemicals (such as carbon monoxide, carbon dioxide, methane, and hydrogen) prior to further reprocessing into monomers/polymers, excluding energy recovery and incineration.

Figure 7: Recycling technologies in the life cycle of plastics.



Source: JRC Technical Report - Environmental and economic assessment of plastic waste recycling (2023)[11]

Chemical recycling should be seen as complementary to mechanical recycling and physical recycling (dissolution) as it provides additional options. It bridges the world of waste management and the petrochemical industry. Chemical recycling can be subdivided into chemical depolymerisation (solvolysis) and thermochemical recycling (pyrolysis and gasification). Dissolution is officially classified under mechanical recycling and is a solvent-based purification. As the process is much closer to chemical recycling, this technology is shortly discussed as well.

Chemical depolymerisation

The depolymerisation process - often referred to as chemolysis or solvolysis - uses different combinations of chemistry, solvents and heat to break down polymers into oligomers or monomers. In the following step, potential contaminants are isolated from the monomers/oligomers to remove them.

The monomers/oligomers are then fed back into the normal plastic production processes as a secondary raw material. The plastics produced this way are of similar quality than those made from traditional fossil resources. Such an approach is most suitable for polymers which are polymerised by polycondensation, such as polyesters (notably PET) and polyamides and is most suitable for homogeneous waste. Several solvolytic processes, where chemicals or solvents are used for polymer breakdown, are investigated, e.g. glycolysis (with ethylene glycol for PET and PA), methanolysis (with methanol for PET), hydrolysis (with water, potentially for PC), ethanolysis (with ethanol, for PS).

Pyrolysis

Pyrolysis is a thermal cracking reaction under the absence of oxygen that breaks down the macrostructure of polymer and leads to the formation of short olefins like ethylene and propylene or fuel-type products (pyrolysis oil). The process parameters, such as temperature, pressure, and residence time, affect the final product. Temperature is one of the most important parameters because it controls the cracking reaction of the polymer chain and influences the product composition.

Higher temperatures of more than 500 degrees Celsius would yield more gaseous or char products, whereas lower temperatures of 300-500 degrees Celsius would produce liquid oil. The hydrocarbon mix can replace feedstock, such as naphtha or natural gas, to make new plastics or be used in other chemical processes. The pyrolysis oil (hydrocarbon mix) can also be used to replace fuels like diesel or kerosine.

The pyrolysis process is a relatively simple technology suitable for recycling plastic waste that is difficult to depolymerise. The process is suitable for polymers with a low oxygen content as polyolefins and PS, as it takes place in the absence of oxygen. Polymers containing a high level of oxygen (PET) or halogens (PVC or plastics containing high amounts of brominated flame retardants) must be removed from the waste input stream. Exemption is the Agylix process that can handle PVC using a pre-reactor for the first heating step in which HCl is released from the PVC.

The drawbacks of pyrolysis are the high energy consumption, sensitivity to feedstock contamination, lower quality recyclates that need further upgrading, and the limitations to scaling up this technology to a 100 kilotonnes scale.

Worldwide there are many initiatives on pyrolysis. In partnership with polymer manufacturers, the pyrolysis oil is further upgraded to produce the monomers for making virgin grade resins[12]: SABIC in partnership with Plastic Energy and Petronas, Fuenix Ecogy and Dow, Shell with Blue Als and Pryme, etc. TRL of these initiatives is between 7-8 (‘Chemical Recycling, Global Status’, AMI2023[13]).

Gasification

Gasification is also a thermal cracking process. Still, it differs from pyrolysis in that it is performed in the presence of a limited but controlled amount of oxygen. The process achieves detailed polymer breakdown and yields a mixture of hydrocarbons and syngas (CO and H2), which can be used to produce energy, hydrogen, chemicals, and by-products, such as tars and chars.[14] It can process almost any organic material — including plastic waste and biomass — and, unlike pyrolysis, can in theory at least, accept polymers containing oxygen or halogens. Compared to pyrolysis, gasification requires fewer process steps. Pre-treatment of the waste (including water removal) is followed by the gasification step and then a cleaning stage to remove contaminants such as ammonia, H2S, alkali metals, NOx and tars. Like pyrolysis, it is an energy-intensive process involving temperatures of 900°C or more. Gasification needs high volumes of feedstock to be economically viable. This technology has – in a circular perspective – a lower priority than pyrolysis as the product gas consists of much smaller molecules that are, thus, less valuable. On the other hand, this technology can cope with lower-quality mixed feedstocks.

Gasification is at a technology readiness level of 9. An example is the Enerkem plant in Canada which produces 38 million litres of biofuel methanol, then ethanol, and ethylene from 100,000 tonnes of plastic waste. Enerkem is a part of the consortium that plans to build a chemical recycling plant in the Netherlands with the capacity to convert 360,000 tonnes of waste to chemicals per year.[15]

Source: Unsplash

Next generation technologies

Researchers are actively developing new technologies operating at temperatures between pyrolysis and gasification with a limited amount of oxygen. These technologies facilitate the conversion of plastic waste into either monomers or a blend of Benzene, Toluene, and Xylene (BTX). Synova, for example, transforms biowaste and polyolefins to monomers, while BioBTX does it from plastic waste to BTX. Both can handle more polluted waste streams compared to pyrolysis and offer a higher added value of output compared to syngas. The Demoplant for BioBTX is scheduled to be ready in 2024, while the demoplant for Synova is currently at the investment stage.

Catalytic depolymerization for polyolefins at low temperatures, a depolymerisation process where the chemical process is accelerated by the addition of a catalyst, exhibits a distinct advantage by consuming less energy due to operating at lower temperatures. However, this technology is still in development and a potential drawback is associated with the stability of the catalyst.[a]

Dissolution

Dissolution is a technology that adds value to the separation and recycling of polymers, additives, or contaminants that standard mechanical recycling technologies cannot separate.

A number of pilot projects are already well advanced: Fraunhofer’s CreaSolv® process is being further developed by CreaCycle GMBH in Germany, and its polystyrene (PS) Loop project in the Netherlands for expanded polystyrene (EPS) recycling both polymer and brominated flame retardant. Obotec focuses on the recycling of polyethylene (PE) and polypropylene (PP).

Germany's APK is also exploring technology to recover low-density PE (LDPE) and polyamide (PA) from multi-layer films.[15]

2. Business development aspects

Mechanical and physical recycling are the preferential waste management options if prevention, reuse, refurbishment or remanufacturing is not an option. Typically mechanical recycling involves sorting and upgrading with a focus on larger fractions with a positive value like the plastics PET, PP or PE. Mechanical recycling poses several challenges and limitations. Given the diversity and complexity of plastics whose components and mixing properties are different, processing or recycling rates may vary compared to other materials or waste streams such as metals

Mechanical recycling can keep materials several times in the loop. Mechanical properties, substances of concern, colour and odour can limit more life cycles. The case of how plastic additives behave during recycling is still a matter of further research.

Chemical recycling is an option if mechanical recycling is not possible anymore and is therefore complementary to mechanical recycling. When implementing robust systems and processes, it is vital to ensure that waste plastic input materials for chemical recycling do not include material that can be economically recycled by mechanical recycling in practice and at scale.

Chemical recycling requires essential sorting out of smaller fractions that hinder chemical recycling. Both mechanical and chemical recycling processes, therefore, involve sorting, separation, cleaning, washing, drying and resizing. Chemical plants are used to well-defined consistent feedstocks but not to heterogeneous solid inputs that can create clogging or form bridges in the installation. Attention in chemical recycling should be paid to the pre-processing for feeding the chemical recycling process in a robust, continuous way. It can include torrefaction, pelletization, or melt.

A dominant application of plastics is for packaging. SUP, Single Use Plastics, pose a major environmental issue. An important advantage of chemical recycling is that it allows the processing of food-grade or contact-sensitive plastics, while for mechanical recycling, this is only possible in closed loops (for example, Deposit Return Systems of PET bottles).

Figure 8: Chemical Recycling partnerships for upscaling in the Dutch ecosystem.

Technology provider Innovative SME	Chemical Corporate partner	CR (*)	Location CR-Plant (**)	Timing	Scale (Kt waste)
Plastic Energy (UK)	SABIC	P	Geleen	Q1 2023	20
Blue Alp	Shell	P	Moerdijk	2024	35
Pryme	Shell	P	Rotterdam	2023	40
Mura (UK)	Dow NL	H-P	Teesside	2023	20
Mura	Dow NL	H-P	Böhlen (D)	2024 (FID)	120
Fuenix Ecogy	Dow NL	P	Weert	2023	15
Clariter	Teijin	P	Delfzijl	2024	60
Alterra	Neste	P	Vlissingen	2025	55
Ioniqa	Indorama	S	Geleen	2020	10
Ioniqa	Koch TS	S	Several	>2024	Roll out
Cure Tech	Niaga Covestro	S	Emmen	2023	25
BioBTX/Agilyx	Teijin	C	Delfzijl	2027	50
Synova	SABIC	C	tbd	2025 (FID)	50
Synova	Trinseo	D	Tessenderlo (B)	2024	15
Gidara	BP	G	Amsterdam	2024	175
Gidara	PoR	G	Rotterdam	2025/2026	180
Enerkem	Shell	G	Rotterdam	2023/2024	360

Source: Analysis by expert team Circular Biobased Delta

Source: Unsplash

Over the last decade, the chemical recycling industry has grown significantly. As of 2022, the global chemical recycling input capacity has reached close to 1.2 million tonnes, with Europe at the forefront of technological developments.

A significant number of demo plants and commercial plants are scheduled to launch and become operational in the upcoming years, and conditions are given for large industry and technology providers to connect for scale-up and connections with sorters to guarantee feedstock.[16]

The size of installations matters and is expected to grow with TRL (Technology Readiness Level) and market maturity. For pyrolysis plants the size is expected to grow from 30-50 kilotonnes per annum in 2021 to 100 kilotonnes per annum in 2030.[17] In parallel, development of improved and more efficient technologies takes place. These include technologies that are more agnostic for feedstock quality, and are better scalable with much larger unit operations via improved process and reactor design. This brochure includes an extensive list of companies and partnerships that are active in scaling up various CR technologies for creating a carbon circular economy in the Netherlands and Europe.

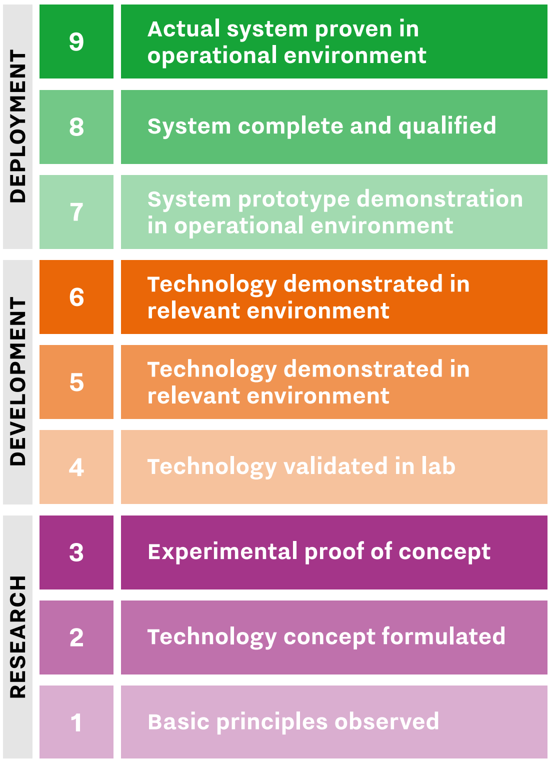
As investment flows into chemical recycling opportunities, the demand for qualified workers is expected to rise across different workstreams to implement new technologies and processes in the newly operational plants. In turn, the dynamics will mobilise the research and education sectors to increase a specialised offer to support the technological transition. And as the different chemical recycling technologies consolidate, the demand for independent environmental assessment service providers, environmentally friendly business methods, and regulatory compliance are also expected to gain prominence.

Chemical Recycling technology

Chemical recycling technologies are still in the early stages of development and technological readiness and further advancements are needed to improve their efficiency, scalability, and cost-effectiveness. Developments are underway towards better industrial Chemical Recycling processes that fit with a sustainable economy and yield intellectual property and know-how that can be monetized. Scope includes depolymerization, pyrolysis, (mild) cracking and gasification. The large scale-up effort, how to speed up development times. Address technical challenges and risks.

Technology Readiness Levels (TRL)

Figure 9: Technology Readiness Level



Technology readiness level can be assigned levels 7-9 as it is a commercially available technology.

Chemical Recycling start-up may need 6-8 years to come to a TRL 9 level, whereas reconverting existing chemical plant infrastructure to renewable energy, green hydrogen, and circular feedstock can take 15-18 yrs.

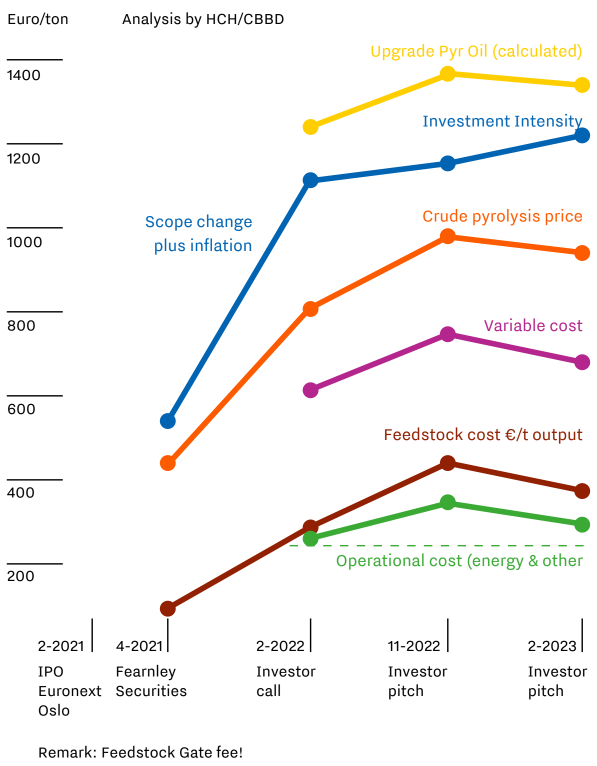
All technologies for chemical and physical recycling are under development and may contribute more or less to the statutory task and sustainability targets in addition to mechanical recycling. We, therefore, do not exclude any technology at this stage in future choices for cooperation, feedstock deployment, and investment.

Today, from the point of view of maximum yield, short-loop technologies are preferred to long-loop technologies. We are talking about the current situation here and collectively want to gain a lot of practical experience and need to tweak the regulatory and support system, which means that in the near future, the situation may/will improve.

Case study with economic indicators (public data)

As noted in a JRC study, there is limited information on the economic aspects of Chemical Recycling initiatives. Below we highlight a specific case on chemical recycling that we have permission to share based on feedstock cost, pyrolysis oil price, capex, and opex.

Figure 10: Pryme Business Case: Industrial validation of scale, commissioning Q2-23



Source: Analysis by expert team Circular Biobased Delta

From Fig.10 we can conclude the following for the period February 2022 to February 2023:

- Feedstock cost moved between 300-400€/tonne
- Energy and other operational cost moved between 310-375€/tonne
- Total Opex was between 600-800€/tonne for crude pyrolysis oil
- Sales price of crude pyrolysis oil was 800-1000€/tonne, leaving a 200€/tonne margin
- Upgrading of the pyrolysis oil via hydrotreating is estimated at 400€/tonne
- Sales price of upgraded pyrolysis oil (naphtha quality) was 1200-1400€/tonne
- Price move up and down with energy and naphtha cost
- Capex has the tendency to go up over the project timeline.

What recycling method is best?

The Circular Biobased Delta applies an 'eight-pack' to de-risk CR) technology that is depicted in Figure 11. It includes eight risk categories with questions to rate the risks of the investment:

Risk 1:
Is there a sufficiently profitable Business case at scale (longer term) with realistic Investment and Operational costs (including costs for feedstock, energy, etc.)?

Risk 2:
Can we use sustainable Feedstock at the right quality for our CR-process at scale from multiple sources? (no single sources)

Risk 3:
Is the Technology safe, scaleable (to 100,000 tonnes per year), continuous, robust with stable operation, is there a realistic chance to become a low cost producer? Is the plastic-to-plastic yield high enough?

Risk 4:
Is there demand for the CR product at current cost and price in the Market with a green premium and acceptable time to market?

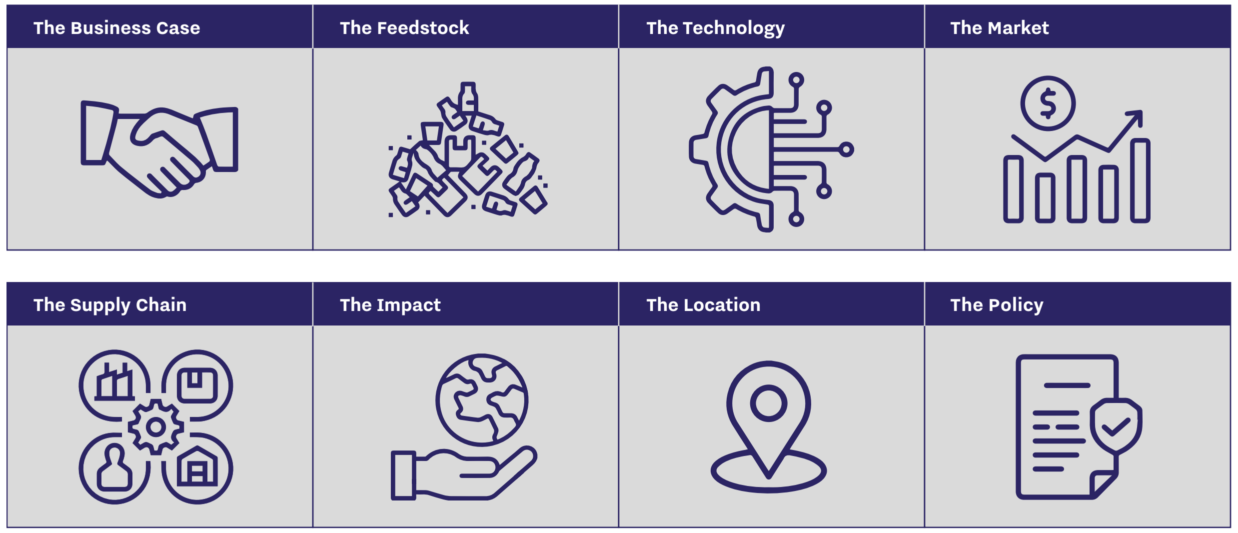
Risk 5:
Is there a transparent, sustainable Supply Chain with low CO_2 emissions and low health effects for workers, neighbours and other stakeholders?

Risk 6:
Is there a sufficient positive Environmental Impact from the CR-process in terms of CO_2 and other emission reductions versus virgin fossil (not incineration)?

Risk 7:
Is the Location attractive in terms of cost, logistics, eco-system, labour market, permitting and proximity to feedstock and market?

Risk 8:
Is there an active and supportive Policy Development to support R&D and 1st of a kind plants with effective instruments?

Figure 11: CBBD eight-pack for de-risking Chemical Recycling technologies



12: Rating the CBBD eight-pack categories

The Business Case	The Feedstock	The Technology	The Market
Capex Opex Margin ROI Sensitivities	Volume Quality Availability Sustainability Multiple sources	Due diligence Safety Scalability Continuous Process TRL/IP/FTO	Off take agreements Volumes & prices Competitive trends Green premium Time2market

The Supply Chain	The Impact	The Location	The Policy
Reliable supply Cost of transport Transparency Long term contracts Safety storage	Energy intensity LCA (CO2+7other) Which Benchmark Max Integration Avoid Lock-Ins	Location cost factors Close2feedstock/ market Ecosystem/ cluster Ease of permitting Skilled Labour	LT Vision and Strategy Incentives for 1st of kind Government as partner R&D support Active Policy Development

In the future, there is likely to be a large number of different recycling options available. When multiple options are available, the optimal recycling technology has to be determined for existing and future waste streams and the types of polymers available. The existing waste hierarchy should not be applied blindly. In order to determine what recycling technology is the best choice, other important factors play a role here as well:

- The costs of the recycling technology
- The environmental impact of technology
- The environmental footprint of the plastic/ additives
- The quantity of the plastic waste input
- Health and safety aspects of recycling technology
- Quality of output (arguably the major driver for chemical recycling)
- Quantity of output

Many of these points can be tackled by executing a Life cycle assessment (LCA) and life cycle costing (LCC) for a full life cycle, like plastic-to-plastic recycling.

The costs for pre-treatment of feedstock and purification and upgrading of the output in line with the strict specifications of the chemical industry will have a price impact that is often not included in initial business models. Furthermore, it is important to realise that every technology will have the desired output flow but also residual flows (either solid, liquid, or gaseous). Both the targeted flow (upgrading & purification for follow-up chemical processes leading to chemical building blocks or intermediates like MeOH) as the residual flows (potentially hazardous substances with high treatment or disposal costs) are likely to ask for further treatment. In the 'circular visualisation of chemical recycling challenges' figure in Chapter 4 gasification and syngas route is indicated as a potential step for residual flows.


Plastic litter ending up at Labadi beach, Accra, Ghana. ©Freek van Eijk

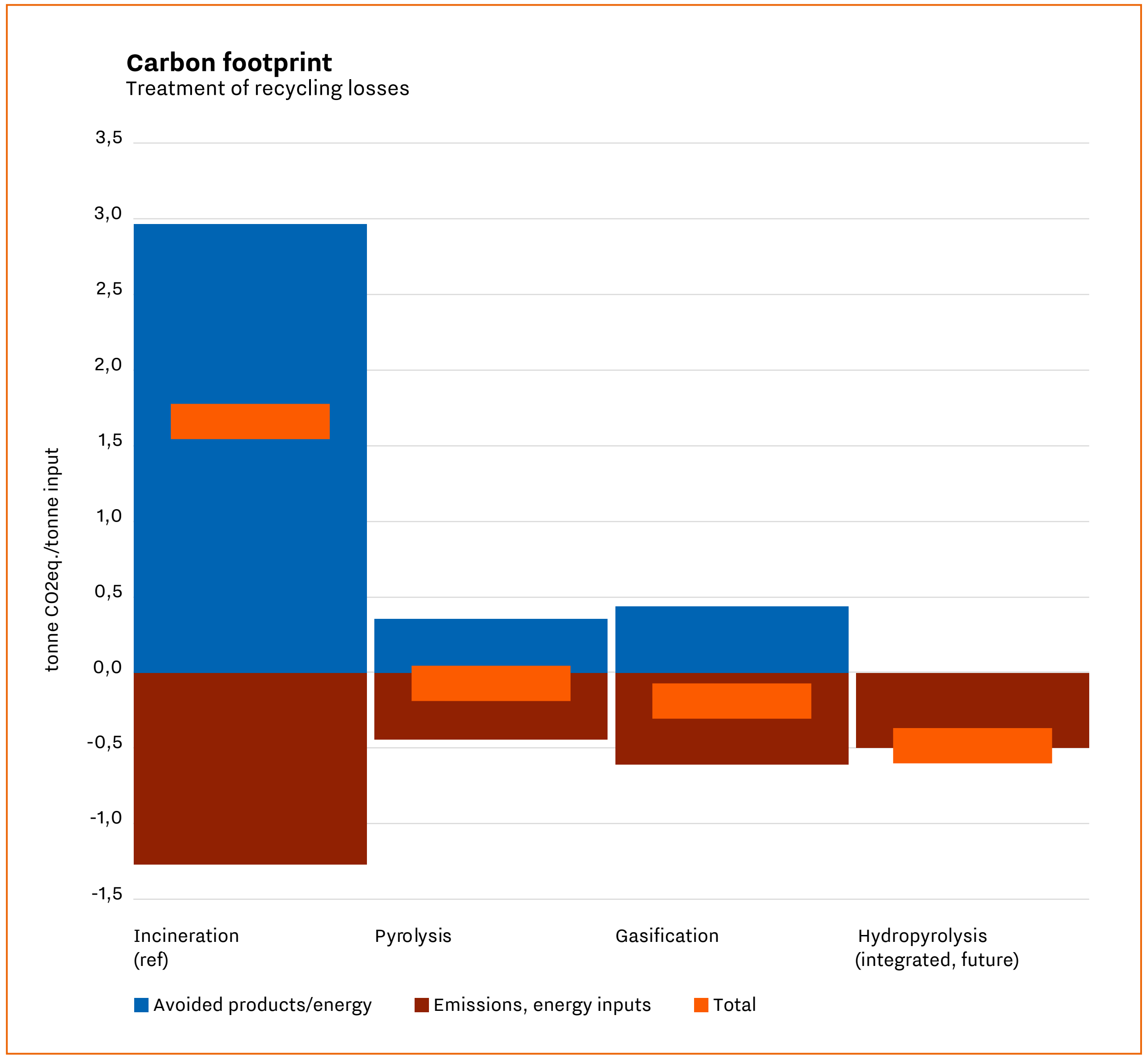
3. Environmental and sustainability aspects

Environmental aspects that need to be addressed and risks that need to be mitigated include CO_2/GHG (Climate impact), particulates, acidification, net energy savings vs fossils, reducing plastic waste in society, replacing substances of very high concern (SVHC). Several studies have calculated the environmental impact of different recycling technologies.

The goal of a CE Delft study (2020) on the potential contribution of chemical recycling to Dutch climate policy was to provide a first estimate of the potential climate change benefits of the chemical recycling of plastic waste streams in the Netherlands. They assessed plastic waste streams that are not suitable for high-value mechanical recycling but could be chemically recycled. Each of the identified waste streams can be treated with different technologies, ranging from incineration to (in some cases) mechanical recycling to various forms of chemical recycling (gasification, pyrolysis, depolymerisation and solvent-based extraction). For applicable technologies, information on the carbon footprint of waste treatment was gathered from previous research. The carbon footprints for chemical recycling technologies are derived from screening life cycle assessment (LCA) studies, based on information about the mass and energy balances of the treatment technology. Data for these screening LCAs was gathered from various companies and complemented with information from (scientific) literature and expert judgments. The carbon footprints indicate the impact on climate change of treating one tonne of plastic waste using various technologies. The carbon footprints consist of two parts: emissions and energy inputs and voided products/energy carriers. All carbon footprints are derived for the Dutch situation, meaning they are based on for instance the current Dutch electricity mix and the average Dutch energy efficiency of waste incinerators.

The carbon footprint results for the treatment of the losses from mechanical recycling are shown in Figure 13.

Figure 13: Carbon footprint of treating recycling losses with various technologies.



Source: CE Delft.[18]

The analysis of CE Delft shows that chemical recycling can make a substantial contribution to the goals of the Dutch government to reduce climate change impacts. If plastic waste streams can be imported from neighbouring countries, the worldwide climate change reduction may exceed 1 million tonnes CO_2 eq. by avoiding the current treatments.

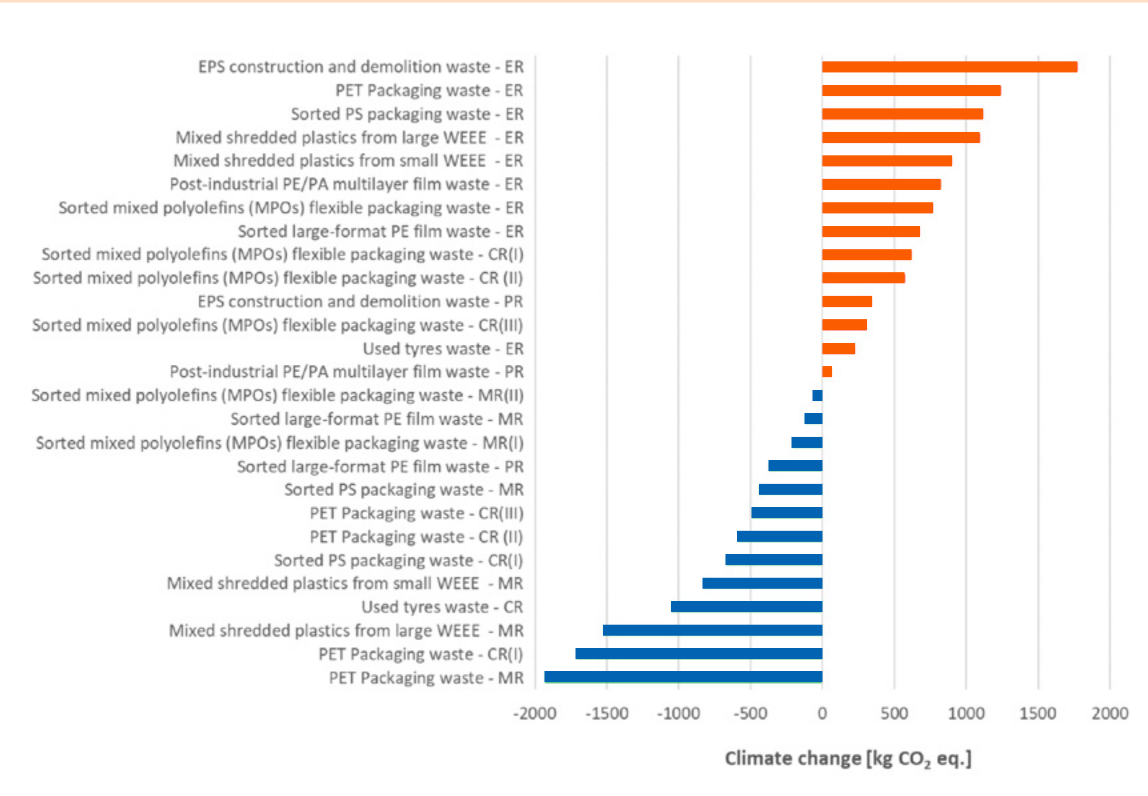
The climate change benefits differ per technology and waste stream. Due to the range in available technologies and their differing carbon footprints, chemical recycling should not be viewed as a single treatment option. Generally, technologies with lower carbon footprints have more specific requirements for the feedstock inputs. The climate change reductions of ‘short loop’ such as depolymerisation and dissolution (sometimes called ‘monomer recycling’) are comparable to mechanical recycling per kg of material input.

In contrast, gasification and pyrolysis (also called ‘feedstock recycling’) can deal with a wider variety of inputs, but offer lower climate change impact reductions. The carbon footprint of these ‘longer loop’ technologies lies in between that of mechanical recycling and incineration with energy recovery (based on Dutch efficiencies).

Summary overview of CO_2 emissions with the management of 1 tonne of various plastic wastes.

The graph below shows a ranking overview of the climate-change impacts for 27 scenarios investigated by the Joint Research Centre (JRC) of the European Commission. Plastic is used as a generic term to disaggregate different materials such as PET, PE and PP that make part of the waste feedstock.

Figure 14: Summary overview of CO_2 emissions with the management of 1 tonne of various plastic wastes.



Source: JRC Technical Report - Environmental and economic assessment of plastic waste recycling (2023)

Negative (blue) bars represent net GHG savings, while positive (orange) ones represent net GHG burden. For more information about the scenarios see JRC report (ref to JRC report). (ER is energy recovery, CR = chemical recycling, PR = physical recycling, MR = mechanical recycling

Contribution to Sustainable Development Goals

With the multiplying effects on employment and sustainability practices, chemical recycling plays a pivotal role in contributing to achieving the Sustainable Development Goals (SDGs).

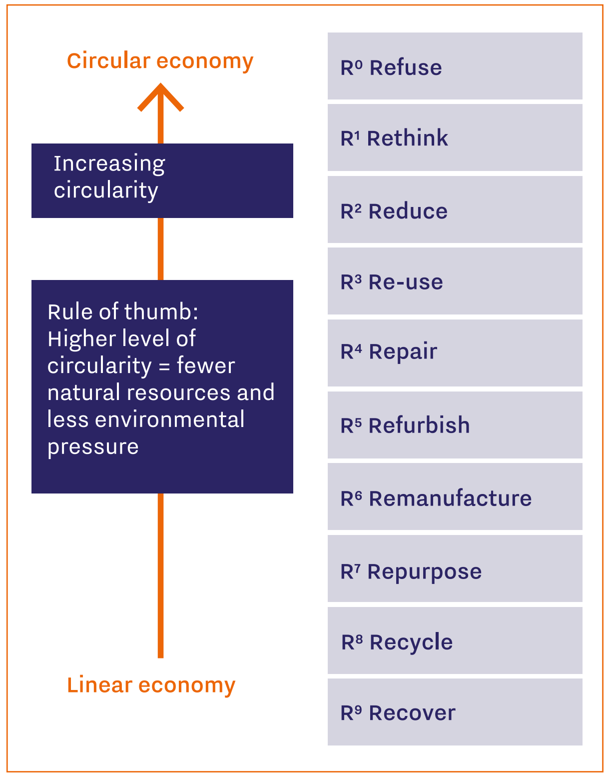
Chemical recycling contributes to multiple Sustainable Development Goals (SDGs). It supports SDG 9 by promoting innovation, sustainable industrialisation, and resilient infrastructure. It aligns with SDG 12 by enabling responsible consumption and production through sustainable resource management and waste reduction.

Chemical recycling also addresses SDG 13 by reducing greenhouse gas emissions and fossil fuel consumption, as well as SDG 15 by preventing land degradation and conserving resources. Lastly, partnerships in chemical recycling align with SDG 17 by fostering collaboration, technology transfer, capacity building, and financing for sustainable development.

Economical, environmental perspective, place in the 9R.

Chemical recycling has positive environmental impacts compared with landfill and incineration.[19/20] Likewise, this technique has positive economic effects.[21/22] Nonetheless, there are two critical challenges. First, large quantities of waste are necessary to guarantee the business's profitability. Although it is an issue, it is also an opportunity due to the high level of plastic consumption. The second challenge is related to the fact that it is a high-energy intensive process representing an economic and environmental problem. It is an opportunity for the chemical industry to invest in new techniques to reduce energy consumption. This all will ask for large investments and for this clear long term policies will be needed.

Figure 15: Levels of circularity



Source: Rood and Kishna (2019), outline of the circular economy. PBL Netherlands Environmental assessment Agency, The Hague. Available at http://pbl.nl/en/publications/outline-of-the-circular- economy

In general, chemical recycling is embedded in the 'Recycle' item of the 9R strategy. It generates new raw materials for different businesses. Earlier we mentioned that pyrolysis oil (hydrocarbon mix) can also be used to replace fuels like diesel or kerosine. The fuel route is considered less circular as it only creates one additional life cycle. In contrast, the route via chemical building blocks for new materials is a potential multicycle one. This is why the Dutch government only counts chemical recycling for chemical building blocks as recycling and considers chemical recycling for fuel as valorisation and not as recycling.

Packaging is the dominant plastic application today. The recycling status is important for waste producers and their eligibility under Extended Producer Responsibility for packaging. If plastic packaging waste is used as fuel it would not contribute to recycling targets under EPR.


Source: Unsplash

Leading the way: The Netherlands thriving Chemical Recycling industry

With the purpose of replacing 10% of domestic plastics production with recyclate from Chemical Recycling by 2030[23], the Netherlands is at the forefront of circular innovation in Europe.

The Netherlands has established an ambitious agenda, including the creation of a National Chemical Recycling Platform with a tailored policy and regulatory framework and active involvement from various inter-institutional stakeholders. This agenda is firmly grounded in the latest scientific evidence and will play a crucial role in the Netherlands' commitment to becoming a fully circular country by 2050.

The National Platform Chemical Recycling initiated the Circular Plastics NL program, which is a public private partnership program of 8 years with a budget of 220 million euros to be doubled by stakeholders.[24] The goal of Circular Plastics NL is to make plastics fully circular and accelerate the transition by technology development and investments in infrastructure as well as investigation of the societal aspects for the circular plastics transition. By fostering such cooperation, the Netherlands ensures a holistic approach to addressing the challenges of chemical recycling, including technological advance-ments, policy frameworks, and market incentives.

Moreover, as the Netherlands continues to experience steady growth, it proudly hosts a dynamic ecosystem comprising several prominent industrial clusters that significantly contribute to the nation's economy. In the following chapters, we will explore specific clusters in more detail, including the Rotterdam-Rijnmond (Rotterdam Port), Port of Moerdijk, the Chemelot Circular Hub in the South of Limburg, Amsterdam Port, and the regions of Delfzijl and Emmen (known as Chemport Europe).

The ARRRA region's journey towards a climate-neutral chemical cluster

In this chapter, we zoom in on the Netherlands; the country is by no means looking in isolation towards a sustainable future of chemistry. The trilateral region of Netherlands-Flanders-North Rhine Westphalia (ARRRA) is a world-class Circular Economy region of significant scale (45 million people) and high economic power (GDP> €2500 billion)[25]. It is also home to the ARRRA cluster: Antwerp-Rotterdam-Rhine Ruhr. This cluster stands as one of the largest chemical networks globally, interconnected through an underground pipeline system facilitating the transport of various feedstock and energy carriers, such as naphtha, ethylene, propylene, syngas, hydrogen, and methane. Currently, the cluster relies on fossil feedstock, this will need to transition to renewable and circular feedstock to reduce the significant CO_2 emissions in the ARRRA region.

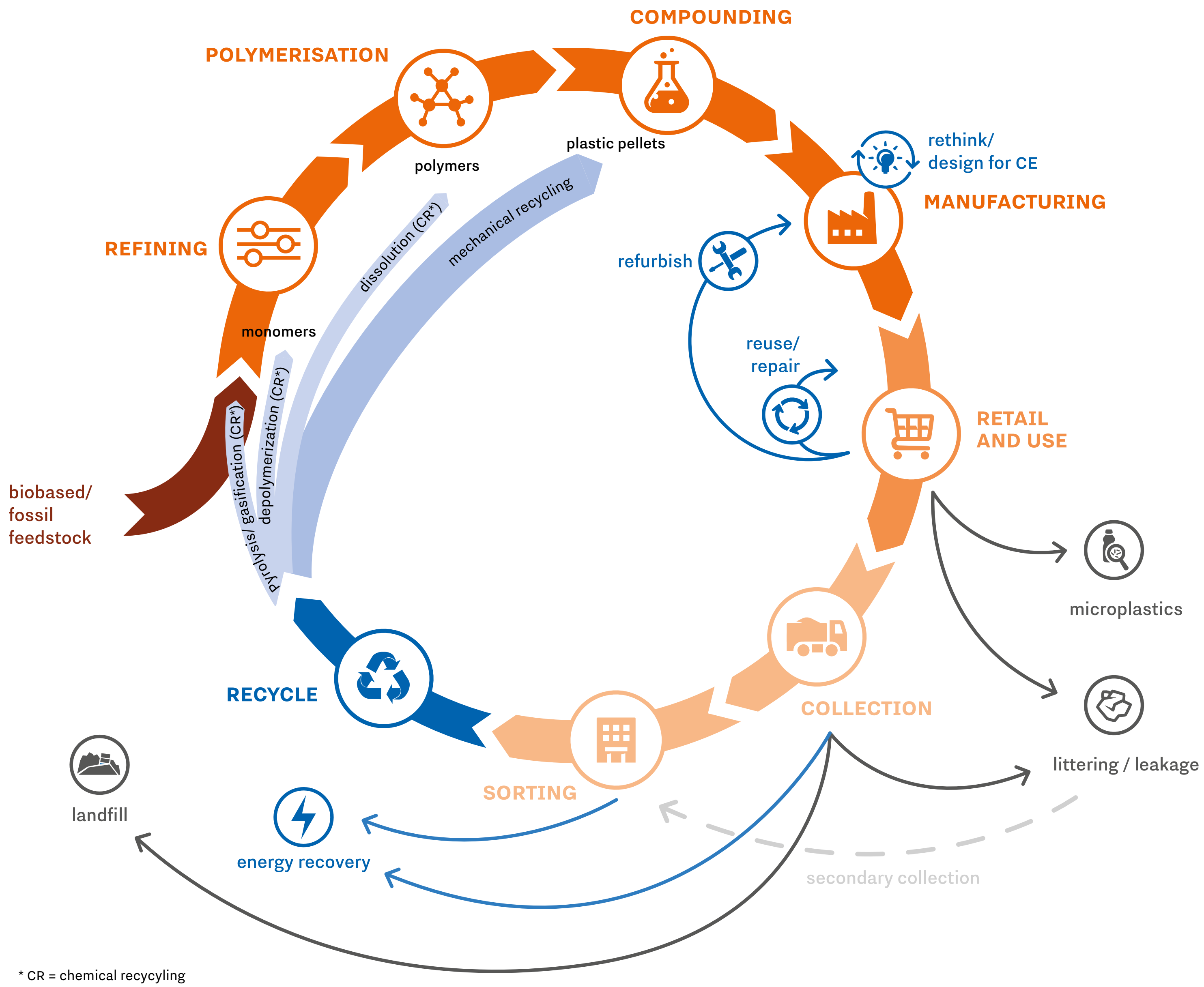
It is the authors' view that this trilateral region can play a leading role in the advancing chemical, thereby contributing towards a climate-neutral chemical cluster.


Source: Adobe Stock

The Netherlands policy milestones in Chemical Recycling (Timeline)

- 2016: The Dutch Raw Materials Agreement and related legislation for the definition of Transition Agendas for Plastics and Consumer Goods provided the framework for the current Chemical Recycling policy and initiatives. The aim is to achieve an **annual chemical recycling output of 250 kilotonnes by 2030**.[27]
- 2021: The Acceleration Table for Chemical Recycling led the efforts towards the Roadmap Chemical Recycling Plastics 2030 NL to foster funding and investment.
- 2019-2025: The ambitious Plastic Pact Plastic-using or -producing parties and other stakeholders pledged to reduce the environmental burden of plastics and promote circularity.
- 2017: With the release of the National Waste Management Plan (LAP3), the government set a conceptual and policy framework to guide the circular transition for several sectors such as packaging, plastics and consumer goods, where chemical recycling could help accelerate the supply of valuable raw materials. The plan is reviewed regularly to reflect regulatory and technological developments.[28]

Figure 15: A circular economy for plastics.



Source: Holland Circular Economy brochure: A Circular Economy for Plastics. (2021)[26]

Figure 16: Plastics roadmap for Chemical Recycling.

Plastics roadmap for Chemical Recycling	Starting point	Intermediate goal	Horizon 2030
Year	2020	2025	2030
Goal	First pilot and test plants are in the making or already running on different feedstock and/or technologies.	Approximately 500 kilotonnes of recycling capacity for plastic waste, along with concrete plans/projects for larger industrial facilities with a processing capacity of around 1 Megatonne.	CR is a mature industry, providing large-scale feedstock for the production of diverse materials, including those used in arts and manufacturing. About 10% of Dutch plastic production uses recycled input, reaching a recycling capacity of 1,000 kilotonnes/1.5 million tonnes of plastic waste.
Recycling Capacity (Kilotonnes)	50	500	1 - 1,5 Million tonnes
Milestones	**Scale-up phase**	**Industrial phase**	**Leading parties**
Pillar 1: Ambition and potential	1. Developing and testing a standardized carbon and CO_2 impact measurement/registration system. 2. Establishing design, collection, and sorting specifications for plastic waste. 3. Investing in initial (pilot) plants with potential for scaling up before 2025.	1. Concrete plans for at least 1 milion tonne recycling capacity comprising 1 or 2 large-scale plants of 200-400 kilotonnes capacity. 2. Permit applications in the pipeline. 3. A working financing ecosystem for scale-up.	Petro-chemical companies Technology developers (current start-ups and scale-ups) Producers of plastic products Financiers
Pillar 2: Feedstock	1. Offering plastic waste test batches for chemical recycling technology. 2. Testing sorting specs and investing in collection capacity. 3. Starting import volumes for chemical recycling by 2025. 4. Developing efficient logistics to recycling plants.	1. Importing up to 1.5 milion tonnes of plastic waste annually for chemical recycling plants. 2. Minimizing plastic in residual waste.	Product designers Plastic waste collectors and sorters Logistics parties (importers) Producer responsibility organisations
Pillar 3: Policy	1. Establish an efficient innovation financing ecosystem to get the first plants off the ground. 2. Develop a policy to enforce the use of recycled content. 3. Address adverse policies and laws, such as permitting food-grade applications. 4. Consolidate and give a full place to chemical recycling in LAP3. 5. Implement REDII at the EU level.	1. Implement an efficient working system for importing feedstock and establish a transparent and uniform registration system for the recycling of molecules/CO_2 allocation in the recycling chain at the EU level. 2. Cease the incineration of recyclable plastic waste.	Knowledge institutions Policy makers Stakeholder organisations Consultants

Source: Holland Circular Hotspot's compilation based on Roadmap Chemical Recycling Kunststof, VNO-NCW, Rebel Group (pag. 7-12).[24]

What needs to be done to achieve this goal

Multi-stakeholder collaboration plays a key role in accelerating Value Chain Alignment for chemical recycling and achieving the 2030 goals. Chemical recycling requires considerable investments and technological developments that will easily span the course of a decade. Accelerating development will thus be crucial to meet the set goals, and multi-stakeholder engagement is needed to facilitate the process.

'The Plastics Roadmap for Chemical Recycling' (2018) has recently gained momentum with the launch of several acceleration program tables, where value chain actors address challenges and bottlenecks in the industry. Among these are barriers to investment, funding opportunities, the feasibility of technologies, a supporting policy framework, and a cooperation platform for value chain collaboration to formulate a clear ambition and programmatic action plans towards 2030.[24]

As a result of this work, in 2020, the Dutch chemical clusters came together, and the **Roadmap on Chemical Recycling in Plastics 2030** was developed. The latter aims at shortening investments that would typically take 5-10 years to 2-5 years and builds upon the three pillars:

1. **The ambition and potential of chemical recycling for the Dutch Plastics Industry/Chemical Cluster (Recycling)**
2. **The Sourcing of plastic feedstock and the impact of the recycling sector**
3. **Supporting a circular policy; and a policy framework for chemical recycling**

The National Chemical Recycling Platform (Moonshot programme Chemical Recycling)

Stakeholder collaboration has resulted in the establishment of the National Chemical Recycling Platform, with the primary goal of promoting knowledge exchange and coordinating related initiatives. The platform works to identify knowledge gaps and areas of opportunity for innovation and R&D, which can then be addressed through tailored programs.

The platform is connected to initiatives in the Netherlands-Germany-Belgium area and was created in response to requests from the Ministries of Infrastructure & Water Management (I&W) and the Ministry of Economic Affairs and Climate Policy (EZK). It includes the participation of ISPT/DPI, Brightsite, TNO, VNO-NCW (Accelerator House), as well as national and international (European) consortia and individual companies throughout the country.[29]

In cooperation with NWO and the Ministries of I&W and EZK, the Platform is developing a programmatic approach to create a public-private funding package for applied research and piloting.

Launched by Circular Biobased Delta (CBBD), the Chemical Recycling Network is an active community that unites companies in the chemical industry dealing with biomass and waste plastics, fostering collaboration, knowledge sharing, and technology updates. With a diverse membership of 20 SMEs and large companies, the network aims to support entrepreneurs in exploring and expanding their presence in the rapidly growing chemical recycling industry.

The Dutch actors have identified the challenges ahead and provided input for a **Chemical Recycling policy framework in the European policy agenda**[17]. (see Chapter 4: Action agenda)

Introducing CBBD Network Chemical Recycling

Equipment & Services

Tech companies

Knowledge parties

Entrepreneurs

Government

Independent organiser

Large companies

Source: Chemport Europe

Driving sustainable solutions: The Dutch chemical industry's trailblazing role

The Dutch chemical industry and clusters

The Dutch chemical industry stands as a well-established and proactive participant in the global effort to combat climate change. The sector contributes significantly to decreasing greenhouse gas (GHG) emissions and promoting circularity thanks to its strong economic ties and favourable trade balance.

The Dutch chemical recycling industry is well-integrated and clustered, both domestically and internationally, particularly within the Antwerp-Rotterdam-Rhine-Ruhr Area (ARRRA) cluster. The sector's diversity is notable, with over 800 companies. Overall, the Dutch chemical industry's role in chemical recycling and its development within chemical clusters reinforces its position as a leader in sustainable solutions.

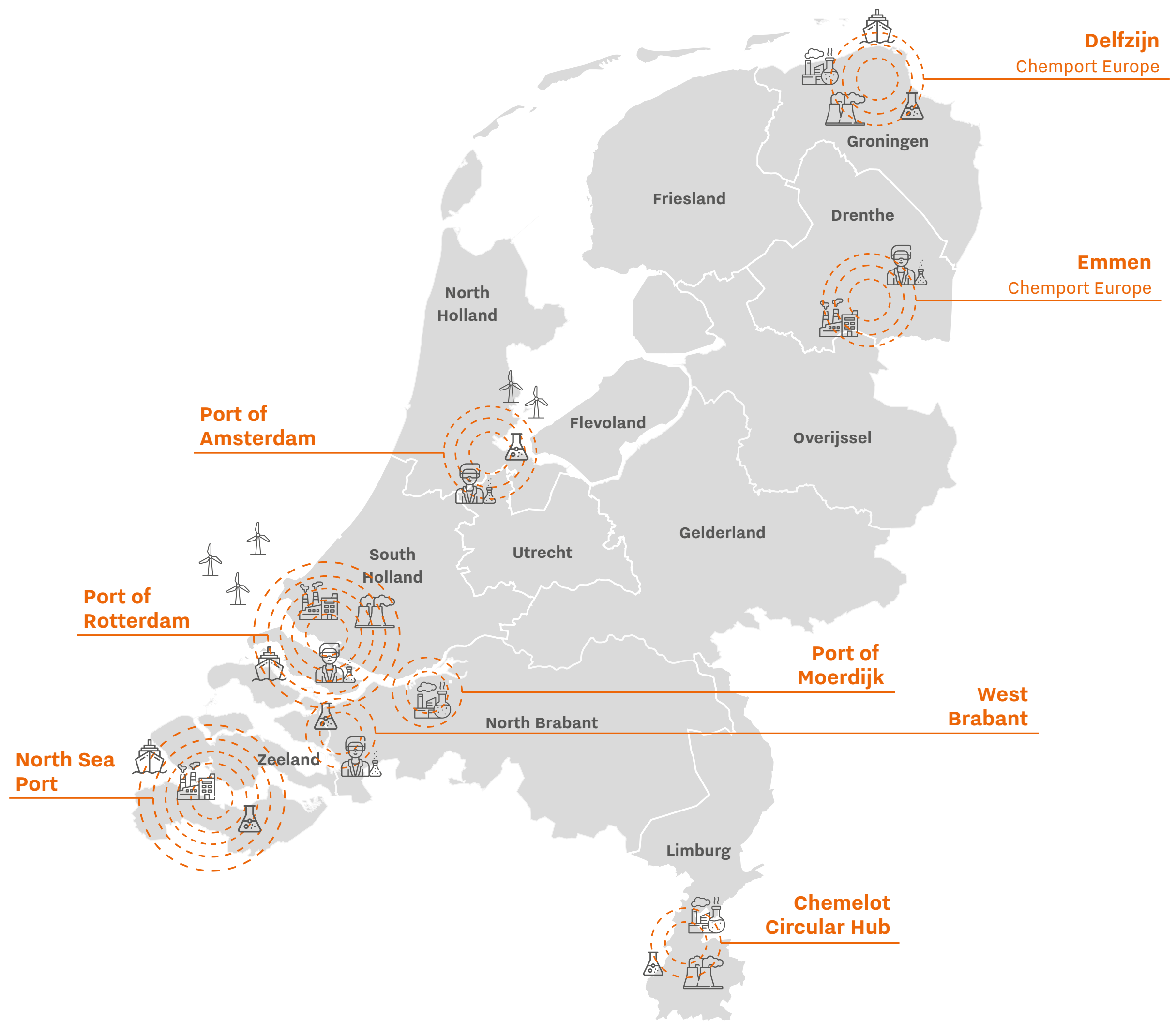
The Netherlands benefits from its advantageous geographic position, which offers quick access to continental Europe and reliable maritime export connections. This has encouraged the growth of businesses across the chemical recycling value chain. These businesses are now becoming tightly woven together, especially in places like Rotterdam Port, Amsterdam Port, Groningen Seaport, Chemelot, Zeeland, and Chemport Europe.

These chemical clusters offer competitive benefits, such as effective energy and material exchange, facilitating logistical and operational efficiency. The Dutch chemical recycling market also benefits from a strong position in knowledge, backed by top-tier technical universities and technological centres, ensuring ongoing innovation and sector expertise.

The prominence of the Dutch chemical industry is a result of its significant economic contributions, global reach, and integration with chemical clusters. To thrive and maintain its preeminence, it leverages competitive advantages such as strategic location, knowledge base, and cooperative networks.

In the Netherlands, six clusters of chemical industries can be observed, characterised by a high degree of integration and innovative power (refer to Figure 17).

Figure 17: Clusters of chemical industries in the Netherlands.



Source:Holland Circular Hotspot (2023)

CHEMELOT CIRCULAR HUB

The Chemelot Circular Hub (CCH) is an ambitious program dedicated to efficient plastic, biomass, and mixed waste recycling. Alongside chemical and mechanical recycling, it prioritises circular design and biogenic resource utilisation.

The project aims to accelerate waste technology advancement through a specialised field lab for solvolysis and chemical recycling. Pyrolysis will be utilised to convert hard-to-recycle waste into valuable cracker feedstocks, with targets of 400 KTPA (Kilotonnes Per Annum) of pyrolysis oil by 2030 and 1 million tonnes per year by 2040.

Additionally, CCH also explores a direct waste-to-cracker approach to enhance efficiency and eliminate the need for existing crackers, transforming tires into carbon black or new rubbers, and producing hydrogen from mixed waste gasification. The program prioritises recycling polyamides and polyesters and plans to establish a low-carbon footprint circular caprolactam demonstration plant by 2030. Solvolysis technology targets the efficient conversion of plastics like High-Impact Polystyrene, Acrylonitrile Butadiene Styrene, and PolyVinyl Chloride into their monomers.

The CCH also focuses on capturing and reusing any remaining CO_2 emissions through gas fermentation and Fischer-Tropsch conversion, promoting a sustainable and circular future at Chemelot.

www.chemelotcircularhub.com

chemelot
for today's future

PORT OF ROTTERDAM

As Europe's largest port and the most significant raw materials cluster in the Netherlands, the Port of Rotterdam (PoR) collaborates closely with regional and value chain partners to develop a new, circular value chain centred around chemical recycling and the reuse and recycling of batteries. Within this cluster, chemicals and other materials such as fuels, edible oils, and fats are produced at a large scale for use in Europe and for global trade.

Comprising 5 oil refineries and over 45 chemical companies, the cluster features the Circular Recycling Company (CRC), specialised in recycling wind turbine blades. CRC relies on a regional supply chain to source end-of-life products made of fibre-reinforced thermoset composites, serving as secondary raw materials.

These recyclates are already being employed in construction and infrastructure technology, while ongoing tests explore their inclusion of thermoplastics to make them suitable for automotive applications. The collection, sorting, and mechanical or chemical processing of these materials creates various recycling streams, leading to CO_2 savings by incorporating recycled composites in new products instead of virgin materials.

Moreover, PoR forms an additional cluster with the petrochemical industry in the Netherlands, Belgium, and Germany, boasting an integrated pipeline connection responsible for 40% of the EU's petrochemical production.

www.portofrotterdam.com

Port of Rotterdam

Chemport Europe - Groningen Seaports

CHEMPORT EUROPE - GRONINGEN SEAPORTS

Chemport Europe is an innovative ecosystem for chemicals and materials in Northern Europe that brings together companies, governments, and knowledge institutes to change the nature of and accelerate the transition towards sustainable chemistry. The ecosystem comprises 120+ companies clustered around Delfzijl/Eemshaven and Emmen, with recycling expertise around Heerenveen.

Additionally, there is a large knowledge cluster of universities, a seaport with access to offshore wind energy, and a highly engaged government. Chemport's ambition is clear: becoming the European green chemistry leader by 2030. Within this playing field, circular polymers and recycling are prominent, alongside biobased materials, CO_2, and hydrogen as feedstock.

Groningen Seaports is part of Chemport. It aims to be Northwest Europe's most important green port and industrial area by 2030. Groningen Seaports is emerging as the circular hub in Northern Netherlands by focusing on biobased chemistry and recycling. Within this hub, the following harvesting raw materials are available: end-of-use plastics, end-of-use electronics, depreciated wind turbine blades, and construction and demolition materials.

www.chemport.eu
www.groningen-seaports.com

CHEMPORT EUROPE
GRONINGEN SEAPORTS

PORT OF MOERDIJK

Port of Moerdijk is the fourth national seaport and second largest container port of the Netherlands. As an industrial and European logistics hub it is strategically located between Rotterdam and Antwerp. Port of Moerdijk has a strong and extensive chemical cluster. Via its pipeline system, it is directly connected with the chemicals clusters in Antwerp, Rotterdam, Northsea Port, North Limburg, and the Ruhr area. Operating circular, chemical, and petro-chemical companies have plenty of opportunities at the Industrial Park Moerdijk to establish new businesses. At the Industrial Park Moerdijk, about 30 hectares are currently allocated and available for circular economy only.

The chemical cluster is constantly creating synergy. Companies exchange basic raw materials such as ethylene oxide, ethylene, and propylene. Residual flows find their way to new users. Steam and CO_2 are waste for some and raw materials for others. At Port of Moerdijk, chemical, recycling, and energy companies make use of each other's raw materials and residual streams and thus close the chains.

www.portofmoerdijk.nl

PORT OF MOERDIJK

PORT OF AMSTERDAM

In the Westpoort industrial area of Amsterdam, a growing cluster of chemical recyclers and biobased production activities is transforming the port's industrial landscape. This shift is steering the port away from its traditional linear, fossil-based industry towards a circular and renewable ecosystem. By employing co-siting, symbiotic processing, utilising existing assets, and sharing knowledge, the Port of Amsterdam and its customers are collectively fostering sustainable and mutual value for the port, city, region, and European hinterland.

A thorough analysis of feedstock, product, and energy flows enables the implementation of 'smart clustering,' ensuring that all stakeholders benefit from improved efficiency, cost reductions, stable production, and product offset. This collaborative effort demonstrates a strong commitment to actively contribute to the development of a more sustainable and prosperous port for the future.

www.portofamsterdam.com

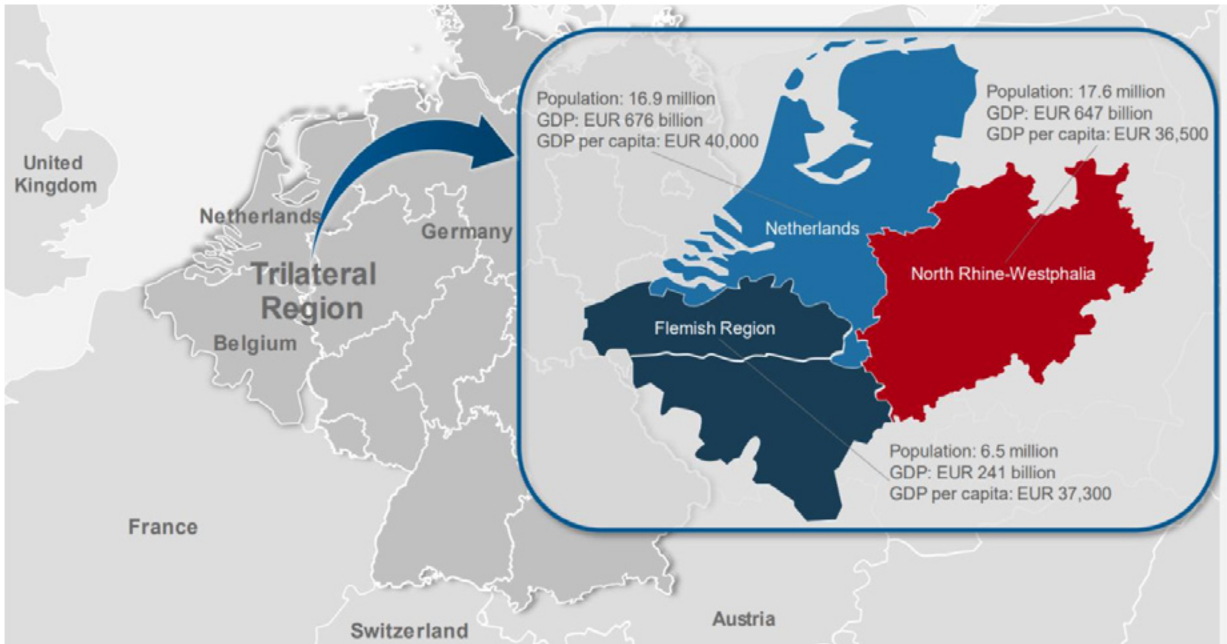
Port of Amsterdam

The Trilateral Agreement Initiative[30]

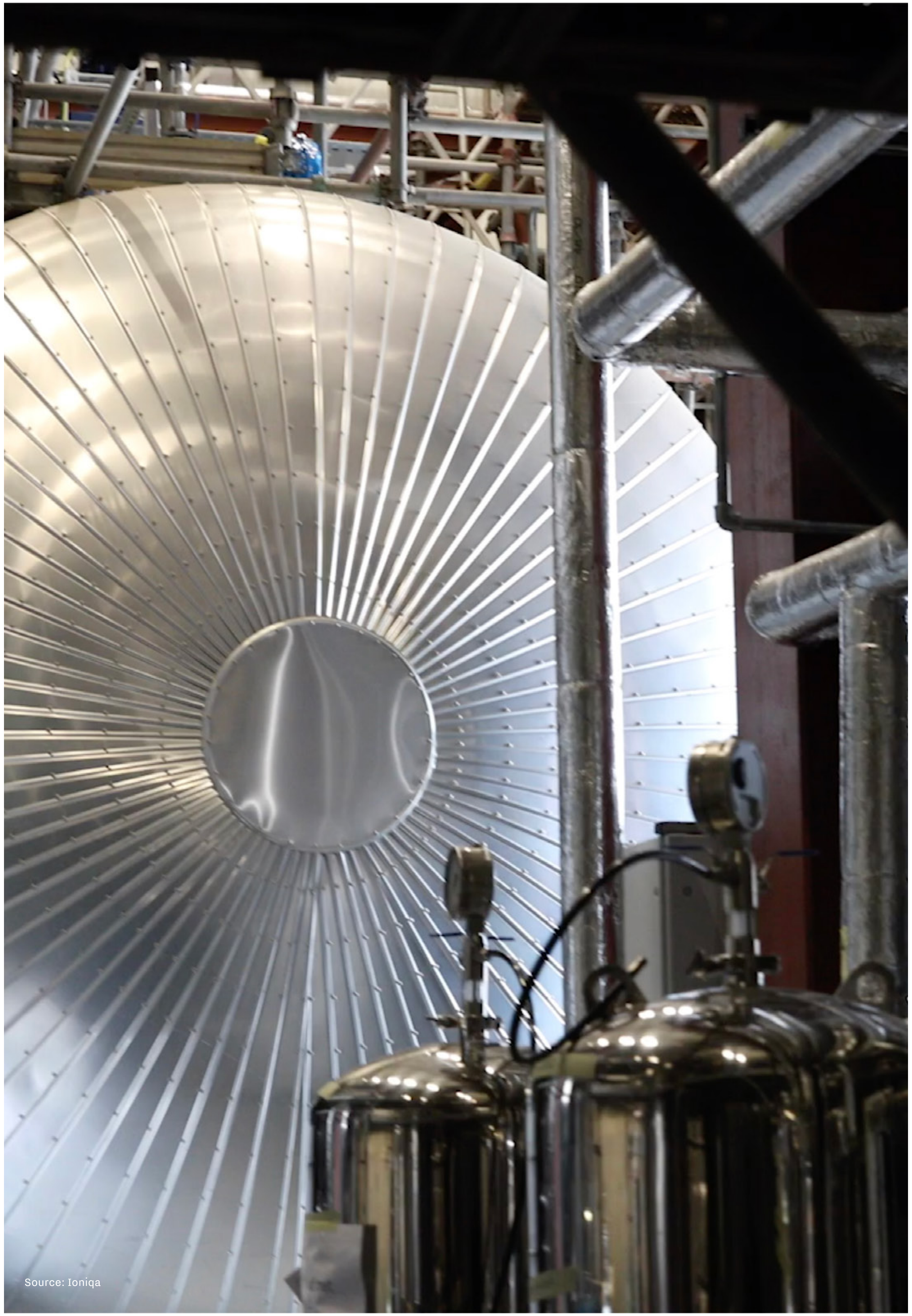
With a turnover of 180 billion euros and more than 350,000 persons employed in the chemical industry (2015), the trilateral region of North Rhine Westphalia (DE), Flanders (BE) and the Netherlands is home to one of the world's most powerful chemical industry clusters with a long history in the three regions. Remarkably, nearly 20% of the European chemical industry's total turnover comes from this region, making it the highest-performing chemical region worldwide.

The trilateral chemical industry's success is attributed to its Verbund structure, which promotes efficient production by integrating chemical plants. This region contributes significantly to downstream value chains and is a major investor in research and development in Europe. The cluster consists of numerous SMEs, start-ups, and a diverse, high-quality R&D landscape.

In the region, the chemical industry accounts for 5.5% of the economy in terms of turnover, solidifying its position as the 'industrial heart' of the European chemical sector.



Source: Trilateral Chemical Region. Retrieved from www.trilateral-chemical-region.eu



Source: Ioniqa

Chapter 3

The Dutch Eco-system and best practices for Chemical Recycling

In the transition from a linear to a circular economy, chemical recycling plays a pivotal role. In the Netherlands, we have a very strong ecosystem living up to the challenge. Technology start-ups as well as large chemical companies, work on developing and scaling up various conversion processes to realise new value chains. Waste handlers, recyclers and big consumer brands also play an active role and support the transition. Historically we have a very strong chemical and materials sector, operating from a number of hot spots in the country where logistics, (shared) facilities, talent and system integration are fundamental to the success. The world-leading universities and research institutions of The Netherlands are the fuel and lubricant in this innovation machine.

In this chapter, we showcase a good number of best practices from this ecosystem working on the material transition. This should give you a good impression without pretending to be complete.

We have structured the showcases into the following categories:

- **Feedstock handling and pre-treatment**
- **Solvolysis and chemical depolimerisation**
- **Thermochemical recycling**
- **Gasification and H2 production**
- **Equipment and services**
- **Ports and industrial sites**

In the transition to a circular economy, we see a variety of new value chains developing. Different feedstocks will be combined with a number of new conversion processes to yield various products. The theoretical number of combinations is large, but only the best solutions resulting in high yields of valuable products with low cost will determine the industry of the future. This complex and dynamic scene makes for interesting times, which are also challenging to navigate with risks that are hard to manage. With this glance into the Dutch ecosystem, we hope to help you in your journey towards a circular economy!

Feedstock handling and pre-treatment

The circular economy starts with **waste handling and pre-treatment**. Turning waste into useful feedstock is a serious business where logistics and technology for separation and cleaning play a major role. Here advanced sensoring, artificial Intelligence and robotization are key tools.

Source: Renewi

RENEWI

Renewi is a leading waste-to-product company that gives new life to used materials every day. For Renewi, waste is an opportunity. That's why Renewi is investing in state-of-the-art sorting lines to further separate mixed commercial and building & demolition waste. From these new sorting lines they sort hard-to-recycle plastic foils as input material for Pyrolysis technologies and a high-caloric waste fraction for gasification. Material that today goes to incineration.

Renewi offers consistent and large quantities of high-quality circular raw materials, state-of-the-art facilities, systems and professional staff as well as an extensive network of customers and partners with shared circular ambitions. The result of our work is less waste and contamina-tion, a smarter use of scarce raw materials, and a reduction in carbon emissions, therefore contributing towards a cleaner, circular world.

www.renewi.com

Solvolysis and chemical depolimerisation

A special conversion process that is developing rapidly is depolimerisation through **solvolysis and chemical depolimerisation**. In value chains where these processes are suitable the potential of high yield, low energy consumprion combined with high product quality is very attractive but not easily obtained.

IONIQA

Ioniqa's technology demonstrates that waste may be endlessly recycled as a secondary raw material, providing the market with a high-quality substitute for virgin products. This allows for a better cost base and addresses a scarcity of recycled PET. By using magnetic particles and a unique separation process, Ioniqa has succeeded in breaking down PET Polyester into coloured, virgin raw materials at competitive prices, prices which are only to a limited extent depending on oil prices. Ioniqa has a 75% lower CO_2 footprint compared to oil-based PET production.

Ioniqa has protected important components of her Intellectual Property (IP) via a portfolio of patents that are applicable in different jurisdictions, including Europe, the USA, China, and Japan. The licensing products provide their IP, know-how, and proprietary catalyst access.

www.ioniqa.com

CURE TECHNOLOGY

CuRe Technology is a consortium of recycling innovators and experts. The companies strive to recycle any kind of used polyester and make this the new normal. The aim is to CuRe any type of used polyester by purifying it and converting it into high-grade, ready-to-use 100% PET, which can replace PET from fossil-derived sources.

CuRe Technology has already joined lab scale experience, capabilities, and forces and has built a pilot plant in Emmen (Netherlands) for rapid scale-up, which aims to provide a sustainable CuRe for used polyester as well as an energy-efficient solution for endless product-to-product transformation to create a fully circular polyester chain. Furthermore, a key objective is to create partnerships all over the world, not only to improve the technology but also to share know-how of how we produce, use, and collect polyester products.

www.curetechnology.com

Source: ioniqa

Thermochemical recycling

For the more challenging and heterogeneous feedstocks thermochemical recycling provides a very robust conversion platform. The possibility to process mixed plastics and mixes of plastics and biomass as well as effective separation of contaminants and inerts is the attractive side of these processes making them promising for the future circular economy.

SYNOVA

Synova technology enables companies to divert waste from landfills and close the loop on the plastic supply chain through a continual use of resources. Synova and Technip Energies provide a process to convert plastic-rich waste (e.g., DKR 350) into the original building blocks: ethylene, propylene, butadiene, benzene. This involves cracking of solid waste feedstock at conditions similar to existing steam cracker units operated on fossil feedstock. The products are cleaned and separated to a quality where these can be added to existing recovery units of petrochemicals plants. Key features of this recycling process are (1) bypassing existing crackers, and (2) allowing feedstock to be contaminated with glass, stones, paper and food residues. This results in cheap feedstock, high yield of products and high CO_2 reduction.

www.synovatech.com

SYNOVA

CLARITER

Clariter is a global cleantech company producing green sustainable petrochemicals upcycled from plastic waste. These high-quality alternatives to fossil-based products can be used in over a thousand industrial and consumer applications and help industries create circularity in their value chain.

Clariter's patented chemical recycling technology can convert different types of plastic waste into three high-purity product families, including solvents, oils, and waxes. The process offers a high yield of around 80%, reduces plastic waste, and decreases global dependency on fossil fuels. The products meet industry and FDA purity standards, providing sustainable alternatives to fossil-based industrial and consumer products. Clariter's technology is a commercially mature solution to the global plastic waste problem, which provides a unique combination of quality, sustainability, and profitability.

www.clariter.com

clariter

Source: Blue Cycle

BLUE CYCLE

Blue Cycle has constructed a pyrolysis plant in Heerenveen (Netherlands) with the capacity to process 20,000 tonnes of waste plastics per year. Some types of plastic are not suitable for mechanical recycling (such as plastic packaging waste) but Blue Cycle includes these difficult-to-recycle and low-tier plastics into the pyrolysis process. The plant is currently operating using chemical recycling methods for consumer plastics. Blue Cycle heats non-recyclable plastics at high temperatures and transforms them into pyrolysis oil through a specialised process. This oil can be utilised as a substitute for fossil fuels in refineries and crackers to produce high-quality plastics. The chemical recycling approach adopted by Blue Cycle aims to aid in the reduction of fossil resource consumption and CO_2 emissions.

www.bluecycle.frl

BLUE CYCLE

SABIC - PLASTIC ENERGY ADVANCED RECYCLING B.V.

Advanced recycling technology company Plastic Energy and global chemicals leader SABIC are in the final stages of construction on their joint 20,000 tonne capacity advanced recycling plant, located in Geleen, the Netherlands. This joint venture (SABIC Plastic Energy Advanced Recycling B.V.) will use Plastic Energy's patented recycling technology to convert end-of-life plastic waste into TACOIL™, an alternative feedstock that can be used to create virgin-quality food-grade plastics. SABIC will use the TACOIL™ as a replacement for fossil oils to manufacture certified circular polymers from their TRUCIRCLE™ portfolio. The collaboration between Plastic Energy and SABIC is important to deliver more recycled content for brands to meet recycled packaging targets, and to build a circular economy in the Netherlands

www.plasticenergy.com
www.sabic.com

سابك sabic | PLASTIC® ENERGY

Source: BioBTX

BIOBTX

At BioBTX technology for a circular world is developed. BTX is produced from biomass and plastics. The BioBTX technology makes it possible to move from a linear fossil world to a circular renewable society. Carbon is a vital component in high-performance materials like coatings, polymers, and pharmaceuticals, which cannot be decarbonised. To enable sustainable materials, it's crucial to obtain renewable sources of carbon. Although biomass provides renewable carbon, recycling all the carbon used in our society would be even better. BioBTX has developed technology that can convert mixed plastic waste and biomass into the chemical building blocks essential in our society. The technology has been developed for over 12 years, and BioBTX is currently in the process of scaling up to the first commercial demonstration plant.

www.biobtx.com

BioBTX

BLUEALP - SHELL

BlueAlp is a recycling company that uses a patented pyrolysis process to recycle plastic waste. BlueAlp's technology produces high-quality pyrolysis oil with low energy consumption. Under a partnership with Shell, two new pyrolysis units will be built in the Netherlands with a capacity of 17 kilotonnes plastic waste per year. Under a Joint Development Agreement Shell and BlueAlp have made big improvements to the technology and are constantly developing the BlueAlp technology further. BlueAlp launched its first pilot plant in Switzerland in 2004 and the first commercial plant in Ostend, Belgium, in 2020. Borealis is one of the chemical giants that has put its trust in the BlueAlp technology to help reach its circular goals. BlueAlp has developed a next version of its technology with an annual capacity of 70 kilotonnes plastic waste per annum to be licensed to current and future customers.

www.bluealp.nl

BLUEALP
Accelerating Plastic Recycling

NESTE

Neste is advancing chemical recycling to process hard-to-recycle plastic waste into raw materials to create new plastics. Many plastic products, such as films and multicomponent materials, cannot efficiently be mechanically recycled – and instead end up in landfill or incineration. Chemical recycling can turn those waste streams into new raw materials, which can be used to replace virgin fossil input in the plastics value chain. Neste has the ambition to process more than 1 million tonnes of plastic waste from 2030 onwards. The plastic waste would be liquefied and then processed into feedstocks for new plastics at Neste's refinery in Porvoo, Finland. There, Neste is expanding capacities in pretreatment and upgrading of liquefied plastic waste in the EU Innovation Fund-backed project PULSE.

www.neste.com

NESTE

Source: Neste

Gasification and H2 production

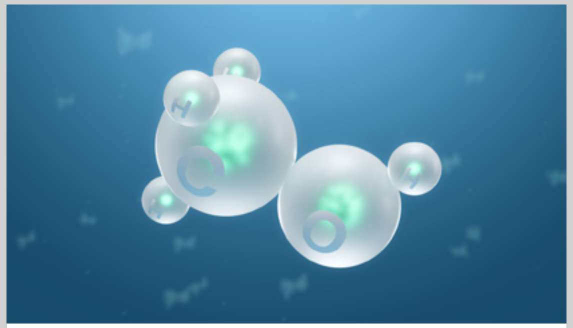
At the next level of even more challenging feedstocks such as true municipal solid waste and rejects out of the other processes pretreatments we find the sweetspot for **gasification and H2 production**. Both sustainable syngas and hydrogen are products that are key in the raw material transition.

RWE FUSE REUSE RECYCLE (FUREC)

RWE's FUREC project aims to produce circular and green hydrogen from non-recyclable municipal solid waste (MSW). It involves a pre-treatment plant that converts MSW into solid recovered fuel pellets. About 700,000 tonnes of MSW, with 50% being biogenic waste, will be processed annually. These pellets will then be used to produce hydrogen at a second RWE plant in Chemelot, generating 54,000 tonnes of hydrogen per year. By using this hydrogen, Chemelot can reduce its natural gas consumption by over 280 million cubic meters annually, resulting in a CO_2 reduction of around 400,000 tonnes per year.

Additionally, the CO_2 released during hydrogen production can be captured and stored, or potentially used as a raw material by industries in the future. The project contributes to sustainable waste management and the transition towards a greener energy system.

https://benelux.rwe.com



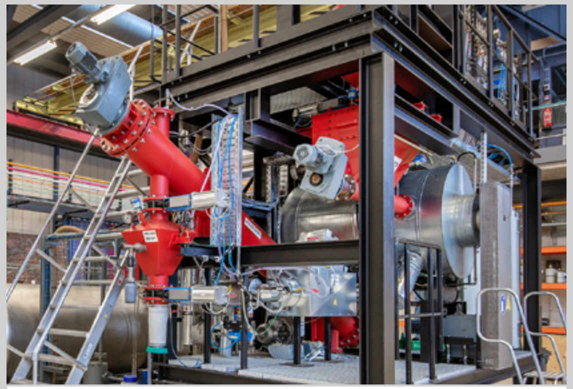
GIDARA ENERGY

Gidara Energy uses its patented technology to convert non-recyclable waste into advanced biofuels and circular chemicals. Through their high-temperature winkler (HTW® 2.0) technology, Gidara Energy can produce valuable circular products and advanced biofuels for use inroad transport, marine and aviation sectors. Gidara Energy aims to meet the demand for cleaner fuels and create a more circular economy while minimizing waste. By replacing fossil resources, these sectors can significantly reduce their carbon emissions and become more sustainable.

With decades of experience in waste gasification, their commercially mature HTW® 2.0 technology is the industry's leading gasification process. Through their innovative approach, Gidara Energy drives the transition towards sustainability, replacing fossil resources and shaping a greener future.

www.gidara-energy.com

Source: RWE Fuse Reuse Recycle



BRIGH2

The BrigH2 project is working towards a sustainable solution for the chemical industry by creating gasification plants that convert torrefied biomass into hydrogen, which can be used as a raw material for chemical processes. The project focuses on developing a 50 MW demo plant that aims to produce biogenic carbon while reducing greenhouse gas emissions. Torrgas is providing gasification expertise based on its 1 MW installation in Groningen, which generates tar-free synthesis gas from biomass. BrigH2's initiative is driven by the increasing demand for hydrogen and biogenic carbon in the Chemelot industrial park, where they currently produce these resources through their synthesis gas processes. By expanding and optimizing these operations, the project aims to meet the industry's growing needs while promoting sustainability and eco-friendly practices.

willemjanvanasselt@brightlands.com

Equipment and services

For a succesfull new value chain reliable **equipment and value added services** such as certification, quality and analytical systems are of fundamental importance. That is why we are proud of the strong players in this field in our eco-system.


Source: Bureau Veritas

BUREAU VERITAS - PRYME

Bureau Veritas provides independent laboratory testing, inspection, and certification services. They offer innovative solutions to help clients ensure that their assets, products, infrastructure, and processes meet standards and regulations.

In a recent project with Pryme, Bureau Veritas was commissioned to inspect and consult on the quality and safety of essential process elements in the construction of their Rotterdam chemical recycling plant. Bureau Veritas' expertise in quality and assurance enabled Pryme to develop a proof of concept that can scale the production of renewable petrochemical products at 40 kilotonnes per year. To ensure that Pryme complies with high sustainability require-ments, the products will be audited by Bureau Veritas under the ISCC PLUS certification.

Bureau Veritas is set to support quality monitoring of the process by testing and analysing samples from feedstock to end product at Pryme's mega recycling plant.

www.group.bureauveritas.com

Source: ALFA Laval

ALFA LAVAL

Alfa Laval specializes in products and solutions that enhance the efficiency of chemical recycling processes, minimize waste, and reduce energy consumption while maximizing water recovery and yield quality.

Their comprehensive product range includes durable welded heat exchangers, centrifugal separators, decanters, and Zero liquid discharge solutions, all of which play crucial roles in chemical recycling and water waste treatment. Moreover, Alfa Laval goes beyond providing equipment and components by offering expertise in various chemical recycling processes, particularly in converting mixed or contaminated plastics into valuable chemicals, fuels, and other high-value products. Their thermal systems efficiently convert waste streams into energy, while their separation technology enables the recovery of valuable materials from waste, even with impurities or variable compositions. Overall, Alfa Laval's solutions optimise efficiency, reduce energy consumption, and contribute to a more sustainable chemical recycling process.

www.alfalaval.com

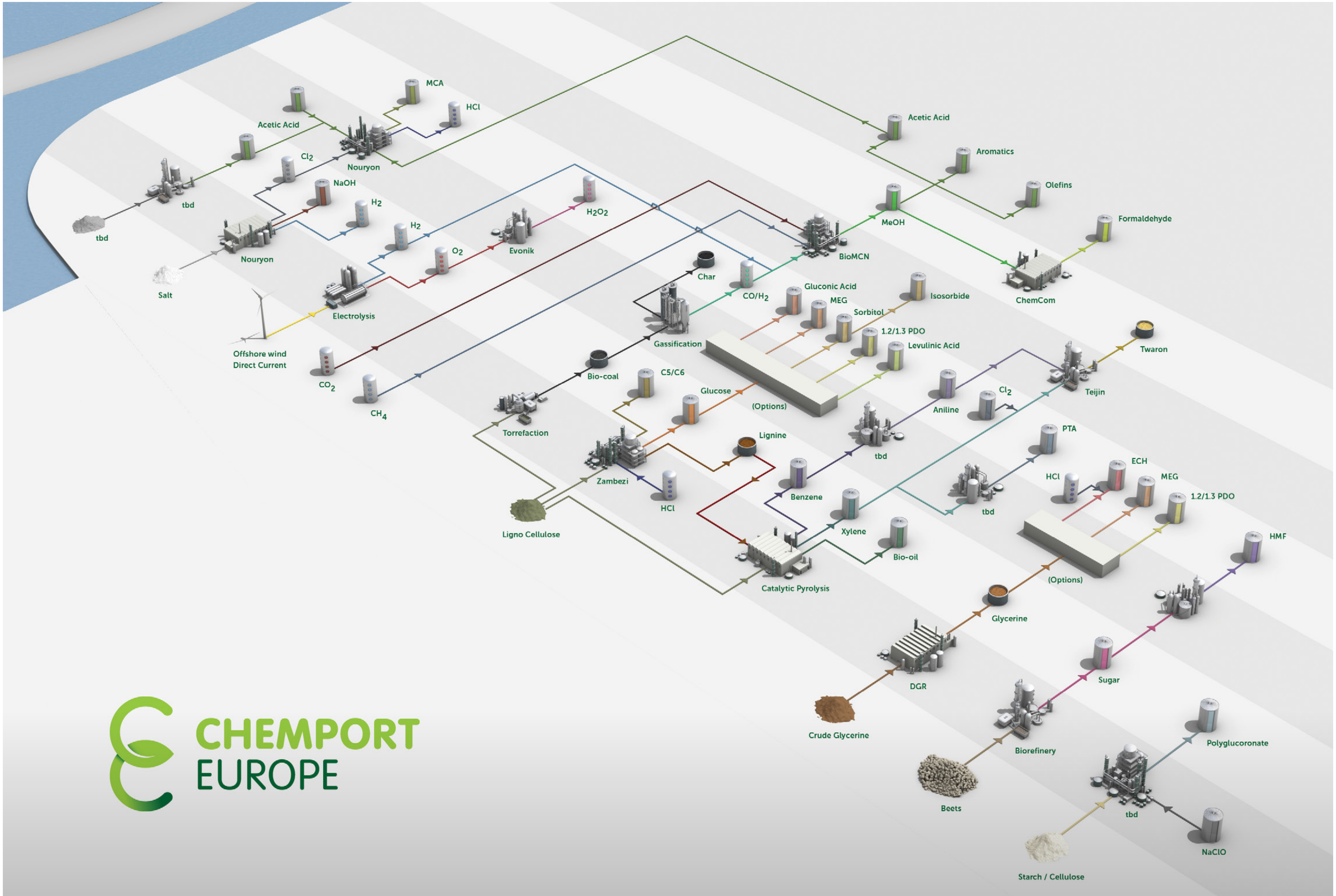
INFINITY RECYCLING

Infinity Recycling is a growth capital firm based in the Netherlands investing in advanced plastic recycling technologies with the aim of accelerating the transition to a circular economy of plastics. By making investments across various technologies and securing offtake, Infinity seeks to accelerate the transformation of the plastic/polymer life cycle and achieve strong returns in a nascent market.

It's first offering, the Circular Plastic Fund (CPF) with an initial target size of €150 million, is an Article 9 'dark green' impact fund under the EU's Sustainable Finance Disclosure Regulation. Since the fund's launch in February 2022, the team has made significant inroads in the advanced recycling market investing in four portfolio companies and embarking on a journey with management to achieve operational excellence for long-term value creation and sustainable development.

https://infinity-recycling.com

Source: Adobe Stock



Source: Chemport, Chemport Cluster in Delfzijl is producing chemical building blocks starting from renewable, non-fossil feedstock

Source: Unsplash

Chapter 4

Future visions and action agenda

Throughout this brochure we discussed the relevance, urgency and opportunities of chemical recycling. To round it up we share four independent visions on the future of chemical recycling by the Trilateral Chemical Region, Unilever, the Association of the Dutch Chemical Industry and Zero Waste Europe. This is followed by a pathway and action agenda by the authors of this publication.

Trilateral collaboration as a key for developing a circular carbon economy

Colette Alma-Zeestraten
Chair of the innovation working group of the Trilateral Chemistry Region

In 2017, Flanders, North Rhine-Westphalia, and The Netherlands agreed on a trilateral strategy for their chemical industry, which represents 20 % of the European chemical industry. They agreed on three work packages: one on logistics, one on energy & feedstock, and one on innovation to achieve their shared aspired goal: a fully sustainable and competitive chemical industry in the trilateral region. A lot has happened since 2017: the present context makes the agreed goal even more relevant and demands an even higher pace toward this goal. It is in this context that recently, a matching event took place where multiple advanced innovation initiatives (pilot and demo phase) laid connections with cross-border partners to accelerate time-to-market. The event was very encouraging: it displayed a high level of creativity and ambition in the industry to develop new circular pathways and many new start-ups with novel business plans.

The challenge is high: to ultimately eliminate all novel fossil inputs, several pathways have to be developed in parallel to process waste streams: mechanical recycling and chemical recycling in various forms such as depolymerization, pyrolysis, and gasification.

Cross-border collaboration can accelerate the associated innovation challenge. We should not forget that, after proving the viability of the technology, major upscaling will be needed, which itself presents its own challenges. Innovation is also needed on the systems level: novel value chains across sectors need to be developed, new collaborations established, and we need to find out which waste streams can best be utilised for which products and how available waste streams can be most efficiently utilised.

> "We need to find out which waste streams can best be utilised for which products and how available waste streams can be most efficiently utilised."

Minimization of energy use for conversion and optimization of product flexibility and product quality will be critical parameters in the design of the system. In view of the many novel routes that will be explored, such a system cannot be designed from a desk. While general boundary conditions (such as environmental and health principles) always need to be fulfilled, the sector needs room for manoeuvring to experiment and optimise the system configuration. Regulations (both on an EU level and national level) on, e.g. waste should help in the transformation and allow for this room for manoeuvre in the transition phase. A genuine 'trilateral system' - through the elimination of border constraints and coordinated national legislation – will lead to a better-optimised system outcome. It is also clear that the regions will have to source a significant portion of their renewable carbon from outside. Combining the logistic strengths and networks of the three regions and establishing good internal connectivity will also be a key factor in the transformation. By joining forces, a flourishing circular chemical sector in 2050 will be within reach.

www.trilateral-chemical-region.eu

Aligning Chemical Recycling with planetary boundaries

Lauriane Veillard
Chemical Recycling and Plastic-to-Fuels Policy Officer, Zero Waste Europe

The latest IPCC (Intergovernmental Panel on Climate Change) report provides clear evidence of the strong connection between global warming and human activities. The Paris Agreement aims to prevent excessive global warming, setting a 1.5 degrees Celsius limit. To manage emissions within this limit, a carbon budget is used in climate policy. It defines the allowable amount of greenhouse gases emitted to achieve a specific level of global warming. If plastic's annual growth remains at 4%, it would use up 32% of the IPCC's budget to meet the Paris Agreement targets. From the perspective of Zero Waste Europe planning for a new approach that respects planetary boundaries and human rights is crucial. Prioritising prevention and reuse measures, like reducing nonessential products that can't be recycled, is part of an effective strategy.

Instead, investing in durable, repairable products with longer lifespans should be promoted. Closed-loop, toxic-free recycling can be considered as a last resort. In this context, the chemical industry's focus should be acting during the production phase. This includes phasing out unsafe products like PVC and adopting circularity principles to ensure sustainable end-of-life treatment while keeping materials within the system. 'Chemical recycling' is recognized as a better option than landfilling or incineration, although there's still some uncertainty about its exact definition and implementation. 'Chemical recycling' covers a broad spectrum of technologies and currently lacks a precise legal definition, leading to different interpretations among stakeholders. It is important to acknowledge that the requirements, needs, and efficiency of technologies vary, and this should be considered when assessing potential within a circular economy model. Based on this observation, we have developed a ranking system distinguishing between chemical recycling and chemical recovery, with the latter being considered lower in the EU Waste Hierarchy. To remain within the carbon budget, we suggest limiting chemical recycling via capping the part of recycled content coming from chemical recovery as suggested by the Dutch consultancy CE Delft, or via introducing sustainability criteria accounting for the energy intensity and environmental impact, thus effectively decarbonizing the industry.

> "By embracing a forward-thinking mindset that aligns with the concept of planetary boundaries, the chemical industry can participate in uniting the circular economy and climate agendas."

In conclusion, by embracing a forward-thinking mindset that aligns with the concept of planetary boundaries, the chemical industry can participate uniting the circular economy and climate agendas. Taking action during the production stage holds the key to unlocking significant environmental and health benefits.

www.zerowasteeurope.eu

Accelerating the transition towards a Circular Economy[31]

Peter Dekkers
General Manager Business Unit Nutrition Unilever Europe/METU/ANZ & Head of Country Netherlands

The Fast-Moving Consumer Goods (FMCG) sector serves billions of consumers every day. This impact comes with a responsibility. As brand owners, we have an obligation to transform the current linear economy in FMCG to a circular economy. This means preventing materials, such as plastic packaging, from ending up in the environment and retaining valuable materials.

"Chemical recycling is a brilliant way to turn trash into treasure."

We have already made some ambitious commitments as a global business, such as using 100% recyclable packaging and collecting & processing more plastic than we introduce to markets across 190 countries. However, we cannot achieve circularity on our own, thanks to - or despite - the 400 brands. We need to work together with a range of organizations & stakeholders to overcome four main barriers: technological, legal, financial, and organizational.

Sharing A Future Vision: Circular Plastics & Net-Zero Emissions
In a circular economy, leakage into the environment is prevented, the environmental impact is reduced, and valuable materials are retained in multiple - ultimately infinite - cycles. Advanced recycling technologies are required to complement limitations in existing recycling facilities. Whilst governments, politicians, societal organizations, and businesses might have different views on the exact means, a shared vision for the future provides an excellent starting point to solve key challenges together. Since action is required from a variety of actors.

- **Technological**: Research & innovation from knowledge institutes, industry players, stimulated by governments are crucial to develop smart sorting solutions & advanced recycling technologies.
- **Legal**: Governments and European institutions need to provide clarity in legislation, recognition for innovations to unlock the necessary investments.
- **Financial**: Professional investors and businesses to develop strong business mitigating high degrees of uncertainty.
- **Organizational**: Partnerships across the value chain and central coordination by governments are needed to ensure improved & consistent quality across the plastic value chain, the ability to transport materials across borders, etc.

Opportunities arise from joint efforts to overcome all barriers and challenges to circularity and net-zero emissions. By combining a range of actions and measures, the transition will be accelerated, resulting in a sustainable future where the traditional trade-off between sustainability and business impact are actually combined; substantially reducing emissions, 80% reduction of plastic entering oceans and multi-billion Euro business opportunities incl. creating relevant jobs.

www.unilever.com

Leaders in sustainable and renewable chemistry

Manon Bloemer
Director General, VNCI – Association of the Dutch Chemical Industry

The Netherlands has a vast and diverse chemical sector that supplies national, European and international markets with chemical building blocks that are used to manufacture all kinds of products: cars, batteries, shampoo, clothes, building materials, food packaging, solar panels, wind turbines, medical devices, you name it. Products that contribute to our health and well-being, and that we cannot do without (think of your phone!) On the other side, we see that these chemical building blocks are responsible for large emissions of CO_2 during production and at the 'end of use' phase.

So to continue to make these building blocks for products that we all want, the chemical industry is facing two major challenges: becoming climate-neutral and circular. These two missions mean that chemical companies will (1) adjust production processes with other (green, renewable) energy sources to reduce the CO_2 emissions from the chimney stack to zero and (2) use sustainable, circular, non-virgin-non-fossil raw materials to reduce CO_2 emissions at the end of life phase.

"No more plastic waste. Waste is the new raw material."

For me, it is easy to write this down, but the execution is not a quick fix. It is like the 'Deltawerken' in the Netherlands, a vision that needs a good execution plan. But we can do this. By committing to the use of bio-based raw materials, recyclable waste, and the reuse of CO_2, we can replace fossil resources with sustainable alternatives. What's more, doing so enables us to close the carbon loop and ensure that waste is converted into new chemical building blocks. No more plastic waste. Waste is the new raw material.

For the chemical sector, these two challenges are to a great extent complementary. In many cases, circular solutions also lead to a reduction in chimney stack emissions. The Netherlands is well placed to be a front runner in this field, with a broad array of chemical companies (large, medium, small, and many startups, in particular in the field of -chemical- recycling and bio-based chemistry) and close cooperation with the academic community and research organisations. As Royal VNCI we believe in this mission: products based on new energy sources and new raw materials. Therefore we connect with waste companies and agriculture. And we combine entrepreneurship with science. We look forward to reaching our vision together.

www.vnci.nl

Pathway and action agenda

The Action Agenda is designed as a rallying call for business, government, and civil society. The aim is to transform existing knowledge into a collective agenda that will inform and mobilise action for the transition to a circular economy. What can regulators do, how can entrepreneurs collaborate towards sensible chemical recycling models, how can the financial sector kick-start development, and how can knowledge institutes fill in the blanks and offer toolboxes?

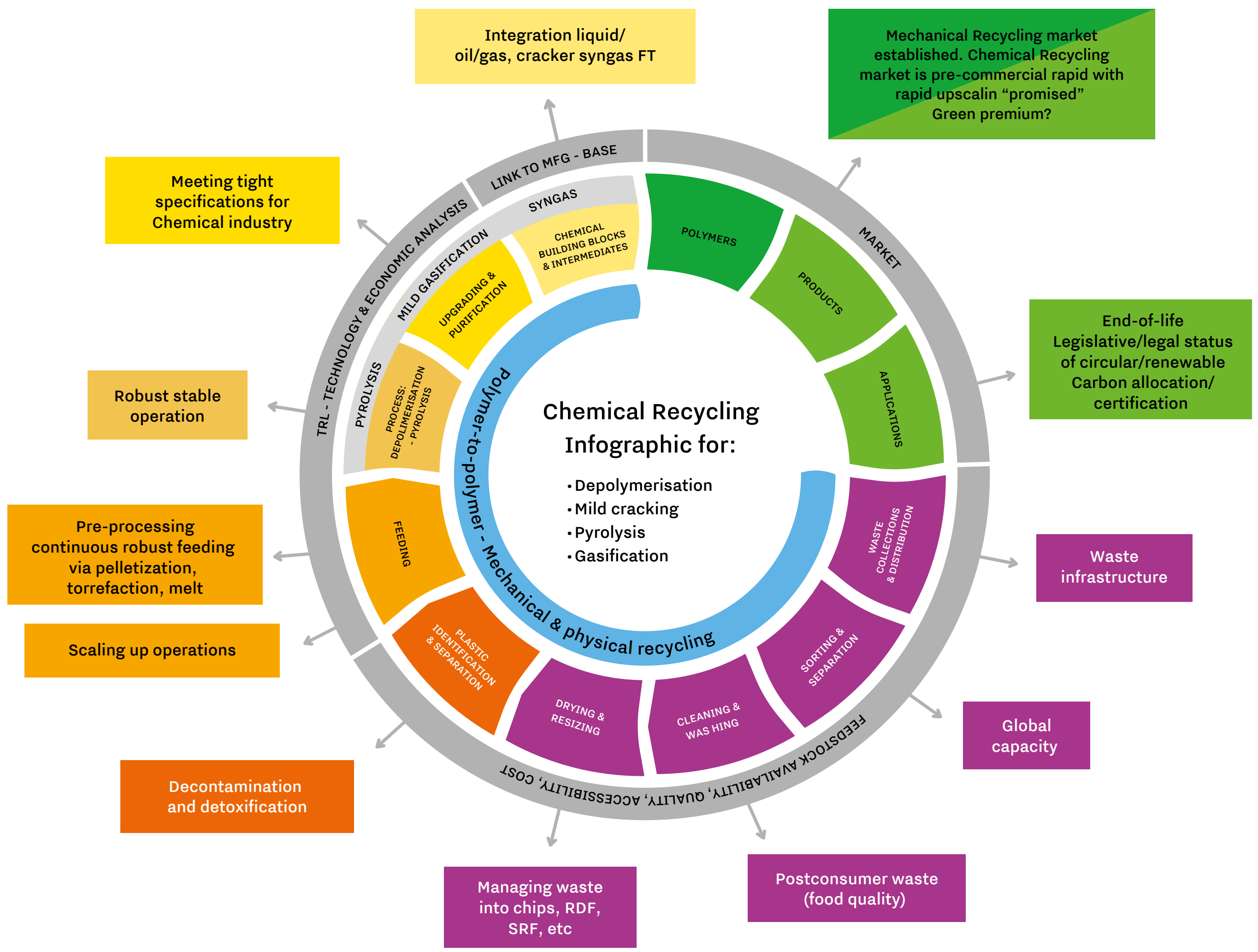
We approach chemical recycling from an economical, environmental, innovation, and financing perspective. We will place chemical recycling in the context of a fully circular economy strategy. This chapter builds on the existing literature to identify actions needed for a better and faster transition.

Whether it is the Climate Goals or Europe's Climate Neutral Future, 2050 is around the corner. For chemical recycling to steer the transition towards a climate-neutral and carbon-neutral chemical industry, urgent action is needed. We have to transition and rebuilt value chains. In Chapter 1 we have seen the magnitude of today's Fossil Fuel Feedstocks to Chemical Products. The demand for products like plastics could triple toward 2050. In a desired vision for a carbon-neutral chemistry sector, the feedstock will come from mechanical and chemical recycling of waste, carbon capture, and utilisation from CO_2 and biobased input.

It is important to recognize that the renewable carbon feedstock transition needed for chemistry and materials is essential for success and should be taken as seriously as the energy or hydrogen transition.

As for an action agenda the authors have drafted a circular visualisation with points of attention along the value chain. We follow the clockwise from the top and will cover the market (polymers and products and applications in green, the domain of feedstock for chemical recycling covers the waste phase infrastructure of collection, sorting, washing, upgrading, to resizing, feeding and chemical recycling processing, purification and the creation of chemical building blocks or intermediates.

Figure 19: Circular visualisation of Chemical Recycling challenges.



Source: Analysis by expert team Circular Biobased Delta

For each phase, there are challenges sketched in the outer ring that we quickly address below. The inner ring (in blue) depicts the mechanical and physical (polymer to polymer) recycling options. The multicoloured middle ring depicts the chemical recycling process.

Market phase

Recycling of plastics or mixed waste flows has a value chain deficit and is an artificial market, it needs regulation (waste regulation, climate regulation) and financing.
For mechanical recycling the market is established in countries which have implemented and enforced waste regulation. There is an established market with quality criteria that, however, is highly dependent on the primary resource prices, e.g. if the oil price is low virgin feedstock will be preferred to secondary resources.

Chemical recycling and advanced recycling are buzzwords containing several technologies each with its own market characteristics but roughly occupying a market area that is price and footprint-wise in between the market for mechanical recycling and incineration. As long as externalities are not priced in for virgin resources the market exists in a pre-commercial phase based on a green premium. Chemical recycling promises to produce virgin quality materials (food grade) with a positive climate and circular impact. Independent verification of environmental footprint, carbon accounting, and certification will be essential.

Further pilots and the development of a policy framework to support a 'carbon tracking system' in which both the carbon and the CO_2 footprint are allocated across the chain and recycling is advisable.

Regulation and policies (EU as reference)

The EU has a long history of generic waste management and specific plastic regulation with supportive targets in place or foreseen for the upcoming years that stimulate Chemical Recycling is a new kid on the block, and regulations will have to be developed further. The lack of a harmonised and supportive regulatory framework for chemical recycling hinders its development and deployment. As circular economy requires a system change, innovations have to mature to higher TRL, and a chemical recycling market has to be created in a pre-commercial stage and temporary government support is needed until the market can 'keep up its own trousers'. A supportive regulatory framework is required to encourage (private) investment, ensure safety, and promote sustainable practices in chemical recycling poses a challenge. To develop the chemical recycling market waste regulation, chemical regulation, climate regulation, and energy regulation (like the European Renewable Energy Directive) should be considered as a whole and aligned where needed to prevent unintended consequences.

Government can work on a long term transition with regulations, policies, and instruments. It can use the carrot and the stick (price incentives) or introduce bans to transition toward a new normal. Governments should not only reserve subsidies and R&D budgets for start-ups and pilots for innovation in chemical recycling technologies but also support scaling up to a high TRL/ commercial level.

Simultaneously frontrunning companies should be willing to not only invest themselves in technology and ecosystem but also pay a green premium to get the market started.

We share some suggestions inspired by earlier publications of Ecopreneur, Afvalfonds, KIDV and Nedvang and CEFIC. The Consumer Goods Forum Plastic Waste Coalition of Action (PWCoA) have co-authored this paper to provide a shared view of the role of pyrolysis-based Chemical Recycling1 (Py-CR) in a circular economy for plastics.

- If Chemical Recycling is to scale, it is essential to adopt a uniform approach to accelerate the financing of chemical recycling and recognize recycled content and/or CO_2 savings through chemical recycling next

Figure 20: European legislative framework on waste management (2020-2035)

- Leading the way with the **European Green Deal**
- Wide and strong legislative framework

	2020	2021	2023	2025	2029	2030	2035
Plastic packaging recyclable by design						100 %	
Single-use plastic ban		100 %					
Separate textile waste collection				Jan.			
Mandatory recycled content in plastic bottles				25% PET only		30% all plastics	
Municipal waste recovery	50 %			55%		60%	65%
Landfill disposal						waste suitable for recycling recovery are not accepted in landfills	10% reduction of the amount of municipal waste landfilled
Plastic packaging recycling target				50 %		55 %	
Plastic packaging tax	**Italy/Spain (2022/2023)** 0,45 Euros per kilogram of **single use** plastic item on market **All members states** 0.80 € per kilogram of **non-recycled plastic packaging waste**						

Source: Technip ERTC paper. (2022)[32]

to the removal of trade barriers and possible bottlenecks in the application of recyclate via chemical recycling;

- The USP of chemical recycling technologies is that it produces high-quality and high yields of recyclate. As long as there are only quantitative obligations, actors (for example Retail Brands or PRO organisations) cannot commit to providing large quantities of feedstock for those technologies that do not provide a sufficient yield of recyclate;
- The 'as good as virgin' material quality aspect of chemical recycling should be recognized to form a market driver. To support this it should be ensured that food grade application of recycled content is permitted by chemical recycling processes, i.c.w. EC and EFSA;
- 'Broaden' the obligation/voluntary objective for recycled content in addition to PET to also cover materials such as PP and PE.

A word of caution: strong government support for Chemical Recycling alone, separate from the stimulation of other 'R-strategies' like redesign or re-use, may also prolong the linear economy and hinder the shift towards waste prevention and circular business models. Recycling is still an end-of-pipe solution, we should not only promote and facilitate recycling of for example fast fashion or single-use plastics but shift away from these practices. Large investments and support from the EU for chemical recycling may divert crucial resources from SMEs working on circular product design.

Next to or as part of regulatory actions public perception and acceptance are crucial. Public understanding and acceptance of chemical recycling are important for its successful implementation. Addressing concerns and providing clear information to the public is a challenge.

Waste phase

Chemical recycling is not a panacea for the circular economy. The feedstock will have to come from many point sources. A circular logistic value chain should be in place to activate sorting and collection and importing larger volumes of plastic feedstock for chemical recycling selected technologies. In order to supply the chemical industry with the volumes it will need towards 2050, transborder flow of suitable feedstock is likely, which requires alignment of Waste Shipment Regulation (WSR) between sender, intermediate, and receiving country. Guaranteeing international trade of feedstock via the WSR and Basel Convention also plays an important role.

Every chemical recycling technology will have its preferred input material and restrictions. Quantity, quality, consistency, continuity of supply and price are determining success factors. It is advisable to support the introduction of quality requirements and standards for plastic waste (sorting) and harmonise them with new technologies within chemical recycling. In order to avoid the use of disruptive substances the mandatory design for recycling is highly recommended.

Mechanical and physical recycling is the preferential waste management option if prevention, reuse, refurbishment, or remanufacturing is not an option. Typically mechanical recycling involves sorting and upgrading with a focus on larger fractions with a positive value like the plastics PET, PP, or PE. Mechanical recycling can keep materials a few times in the loop. Mechanical properties, substances of concern, colour, and odour can limit more life cycles. Chemical recycling is an obvious alternative when mechanical recycling is not an option. When implementing robust systems and processes ensure that waste plastic input materials for chemical recycling do not include material that can be economically recycled by mechanical recycling in practice and at scale.

Chemical recycling requires essential sorting out of smaller fractions that hinder chemical recycling. Both processes involve sorting, separation, cleaning, washing, drying, and resizing.

The evolution away from dumping and landfilling is a long process as described in the publication 'Waste management as a catalyst to a circular economy'. Waste management has a value-chain deficit. It involves introducing a waste hierarchy, setting minimum standards for the treatment of specific waste types, introducing a separate collection of valuable waste streams like plastics, and introduction of economical steering instruments like landfill (and later incineration) taxes combined with landfill bans for specific waste flows and the set up of Extended Producer Responsibility to finance the transition. Furthermore, it requires an adequate waste infrastructure planning, the introduction of a (municipal) waste tax that covers all costs including for example landfill after-care, and requires cooperation between authorities at municipal, provincial, and national levels for example on regulations, infrastructure planning, enforcement, and communication.

Infrastructure, support and investment

Developing the necessary infrastructure for chemical recycling, including collection and sorting systems, requires significant investment and coordination among stakeholders.

Experts mention the need to commoditize the waste feedstock, otherwise, the whole effort remains pretty niche in 2040. This cannot be done by keeping the work of every company isolated. There is a need for collaboration to build up value chains with involvement, from both investors and strategic (industrial) partners over the entire value chain. There will be new ways of innovative collaboration, cross-sector, notably between innovative SMEs and large corporations. New value chains, the use of waste as a feedstock, and innovations aimed at development and deployment at large scale. New collaborations require a common goal and mutual understanding,

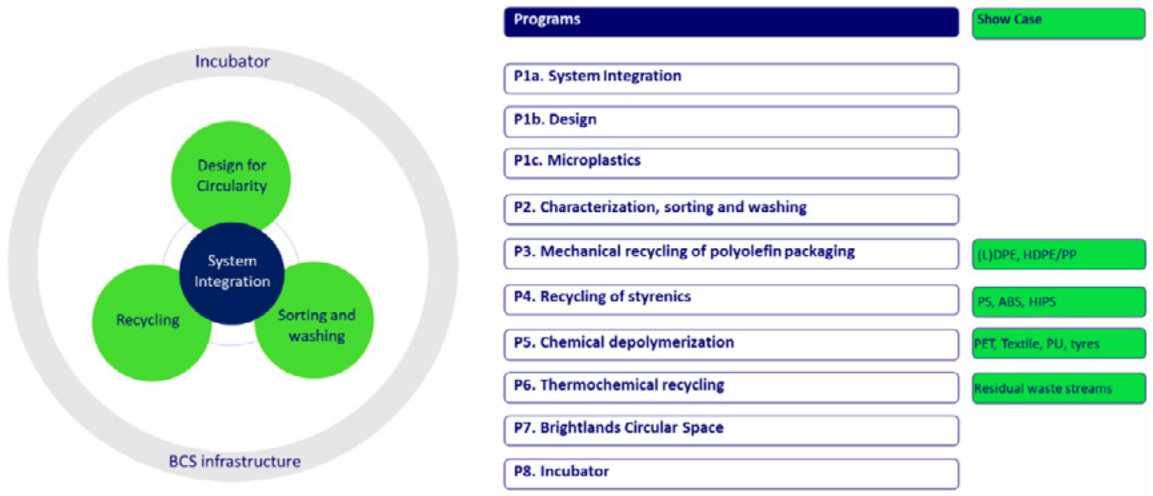
In order to support and catalyse the development and implementation of chemical recycling in the Netherlands various financial tools are available. Most are managed through the Netherlands Enterprise Agency (RVO). The tools vary from subsidies for very early phase research to loans for higher TRL developments. Some typical examples worth mentioning are:

- MIT subsidy especially for supporting SMEs in innovative developments;
- WBSO is a tax reduction measure to stimulate R&D at companies large and small;
- TSE Industry subsidy for entrepreneurs in the industry to support the feasibility of innovative pilot and demonstration projects;
- Region Deals where various regional partners collaborate with the national government to improve sustainability;
- KIA-CE is a subsidy for entrepreneurs who investigate the possibilities for cost-effective circular products;
- SDE++ subsidy for companies and government to reduce CO_2 emissions;
- For the more scientific and low TRL research we have tools to support activities through NWO (Dutch Research Council).

World Economic Forum's LCET R&D Hub hosted by TNO

TNO hosts an R&D Hub for Plastic Waste Processing, the first project inside the World Economic Forum's LCET (Low carbon emitting technologies) initiative. The hub focuses on early-stage technologies (TRL 2 to 5) with the objective to develop new technologies for waste processing with a low CO_2 footprint, which enable recycling of more plastic waste than today. For that purpose joint technology needs and collaboration opportunities are defined and joint research projects are executed. The projects cover topics in the field of chemical recycling, sensing and sorting of waste as well as mechanical recycling.

The Netherlands is strong in collaborations between R&D and universities, RTO's and government (regional and national) have a rich history of successful innovation in an open innovation style. This culture supported by the financial tools has resulted in remarkable success in the past and will do so in the future!



Circular Plastics NL

Circular Plastics NL is an initiative within the National Grow Fund. The goal is to make plastics fully circular and use subsidies to accelerate the transition. The program runs for eight years and has a budget of €220 million that should be doubled by stakeholders. Circular Plastics NL consists of eight program lines including showcases to realise material and process innovations for circular plastics. The aim is to work towards 50% circularity in 2030 and 100% circularity in 2050 and offer the Dutch economy sustainable growth opportunities. The program lines are: (1) system integration and design; (2) characterization, sorting, and washing; (3) mechanical recycling of polyolefin packaging; (4) recycling of styrene-based materials, (5) chemical depolymerization; (6) thermochemical recycling; (7) Brightlands Circular Space facilities to accelerate the scale-up from design to recycling and (8) incubator for the development of innovative disruptive technology. Over 150 stakeholders gave their support to the program.

www.circularplasticsnl.com

Investment Perspective

The advanced recycling market has seen strong positive momentum with several plants, partnerships and initiatives. However, as is often the case, perception precedes reality. Demand for advanced recycled polymers is growing but supply is still limited. This is not only due to a chronic lack of capital but also a result of the unique challenges a disruptive transition to a decentralised circular economy poses.
Stakeholders across the value chain need to acknowledge that roles and responsibilities will change and that a circular economy in plastics can only be successful if it can compete with the linear economy on both price and quality. In addition, it is important for the industry to engage with governments to ensure that priority is given to recycling of what is ultimately a highly effective material, rather than looking for environmentally inferior alternatives.
With the majority of plastics being used for applications requiring virgin quality polymers (e.g. contact sensitivity, molecular strength), chemical or advanced recycling is expected to represent over €500 billion in revenues by 2050 (assessment by Infinity Recycling, initiators of the Circular Plastic Fund). This market potential can be captured through an adequate combination of time, capital and cross-value-chain collaboration.

End-of-Waste (EoW)

Waste or product? The end of waste status
Once a product is discarded it is considered to be waste. The chemical industry does not want to work under strict waste management regulations. This implies that before processing in a chemical plant a transition is needed to an end-of-waste status. Once an end-of-waste status is applicable the chemical regulation (like REACH in Europe) and/or specific product regulation becomes applicable.
Circular input material as waste plastics and organised residues more often than not qualify as waste. This means that waste regulation is applicable for transport and that permits should allow for waste handling. In Europe, End-of-waste criteria specify when certain waste ceases to be waste and becomes a product, or a secondary raw material. When no EU criteria have been set national criteria can be set. Both the feedstock and output market for Chemical Recycling is likely to be international alignment over the border is needed.

Barriers GCNE in its study[33]

- Lack of clarity: The requirements for EoW status are not clear, making it difficult for recyclers to navigate the process;
- Self-declaration: EoW status is essentially self-declared, lacking a robust verification system. This leads to a lack of legal certainty for recyclers, customers, and investors;
- Delayed investments: The uncertainty surrounding EoW status hampers investment in recycling infrastructure and technology, leading to delays in scaling up circular companies;
- Customer demand: Customers are hesitant to purchase recycled products without clear evidence of safe use and market demand, further hindering the growth of circular companies.

Improvement opportunities
Increasing Accessibility and Knowledge:

- Providing recyclers with access to a single point of contact and centralised expertise;
- Raising awareness among recyclers and investors about the End of Waste (EoW) criteria and the sufficiency of self-declaration;
- Clarifying requirements for proving compliance with the EoW criteria, particularly regarding safe use for humans and the environment;
- Developing good guidance and emphasising the applicability of product legislation.

Regulatory Improvements:

- Creating legal certainty by allowing EoW rulings to be used as arguments to support EoW claims;
- Working towards mutual recognition of EoW rulings across the EU;
- Developing specific EoW criteria, with a focus on plastic and biobased waste streams;
- Recognition of industry-led certification schemes as an alternative, precursor or complement to a harmonised regulatory framework on EoW;
- These schemes can cover specific waste streams, recycling technologies, or applications.

Recycling status

There is a lack of clarity and consensus on the definition and classification of chemical recycling, making it difficult to establish common standards and regulations.

Waste hierarchy and competition:
Chemical recycling should complement and not compete with mechanical recycling and waste reduction efforts. Ensuring a balanced approach and avoiding conflicts in the waste hierarchy is a challenge.

Environmental impact and status of Chemical Recycling technologies

In the Netherlands' 3rd National Waste Management Plan (LAP3), recycling technologies that can be used for a particular waste category are indicated by a three-rung order of preference (C1, C2, C3), on which chemical recycling is presently on the third, lowest rung.
In an advisory study, commissioned by Rijkswaterstaat and the Ministry of Infrastructure and Water Management, CE Delft addresses the question of whether the various forms of chemical recycling should not be listed differently in LAP3. CE Delft's recommendation is to promote dissolution and depolymerization to the top rung (C1) and pyrolysis and gasification to the second (C2).

The Netherlands took the first steps by recognizing chemical recycling as recycling in the revision of National Waste Plan LAP3. But attention still needs to be paid to the interpretation of the European Renewable Energy Directive II and final decisions concerning recycling techniques in LAP3.

Material or fuel?

If chemical recycling produces a fuel, the lifetime will be maximum 1 cycle. If you make a material with chemical recycling that is of virgin quality, the product can be repeated and repeated as it circles endlessly. That is why governments like the Netherlands can consider (some) chemical recycling material routes as recycling but fuel routes as recovery.
For various flows linked to plastics like for example packaging or WEEE or End-of-Life Vehicles strict collection and recycling targets exist, often under Extended Producer Responsibility (EPR) regulation based on the polluter pays principle and implies financial obligations. Qualifying the fuel-route as recovery means that, for example, plastic packaging materials used as feedstock for fuel, can not claim a contribution to EPR recycling targets. It is in the interest of all parties that the legal status of the various forms of chemical recycling is clear for all actors.

Carbon tracking system and accounting

As Chemical Recycling is linked to EPR financing and Climate Impact, a clear accounting system will be needed. Some recommendations have been suggested:

- Set up pilots and develop a policy framework to support a 'carbon tracking system' in which both the carbon and the CO_2 footprint are allocated across the chain and recycling is stimulated;
- Introduce a market standard for registration of CO_2 savings through chemical recycling (LCA approach) + registration system of recycled content from chemical recycling in new plastic products;
- Prepare the policy field for carbon accounting and incentive scheme for CO_2 emissions over the entire plastic production chain and encourage the use of CO_2-saving materials;
- The Consumer Goods Forum Plastic Waste Coalition of Action (PWCoA) proposed with regard to material traceability to:
  a. only count feedstock carbon and not energy carbon in the allocation of feedstocks to material outputs in a mass balance protocol.
  b. Continued integrity and robust defense against double counting.
  c. Provide transparent reporting on the approach that is taken to physical connection in a mass balance protocol, so that companies purchasing plastics produced by chemical recycling can make informed decisions.

Finally, to keep the overview we provide you with the summary of CEFIC on Chemical recycling summarising most of the recommendations in the boxes described above.

CEFIC: Chemical Recycling: Enabling plastic waste to become a valuable resource[34]

The following are general recommendations to enable a policy-led framework for chemical recycling by 2025: Main conditions for the industry's efforts in chemical recycling:
Collaboration and Integration:

- Accelerate the development of business cases, investments, and new facilities;
- Close the loop for hard-to-recycle plastic waste streams;
- Engage in the development of quality standards and certification schemes.

Data Generation and Environmental Performance:

- Conduct Life Cycle Assessment (LCA) studies and publish findings;
- Work on managing legacy chemicals and substances of concern;
- Measure the environmental impact throughout the life cycle of plastic products.

Transparency and Standards:

- Promote a chain of custody mass balance approach;
- Contribute to the development of uniform standards and certification systems;
- Implement transparent certification and independent auditing.

Enabling Policy Framework:

- Accept chemical recycling as a part of the circular economy for plastics;
- Adapt and harmonise definitions for recycling and recyclability;
- Implement and enforce waste legislation and divert plastic waste from landfilling and incineration.

Policy Support for Chemical Recycling:

- Include chemical recycling in waste recycling-rate calculations;
- Develop harmonised calculation rules for recycled content in products;
- Resolve inconsistencies and uncertainties regarding End of Waste status and product regulations;
- Establish a regulatory framework for recycled plastics in food contact applications;
- Harmonise waste shipment regulations and create an open market for plastic waste and secondary raw materials.

Investment Support:

- Support the inclusion of chemical recycling in the EU Taxonomy for sustainable investment;
- Drive investments into R&D programs and new business models;
- Enable investment for scale-up and integration of chemical recycling, creating new jobs and value chains.

Closing words

In this brochure we showcased the current state, and made an effort to present in a fact-based and objective manner to stimulate debate. We approached chemical recycling from economical, environmental, innovation and financing perspectives and placed it in the context of a fully circular economy strategy.

To show that the topic of chemical recycling has momentum in the Netherlands, multiple Dutch cases, toolboxes and approaches have illustrated how chemical recycling can be put into practice.

The last chapter showed a pathway and action agenda. By publishing this brochure, the authors and brochure partners hope to stimulate discussions and to inspire regulators, the knowledge community, entrepreneurs and investors to work together towards sensible chemical recycling models. By sharing lessons internationally, others can accelerate development in a sensible direction and avoid pitfalls. The journey is rewarding. Together we can adapt the Dutch solutions and practices to the local context, solve environmental issues and by doing so create meaningful local jobs, contribute to the climate goals and the Sustainable Development Goals.

If you want to read more on circular economy opportunities by market segment, do read our other reports here: www.hollandcircularhotspot.nl/publications/.

If you want to work together with us, then send your ideas, thoughts and proposals to info@hollandcircularhotspot.nl.

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Glossary

Contamination: When non-target items are added to recycling waste streams, contamination occurs. These non-target components can be polymer mixes, other chemicals, or organic waste. The secondary raw material's physico-chemical characteristics are changed by contamination.

Circularity: Resource efficiency is measured by circularity, or the extent to which new, virgin materials are replaced by (re)used materials. The circularity metric used in this study is defined as the percentage of plastic utility that is either diminished, replaced by circular materials, or mechanically or chemically recycled. It does not include plastic that is added to stock or that is disposed of linearly.

Downcycling: The conversion of waste materials into products of lower value or quality.

Downstream solutions: Solutions implemented post-consumer. Collection, sorting, mechanical recycling, chemical recycling, and disposal are all composed of this.

EPS: Expanded Polystyrene is an extremely lightweight product that is made of expanded polystyrene beads. EPS foam is more than 95% air and only about 5% plastic. From being used as building materials to white foam packaging, expanded polystyrene has a wide range of end-use applications.

Feedstock: Any large-scale raw material, whether secondary or virgin, that serves as the main input into an industrial production process. The primary source of plastic production today is petrochemical feedstock, especially fossil fuels.

Life Cycle Assessment: Life cycle assessment (LCA) constitutes a method to evaluate the environmental impacts of a product, process, or service, considering all stages of the life cycle. Based on this methodology, it is feasible to identify the steps that have a significant environmental impact.

Net zero carbon economy: A system which strived to create a balance between emissions of greenhouse gases and their removal or offset from the atmosphere. To achieve zero net emissions of greenhouse gases, providing an mitigating strategy to climate change.

PA: Polyamide (also known as Nylon). PA is usually used for coil, connector, fan frame, electrical housing, bearing blade. PA is tough, firm, wear-resistant, non-toxic

PE: Polyethylene is the most common plastic worldwide and is used to produce plastic grocery bags, shampoo bottles, toys, and garbage cans.

PET: Polyethylene terephthalate is the most common thermoplastic polymer resin of the polyester family and is used in clothing fibres, containers for liquids and foods, or thermoforming for manufacturing.

PP: Polypropylene is often used in the production of toys, food containers, bottles (medical), and more.

PS: Polystyrene is a hard, solid plastic most often used to produce food packaging, electronics, automobile parts, appliances, and more.

Recyclate (secondary plastic): Recyclate is the output material of recycling processes that can be directly used as a secondary raw material for plastic conversion.

Sorting: Techniques and procedures for physically separating elements from waste streams. Sorting is typically performed in Material Recovery Facilities (MRFs) or specific Plastic Recovery Facilities (PRFs). Sorting can be performed automatically with sorting technologies or manually.

Upcycling: The process of turning waste into goods that are more valuable or high-quality.

Upstream solutions: Solutions applied pre-consumer. This includes design for recycling (D4R); Reduce levers such as eliminate, reuse (consumer), reuse (new delivery model); and Substitute levers such as paper, coated paper and compostable plastic.

Virgin plastic: Virgin plastic is the polymer resin produced directly from the petrochemical feedstock

Waste Hierarchy: Waste management alternatives are outlined in a hierarchy by the EU in the Waste Framework Directive, starting with prevention and progressing through planning for reuse, recycling, recovery, and disposal.

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Colophon

This publication is the result of a collaboration between Holland Circular Hotspot, The Netherlands Ministry of Infrastructure and Water Management, The Network Chemical Recycling of the Circular Biobased Delta, TNO, Chemport Europe, Chemelot Circular Hub, Chemistry NL and Infinity Recycling.

The authors would like to thank all contributors, editors, reviewers, best practice providers, and any individual or organisation that took part in the production of this document.

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August 2023