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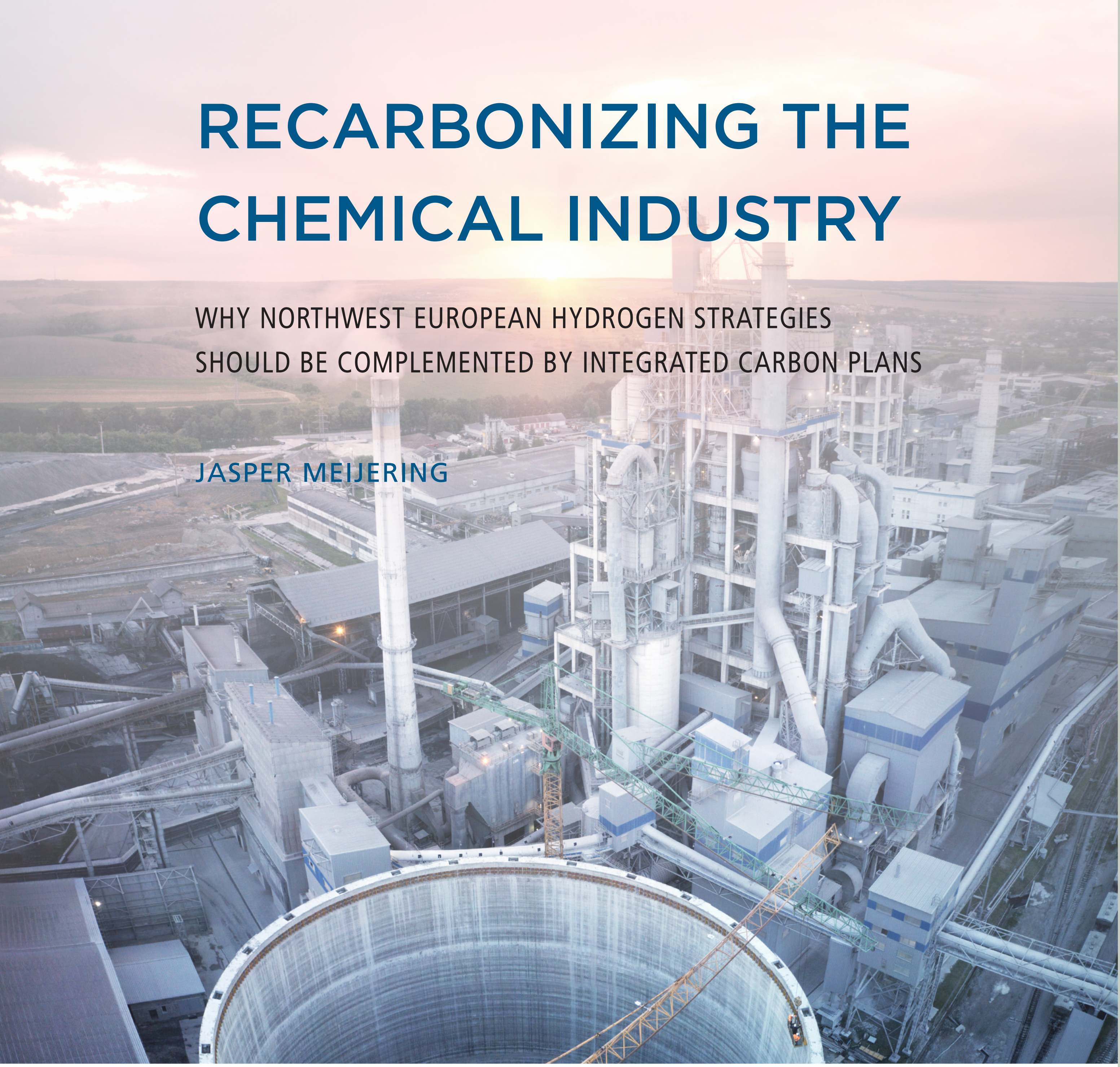

RECARBONIZING THE CHEMICAL INDUSTRY

WHY NORTHWEST EUROPEAN HYDROGEN STRATEGIES SHOULD BE COMPLEMENTED BY INTEGRATED CARBON PLANS

JASPER MEIJERING

PART OF THE **Cracking the Clean Molecule** PROJECT

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PART OF THE **Cracking the Clean Molecule** PROJECT

In the ongoing '**Cracking the Clean Molecule**' project we explore the future of organic chemicals production against the backdrop of society's push towards net-zero emissions. The organic chemical industry is responsible for ensuring that the countless indispensable products that it produces are safe for human health and the environment. At the same time, it must continue to provide employment for thousands of workers and create added value from a societal and private perspective in a world that is highly globalized but which shows signs of increasing fragmentation. The focus of this project is to explore and analyze the prospects of a third feedstock transition in the Antwerp, Rotterdam, Rhine, Ruhr Area (ARRRA) organic chemical cluster.

The first paper in this project provided an analytical basis and described the internal logic behind the ARRRA cluster. This second paper builds on this work and describes how the industry could change as a result of various (new) EU policy ambitions and given the availability of technical options. The two papers share the conception that changes outside the chemical sector historically have been – and will continue to be – a key driver of change in the organic chemical value chain. (Sub)national governments and industry partners can respond to this reality by complementing their hydrogen strategies with integrated carbon plans.

PREFACE

It is difficult to imagine an effective energy and feedstock transition that does not include a larger role for hydrogen. In many countries, including those in the region of Northwest Europe, national policies and project plans for hydrogen development are being brought together to explore opportunities to tap into the full potential of hydrogen as a clean energy vector.

While hydrogen is fundamental for the transition, the scope of its possibilities is not endless. As CIEP argued before, an integral energy systems perspective is needed to assess its changing role. Without question, one thing that hydrogen cannot do is take on the role of carbon in a hydrocarbon molecule. Per definition, hydrocarbons, whether of a renewable or non-renewable origin, consist of hydrogen and carbon molecules. While the number of national policies and projects to reduce GHG emissions in the hydrogen value chain is rapidly growing, surprisingly little attention is being paid to the question of how to source the carbon molecule in a net-zero world.

One possible explanation for this asymmetry is the persistent view that hydrocarbons will soon be phased out. This position is ill-informed, and those embracing it run the risk of standing in the way of reducing emissions in sectors that rely on hydrocarbons for their emissions reduction strategies, including aviation, maritime transport and chemicals.

One of the industries for which this question is especially important is organic chemicals production. As part of an earlier publication in the ‘Cracking the Clean Molecule’ project, CIEP described the emergence and nature of this industry, which requires significant quantities of carbon. As of today, the vast majority of carbon is of fossil origin. In the coming decades, increasing quantities of carbon will be able to be sourced from recycled waste, off-gases, the air and biomass, to produce the countless everyday products that are derived from the organic chemical value chain.

The current energy crisis, caused by the war in Ukraine and the subsequent sanctions, is a complication facing the organic chemical industry of which the consequences are still unknown. Nevertheless, the industry’s present day competitiveness, already an issue in the energy and feedstock transition, will be further challenged by this recent turn of events.

Recently, the European Commission shared new ambitions and policy initiatives to increase the sustainable use of non-fossil sourced carbon in the production of chemicals and polymers. This paper describes how these announcements correspond to the evolving EU policy landscape. In addition, it describes the available technical options to reach new ambitions by altering the organic chemical value chain. It furthermore describes how players active in this value chain may be affected by new upstream investments, partly induced by transportation fuel policy. It concludes by reflecting on what (sub)national governments and industry partners could do going forward.

Today, oil and gas are Europe's primary sources of energy and chemical feedstock. Yet the discussions on energy & transportation fuels policy and chemicals & polymer policy seem to be held in distinct spheres. Recent policy announcements by the European Commission have the potential to bring these two realities closer together. With this paper, CIEP hopes to aid this process and contribute to a more systemic understanding of the transition – one that is relevant from among others an emissions reduction, waste management and security of supply perspective and which should be seen as an energy as well as a feedstock transition.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

This paper takes a comprehensive look at the development of the Antwerp, Rotterdam, Rhine, Ruhr Area (ARRRA). This organic chemical cluster spans across Belgium, the Netherlands and western Germany and represents Europe's largest cluster for transforming hydrocarbons into organic chemical products. The development of this cluster is affected by many EU policy initiatives, of which the newest addition was announced in the Sustainable Carbon Cycle communication (COM (2021) 8000).[1] In this communication, the European Commission revealed its ambition that by 2030 at least 20% of the carbon used in chemical and plastic products should be from sustainable non-fossil sources.

Currently, it is unclear how the European Commission aims to fulfil its 20% non-fossil carbon use ambition**.** What is clear, though, is that at this time there are no dedicated policy mechanisms present at the member state level to increase non-fossil carbon use in chemical & polymer production. In contrast, such mechanisms *are* part of the energy & transportation fuel policy framework. Every day in the EU, mature policy instruments, such as the obligations and tradable credit system used in Germany and the Netherlands, increase the uptake of renewable transportation fuels to reach EU targets. The production of fuels, chemicals and polymers all takes place in the same interlinked value chain. The presence of mechanisms to incentivize renewable fuel production in this value chain affects the development of organic chemicals production in the ARRRA. If similar mechanisms to increase renewable carbon use are absent in the chemical sector, as is currently the case, renewable fuel policy impinges the uptake of non-fossil carbon use in chemicals and polymers.

To reach the non-fossil carbon use ambition for the production of chemicals and polymers, several technical options are available. On a systems level, four ways of intervening in the value chain can be distinguished. These are: changing how products are made; changing what happens to products that are produced; changing what products come out of the value chain; and lastly, changing what feedstocks go into the value chain. EU policy makes use of all these levers. Recently, there has been increased interest in the latter, as can be observed from the announced non-fossil carbon ambition. There are many process technologies available to switch from

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[1] European Commission (2021). Sustainable Carbon Cycles.

using oil and gas derivatives to renewable feedstocks. Carbon can be sourced from recycled waste, off-gases, the air and biomass, and subsequently fed into the organic chemical value chain, following the routes shown in Figure 1 (see page 15). Yet while the laws of chemistry and physics determine the technical limits of the available process technologies, technical specificities alone do not define how the ARRRA chemical cluster will change going forward. Therefore, a wider perspective is needed.

All available options for changing the organic chemical value chain face significant implementation barriers. As is shown in this paper, these barriers are often of a non-technical nature and will, at least in the short-to-medium term, be difficult to overcome. This supports the argument that, over time, a hybrid system for the production of chemicals & polymers will emerge in the ARRRA. In such a system, alternative sources of carbon will be fed into the value chain at various places, complementing the use of oil and gas derivatives as feedstocks. Based on these alternative feedstocks, fewer and different types of products will be produced for European consumers. Both the processes to produce these products and the processes to manage waste in this system have a smaller greenhouse gas emissions footprint than the current system. As indicated, the described hybrid system is emerging in a policy landscape that has established policy mechanisms for the uptake of transportation fuels but no comparable mechanisms to increase non-fossil carbon use in the production of chemicals and polymers. This has ramifications for the emergence of this hybrid system.

The uptake of renewable carbon in the organic chemical value chain is not driven by chemicals & polymers policy. In contrast, to a large extent it is driven by transportation fuels policy. On the one hand, transportation fuels policy provisions increase competition for renewable feedstocks, making it more challenging for players in the chemical sector to compete for feedstock. On the other hand, transportation fuels policy enables investments in bio- and e-refineries that produce chemical feedstocks as byproducts. In this way, transportation fuels policy indirectly pushes renewable feedstocks into the organic chemical value chain. The effect of transportation fuels policy on the development of the organic chemical value chain is therefore multifaceted: fuels policy both obstructs and incentivizes the uptake of non-fossil carbon use in the production of chemicals and polymers.

Policymakers in the ARRRA could respond in several ways to a non-fossil carbon use ambition while at the same time accounting for these multifaceted effects of transportation fuels policy. First, the (sub)national governments of Flanders, North

Rhine-Westphalia and the Netherlands[2] could contemplate to increase efforts to attract new bio- and e-refinery investments to the cluster, as this could lead to an accelerated uptake of renewable feedstocks in chemical plants. Second, implementing an additional policy instrument could be considered. This is especially relevant if policymakers aim to increase the uptake of non-fossil carbon above levels that are directed by transportation policy. In the design of such an instrument, policymakers could take inspiration from existing instruments for the creation and development of markets for specific products that are being used in the region, such as the aforementioned mechanisms for increasing the uptake of renewable fuels. Implementing such an instrument could contribute to creating stable demand and, as such, increase certainty for potential producers, importers and consumers of renewable chemical feedstocks.

By establishing integrated carbon plans, (sub)national governments in the ARRRA could provide insight into how carbon is used in our society today and set direction on how this might change in the future. Independent of decisions regarding the implementation of the non-fossil carbon ambition, such plans could contribute to creating increased certainty for producers, consumers and other value chain partners as they invest in new and repurposed assets. Sector-wide investments are, without exception, associated with risk. Yet for these projects to reach final investment decisions, it is important that conditions be created in which the uncertainties are manageable. This is an area in which (sub)national governments can provide assistance. Establishing the intention to attract increased levels of bio- and e-refining investments could be part of integrated carbon plans or any other formal communication that fulfils a similar purpose. The same is true for the development and alignment of policy instruments in the ARRRA. Furthermore, in crafting integrated carbon plans, (sub)national governments and industry partners may take inspiration from the value chain approach that has been used to develop hydrogen strategies over the past years.

In an evolving EU policy landscape with mature transportation fuels policy mechanisms, the ARRRA is developing into a hybrid cluster for the production of chemicals and polymers. Nevertheless, closing the carbon loop presents a major challenge for the region's chemical sector. While it is relevant that the European Commission shared its ambition for non-fossil carbon use, this will not lead to an

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[2] This paper uses '(sub)national governments in the ARRRA' to refer to the Dutch national government, the government of the Flemish Region of Belgium and the government of the German state of North Rhine-Westphalia. These (sub)national governments concern themselves with the ARRRA cluster, among others in the Trilateral Chemical Region initiative, also see Clingendael International Energy Programme (2021). The Dynamic Development of Organic Chemistry in North-West Europe.

overnight change in the cluster's prevailing dynamics. The success of the effort to start closing the carbon loop largely depends on the implementation choices that will be made in the coming period. That these choices now have to be made in the context of an energy and feedstock crisis, makes them all the more relevant.

Based on the presented analysis, this paper suggests the following areas for further action:

National and sub-national policymakers in the ARRRA may consider:

- Complementing existing hydrogen strategies with integrated carbon plans. Providing insight into how carbon is used in society today as well as direction on how this might change in the future can create certainty for producers, consumers and other value chain partners, especially if policy instruments are designed accordingly.
- Recognizing that chemical feedstocks produced in bio- and e-refineries can benefit the feedstock transition in the ARRRA and, as such, contribute to circular economy concepts. Attracting investments in bio and e-refineries, in addition to chemical recycling plants, can be a key step towards simultaneously meeting energy transition, feedstock transition and to some extent security of supply objectives.
- Promotion of an additional, harmonized policy mechanism, especially if an increased uptake of non-fossil carbon above levels that are directed by transportation policy, is aspired to. Such an instrument could be similar to instruments used to increase the uptake of renewable transportation fuels in the region.
- Including promising non-fossil carbon projects in public funding schemes to help them come to a financial close. Collectively realizing a diverse project portfolio of carbon projects can contribute to a value chain that continues to evolve.

At the same time, industry partners in the ARRRA may consider:

- Explaining more effectively how the transition pathways available to the chemical sector relate to developments and challenges from outside the sector, thereby refraining from applying a too siloed perspective and instead considering the transitions at a systems level.
- Exploring transition pathways based on changing product ranges, including variants that represent a shift from polyolefins to polyester-based products. These pathways can be studied in addition to transition pathways that are based on drop-in feedstocks.
- Working together with policymakers on developing integrated carbon plans and making investment opportunities and their wider societal benefits more explicit.

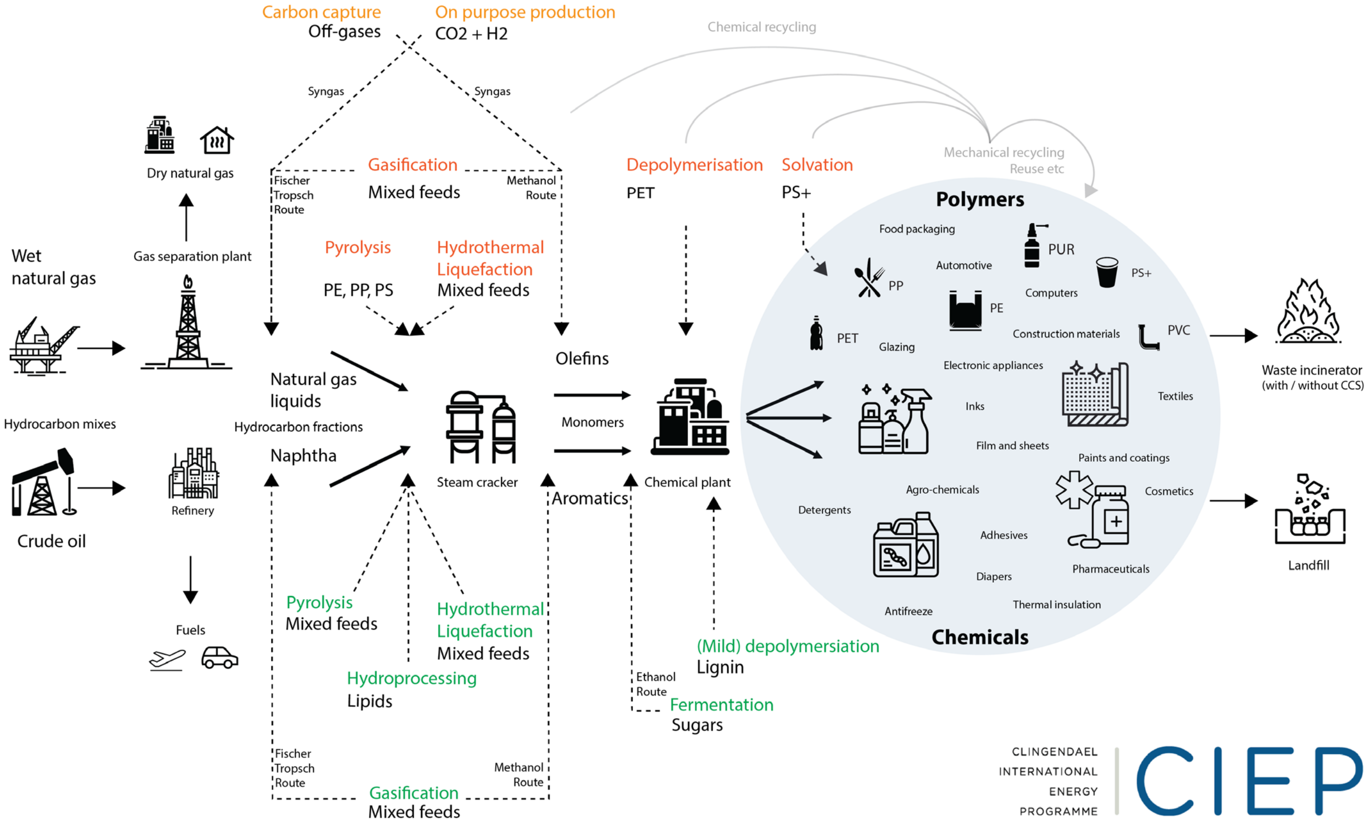

FIGURE 1. The organic chemical value chain, including key drop-in feedstock routes, arranged by carbon origin

In addition to carbon from oil and gas derivatives (in black), carbon sourced from recycled waste (red), biomass (green) or captured carbon (yellow) can be fed into the organic chemical value chain. A wide palette of process technologies can be used to convert carbon from these sources into appropriate drop-in feedstocks. These include pyrolysis and hydrothermal liquefaction of mixed (biomass and/or plastic waste) feeds, as well as the hydroprocessing of lipids in an HVO or HEFA process. These three routes produce chemical feedstocks with properties similar to fossil-based naphtha. Gasification of mixed (biomass and/or plastic waste) feeds can be used to generate syn-gas that in turn can be converted into longer hydrocarbons – including naphtha – in a Fischer Tropsch process, or into methanol, which can be converted into olefins and/or aromatics. The Fischer-Tropsch and methanol routes can also be used based on carbon captured from off-gases or the air. An additional route that can be used is the fermentation of sugars, to produce ethanol that, among others, can be used to produce ethylene. Depolymerization can be used to break down polymers, including lignin and PET, into monomers or polymer intermediates, for example aromatics and TPA and MEG. Solvation processes can be allocated, for example to extract polymers from polystyrene waste streams. In addition to changing what goes in to the value chain by increasing the use of these drop-in feedstocks with the aforementioned processes, a number of other measures can be used to alter the value chain of organic chemicals. A discussion of all available measures, including their key drivers and barriers, can be found in Chapter 3.

1 INTRODUCTION

Europe's Antwerp, Rotterdam, Rhine, Ruhr Area (ARRRA) is home to the continent's largest cluster for the transformation of hydrocarbons into organic chemical products. The chemical sector in this region has to live up to a wide array of challenges. It needs to produce products that are safe for human health and the environment, while at the same time lowering its greenhouse gas emissions footprint. It does so by contributing to waste prevention and reduction of GHG emissions from its own operations as well as from consumers that use products derived from chemicals and polymers. At the same time, the sector must continue to provide employment for thousands of workers and create added value from a societal and private perspective in a world that is highly globalized but which shows signs of increasing fragmentation.

The term 'the chemical sector' connotes that it is a singular entity, while in reality it consists of hundreds of companies and represents a diversity of products, intermediates and feedstocks.[3] Within the cluster, stakeholders aim to stimulate co-operation through the Trilateral Chemical Region initiative and via several other platforms. Alignment of strategies and policies remains challenging, however, in a cluster that spans across the borders of Belgium, the Netherlands and Germany. Institutions governing the sector are diverse and not only consist of countless departments that are each assigned to oversee one element of the system, they can also have diverging or even conflicting mandates derived from regional, national, European or international legislation.

In recent years, the chemical industry in the region has published various studies, roadmaps and visions to transform itself towards meeting the aims for 2050.[4] These studies range from extensive model-based evolutions of transition pathways to more qualitative discussions of effective policy instruments. In a similar manner, legislators also engage in a continuous process of commissioning studies, sharing ambitions,

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[3] The list of products produced from polymers and chemicals is long and ranges from construction materials, textiles, food packaging and electronic appliances, to inks, adhesives, detergents, films, paints, coatings, cosmetics, diapers, glazing and pharmaceuticals.

[4] See e.g. CEFIC (2019). Molecule Managers A journey into the Future of Europe with the European Chemical Industry; SUSCHEM (2020). Sustainable Plastics Strategy; Plastics Europe (2022). ReShaping Plastics; VCI (2019). Roadmap Chemie 2050; Essenscia (2019). Chemie & life sciences: dé formule voor meer welvaart en meer welzijn; VNCI (2018). Chemistry for climate; and VNCI (2021). Van Routekaart naar Realiteit.

putting forward strategies, settings targets and designing policy instruments. In 2021 CIEP contributed to this discourse by publishing a study describing the emergence and present-day architecture of the organic chemical ecosystem in Northwest Europe.

Recently, the European Commission announced several policy initiatives and ambitions that have the potential to affect the organic chemical value chain in the decades to come. Part of the ambitions are set out in the EU's Chemicals Strategy for Sustainability.[5] In addition, they include the ambition, shared in the Sustainable Carbon Cycles communication, to ensure that at least 20% of carbon use in chemical and plastic products comes from sustainable non-fossil sources by 2030.[6,7] Currently, the organic chemical value chain largely depends on oil and gas derivatives as feedstock, especially at the level of the steam cracker. It is currently still unclear how players active in this field will deliver on these new targets. This paper aims to contribute to the debate on how the organic chemical value chain in the ARRRA can develop in this continuously evolving policy landscape.

This second paper of the 'Cracking the Clean Molecule' project adopts the analytical framework from the earlier study to examine the future in three steps.

First, it describes how the recently published ambitions and policy initiatives by the European Commission fit into the wider EU policy landscape. In this landscape, energy and transportation fuels policy has evolved rather independently from policy for chemicals and polymers.

Second, it describes various options for altering the organic chemical value chain to achieve the new policy ambitions. Instead of presenting a techno-economic assessment on a plant level, the value chain is considered from a systems perspective. The notion that the set of available adjustments to the value chain is not endless, but instead bound by the laws of physics and chemistry, helps to distinguish four types of options to intervene in the value chain, along with their most apparent barriers and drivers.

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[5] European Commission (2020). Chemicals Strategy for Sustainability.

[6] European Commission (2021). Sustainable Carbon Cycles.

[7] What the 'at least 20% of carbon use' ambition exactly means in terms of additional non-fossil carbon sources that need to be developed is currently largely unclear. One of the reasons for this is that there is no shared understanding about the current level of 'sustainable, non-fossil carbon use' in chemicals in plastics production. The European Commission's communication is, for example, unclear about whether recycled waste also qualifies as sustainable non-fossil carbon. If we nevertheless want to put the ambition in perspective, we see that in 2020 Nova-Institute and COWI estimated that the current average renewable carbon share in the European chemicals and plastics industries lies between 20 and 25%, with 15% coming from biomass and 5-10% from recycling. See Nova Institute (2020). Market development, trends and prospects.

Third, it describes how players active in the organic chemical value chain may be affected by new investments, partly due to proposed *European Green Deal* policy. The value chain is expected to feel not only the direct effects of chemicals and polymers policy but also the indirect effects of, among others, new policies for the transportation sector.

These three steps are presented in individual chapters that build on each other and set the stage for Chapter 5, which reflects on how (sub)national governments and industry partners can respond to the non-fossil carbon ambition shared by the European Commission. The conclusion highlights the main message and includes several considerations to keep in mind when taking further action.

The energy and feedstock transition presents a major challenge for companies active in the organic chemical value chain in the ARRRA. They must overcome a wide array of barriers inherent to developing innovative projects. Adjusting the value chain will also result in the introduction of new negative externalities that will have to be accounted for. The transition furthermore must take place ‘with the motor running’. Not only do plants have to keep operating while new projects are being developed; at the industry level European players must maintain their competitiveness vis-à-vis chemical clusters in the US, Russia, the Middle East and China. This notion forms an integral element in the reasoning put forth in this paper.

2 HOW EU POLICY STEERS DEVELOPMENTS IN THE ORGANIC CHEMICAL VALUE CHAIN

While having distinct features, certain hydrocarbon product groups for transportation fuels – and others for chemicals and polymers – are connected through their value chains, which share intertwined production and conversion facilities. These facilities are also heavily clustered. An historic perspective on previous transitions in the energy and the chemicals & polymers sectors shows that their evolution has been closely interrelated.[8] Nevertheless, policy interventions in these sectors are developed relatively independently of each other.

This can be observed, among others, in the introduction of new policy instruments for these sectors. In the summer of 2021 the European Commission published its *Fit for 55* package, comprising of 13 proposals to make the EU's climate, energy, land use, transport and taxation policies fit for reducing net greenhouse gas emissions by at least 55% by 2030. Proposals to revise and expand on EU policy for chemicals and polymers are expected later.

Among these proposals is one for a revised packaging and packaging waste directive, along with newly proposed rules for bio-based, biodegradable and compostable plastics that are expected to be published by the European Commission in 2022.[9],[10],[11] New EU legislation on these topics was announced part of the New Circular Action Plan, one of the main building blocks of the Commission's *European Green Deal*.[12] The discussion on these directives includes, among others, the adoption of recycled content targets.[13,14,15] Introducing these targets would imply that instead of just

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[8] Clingendael International Energy Programme (2021). The Dynamic Development of Organic Chemistry in North-West Europe.

[9] Eurativ (2021). On packaging recycling, EU aims to close the loop.

[10] The European Parliament and the Council of the European Union (2021). Reducing packaging waste – review of rules.

[11] European Commission (2021). Policy framework on bio-based, biodegradable and compostable plastics.

[12] European Commission (2020). Circular economy action plan.

[13] Idem.

[14] Eurativ (2021). On packaging recycling, EU aims to close the loop.

[15] See, e.g., Future Proof Plastics conference 2021, video contribution Diederik Samsom, Head of Cabinet for First Vice-President of the European Commission Frans Timmermans.

setting targets for waste collection, new products would need to include a share of collected and recycled waste. In addition to setting content targets for recycled feedstocks, the Commission also announced the ambition to make sure at least 20% of the carbon used in making chemical and plastic products comes from sustainable non-fossil sources by 2030. This ambition was shared as part of the Sustainable Carbon Cycles communication in late 2021.[16]

Mandating the uptake of desired resources is not new. In the chemical sector, recycled content targets were first introduced in 2019 for a limited group of products in the Single-Use Plastics Directive. Moreover, in the energy sector, targets for the uptake of desired resources or technologies are a common feature of EU legislation. The Renewable Energy Directive (RED), for example, set mandated shares of renewable energy consumption in 2009.[17] Before that, the 2003 directive on the promotion of the use of biofuels or other renewable fuels for transport included specific biofuels targets as well.[18]

Now that a wider introduction of non-fossil carbon targets seems imminent, it is justifiable to look at the effects of having different policy approaches to the development of the energy and the chemicals & polymers sectors. While it is entirely understandable that EU policy experts divided the problems and policy dossiers on the energy and the chemical sectors over different departments, this decision nevertheless influences the development of both sectors.

This chapter discusses the emergence, nature and effect of the differences between the apparent policy frameworks for energy & transportation fuels and for chemicals & polymers.[19] Is does so in three steps. First, it discusses how the policy framework for energy & transportation fuels developed into its current form. Second, it presents the apparent policy framework for chemicals & plastics and how it came into being. Third, it highlights key differences between these frameworks and examines the

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[16] European Commission (2021) Sustainable Carbon Cycles.

[17] The European Parliament and the Council of the European Union (2009) Directive 2009/28/EC on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC.

[18] The European Parliament and the Council of the European Union (2003). Directive 2003/30/EC on the promotion of the use of biofuels or other renewable fuels for transport.

[19] Conceptualisations of EU policy frameworks might differ among policy experts. This paper chooses to describe policy frameworks based on how they regulate various parts of the same value chain. The upstream parts of this value chain produce various energy products and transportation fuels (mainly through oil refining), while assets downstream produce various polymers & chemical products (through the various processes belonging to the organic chemical value chain). While referring to the EU policy framework for energy & transportation fuels or polymers & chemicals, this paper does not refer to any specific, formal piece of EU legislation but rather to the described collection of pieces of EU legislation that together make up these apparent policy frameworks.

implications of these observed differences on the development of these interconnected sectors. It thereby sets the scene for the following chapters, which discuss the barriers to and drivers behind the available technical options for altering the value chain and the ways in which the value chain is affected by upstream investments guided by transportation fuels policy.

2.1 EMERGENCE OF AN EU POLICY FRAMEWORK FOR ENERGY & TRANSPORTATION FUELS

Co-operation on energy and industry issues is arguably the foundation of European integration. The establishment of the European Coal and Steel Community (ECSC; Treaty of Paris, 1951), and later the founding of the European Atomic Energy Community (Euratom, 1957) and the Treaty of Rome, establishing the European Economic Community (1957), tied states with potentially diverging interests closer together. In 1967 these three institutions were merged into the European Communities (Treaty of Brussels, also known as the Merger Treaty). Integration continued with the Maastricht Treaty, which was concluded in 1992 against the backdrop of the end of the Cold War, the re-unification of Germany and accelerated globalization. The Maastricht Treaty established the European Union – with its internal market – on the foundations of the ECSC, Euratom and the European Economic Community (EEC). In addition, the treaty paved the way for monetary integration. In 2009, the treaty of Lisbon amended the treaties of Maastricht and Rome and, among others, established a legal basis for energy policy in primary EU law.[20]

The policy framework of the newly formed European Union for energy & transportation fuels was shaped by several key pieces of secondary law (see Figure 2 for a timeline). These include the 1st - 4th energy packages that enacted the liberalization of European energy markets, the Burden Sharing Agreement (BSA) that established differentiated national emissions targets[21], the EU-ETS that placed a cap on emissions and introduced greenhouse gas emissions trading,

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[20] The Treaty on the Functioning of the European Union (one of the two treaties that was amended by the Treaty of Lisbon) established, among others, the objectives of EU energy policy and the procedure to be followed in adopting secondary law to achieve them, and provides an explicit delimitation of EU competences in the pursuit of these objectives. Article 194(2) of the treaty states that measures taken to further the objectives of EU energy policy 'shall not affect a Member State's right to determine the conditions for exploiting its energy resources, its choice between different energy sources and the general structure of its energy supply.' As such, EU law enables the legislative bodies of the EU to establish measures to achieve common energy objectives while allowing Member States to maintain the right to determine their own energy mix.

[21] Under the Kyto Protocol, the European Community committed itself to reducing its greenhouse gas emissions by 8% during the period 2008 to 2012 in comparison with 1990 levels. The Kyoto Protocol allowed for the redistribution of the EU target among EU Member States. To agree on redistribution targets, the Burden Sharing Agreement (BSA) was negotiated. Through this agreement Member States agreed on differentiated emissions targets, ranging from -28% to +27% compared to 1990 levels for the 2008-2012 period.

the Fuel Quality Directives (FQD) that stipulated greenhouse gas and air pollutant emissions targets for transport fuels and the adoption of the climate and energy package that steered the development of the energy sector towards the year 2020 by means of the Effort Sharing Decision (ESD), the Renewable Energy Directive (RED), and later the Energy Efficiency Directive (EED).

Central to the emerging energy framework was the idea that a competitive energy-industrial complex that lived up to the expectations in terms of affordability, availability and acceptability (among others in terms of employment and – increasingly – decarbonization) could be achieved by the introduction and regulation of markets for energy and greenhouse gas emissions. Sectors included in the emissions trading system were electricity and heat generation, energy-intensive industrial sectors and (later) commercial aviation within the European Economic Area.

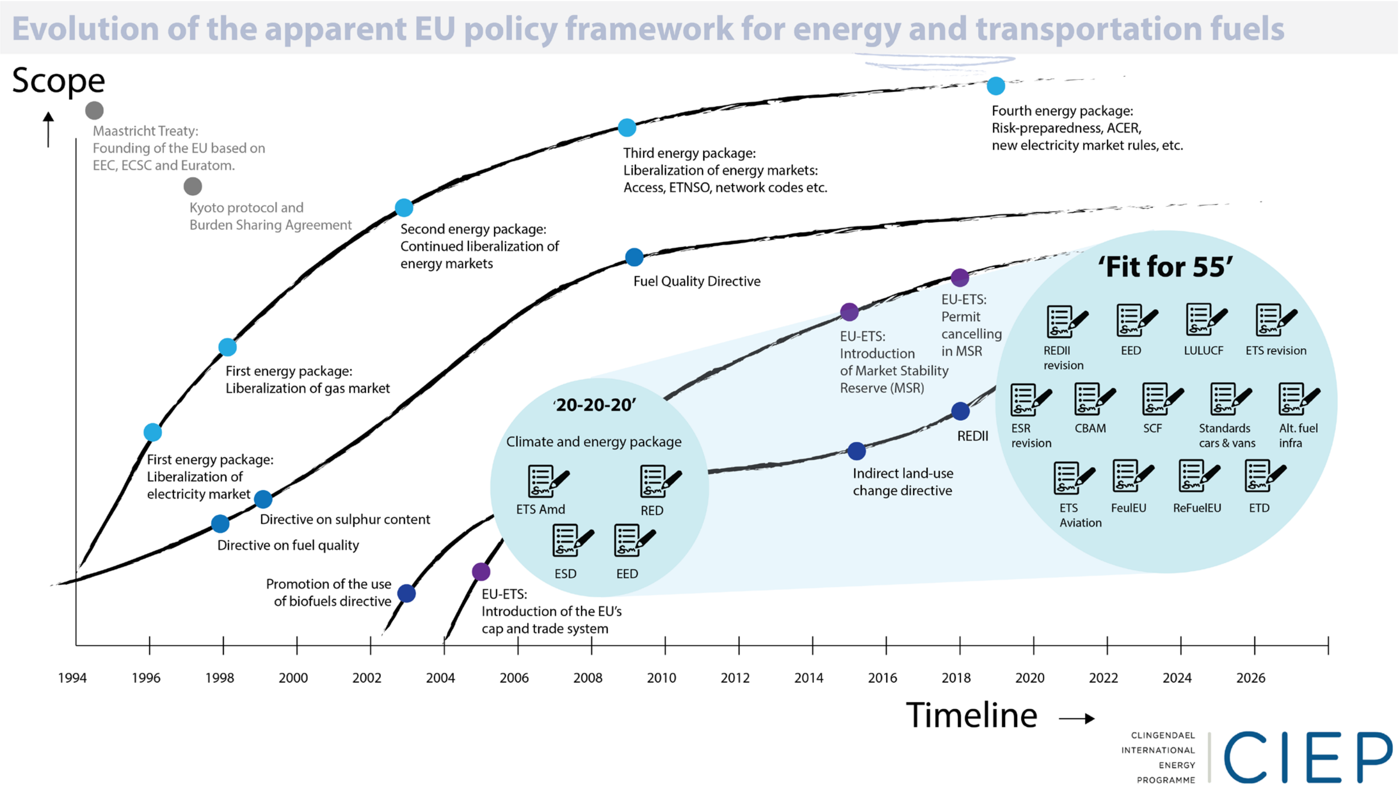

FIGURE 2. Policy timeline for the EU's apparent policy framework for energy & transportation fuels

Even though market-based instruments had to play a crucial role, they were introduced as part of a wider set of measures that included legal and regulatory instruments as well as economic and financial instruments. The RED set individual renewable targets for each Member State, including a target for energy from renewable energy consumption in the transport sector (see Appendix A on the evolution of the Renewable Energy Directive), while special funds were made available for energy efficiency. Many sectors were confronted with multiple – and in some cases hybrid – policy instruments. Member States, for example, saw their electricity sectors being steered by both the EU-ETS and national targets for renewable energy consumption, for which feed-in tariffs and tendering schemes (among others) were introduced by national governments.

In sectors not covered by the EU-ETS, such as road transport, buildings, agriculture and waste, emissions reduction was to be be realized through the Effort Sharing Decision (ESD) and Effort Sharing Regulation (ESR).[22] Member States agreed on national targets for emissions reduction, while largely preserving the freedom to decide how to realize them. In many cases, sectoral targets based on EU legislation overlap. This, for example, is the case in the transport sector, where Member States have to comply with RED targets, FQD targets and the overall ESD targets.[23]

The described policy framework for energy & transportation fuels consists of a large number of different instruments that aim to attain the targets and subtargets that are specified in the various pieces of legislation. Specifically, several targets and subtargets for GHG emission reduction are included. To reach these targets, energy & transportation fuels policy concentrates on emissions reduction at assets that are controlled or owned by the covered industry (scope 1 emissions) and also on emissions reduction at assets that are not directly controlled by the companies in this industry. The latter emissions are also referred to as value chain (or scope 3) emissions. Of the provisions that aim to lower value chain emissions, Articles 25 to

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[22] Under the Effort Sharing Decision (ESD), EU Member States again agreed on emissions targets for the 2012-2020 period. The overall target for ESD sectors was set to a 10% reduction, while national targets ranged from a 20% reduction by 2020 from 2005 levels for the richest member states to a 20% increase for the least wealthy one. In 2018, new targets were agreed upon this time under the Effort Sharing Regulation (ESR). This set an overall target for ESR sectors of 30% as well as national emissions reduction targets for all Member States, ranging from 0% to -40% (all from 2005 levels). As part of the Fit for 55 package, the European Commission proposed to increase the overall target from 30% to 40% and the national targets to the -10% to -50% range (compared to 2005 levels).

[23] See Appendix B for a discussion on how these directives relate to the proposed Fit for 55 package. At of time of writing, this package is being discussed in the EU Parliament and Council. This paper tries to stay away from the political negotiation process. Instead, it focuses on the analytical exercise of assessing how policy approaches differ between the transportation fuels and chemicals sectors, independently of whether specific pieces of legislation are or are not implemented as proposed.

29 in RED2 are a good example.[24] National instruments based on these provisions specifically aim to decrease value-chain emissions by setting an obligation on fuel suppliers and offering the opportunity to trade renewable fuel credits (certificates or tickets). With the introduction of these mechanisms, Member States effectively regulate the creation and development of new markets for transportation fuels (see Box 1). As we will see, provisions of this kind are non-existent in present-day chemicals & polymers policy.

Box 1 – Reaching EU renewable transport fuel targets with national market creation and development mechanisms.

Over the past years, EU Member States designed, implemented and developed national policy mechanism to reach targets set out in the RED and FQD along with their national ambitions.[25] In Germany and the Netherland, for example, national instruments are implemented that both place obligations on fuel suppliers and introduce a national credit trading system to help companies meet their obligations in a cost-effective manner.[26, 27]

Under these obligations and tradable credit systems, credits are created when a company delivers renewable energy to the transport sector and registers the relevant deliveries in a registry. To meet their obligations, companies that deliver fuel to the transport sector must ensure they hold sufficient credits in their account on a specific date. In addition to obtaining credits by delivering renewable energy, companies can obtain credits by purchasing them from other companies.

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[24] The European Parliament and the Council of the European Union (2018). Directive 2018/2001 on the promotion of the use of energy from renewable sources (recast). This directive was adopted as part of the EU's Clean energy for all Europeans package that is not discussed more extensively here.

[25] For an overview of national biofuel policies see ePURE (2022). Overview of biofuels policies and markets across the EU-27 and the UK.

[26] In the Netherlands, companies that deliver fuels to the transport sector are required to increase the share of renewable energy annually from 17.9% in 2022 to 28.0% in 2030. This is the annual obligation, which mainly concerns deliveries of petrol and diesel made in the Netherlands. The annual obligation is partly based on provisions in the RED2, which sets a minimum share of 14% renewable energy in final consumption in transport for 2030. In addition, they are in part based on the Dutch Climate Agreement, which sets higher ambitions. Apart from the obligation to increase the share of renewable energy, the EU Fuel Quality Directive (FQD) requires that companies that deliver fuels to the transport sector must reduce the greenhouse gas emissions from their fuels by 6% compared to a 2010 baseline. Also see: Dutch Emissions Authority (2022). General - Renewable Energy for Transport 2022-2030.

[27] Since 2015, Germany uses a tradeable greenhouse gas reduction certificates system. Companies receive these certificates for each tonne of CO2 equivalent saved when incorporating more renewable fuels into gasoline and diesel than needed to meet GHG savings targets. In 2021, the German greenhouse gas reduction quota for transport has been set to 22 percent for the year 2030 see BMUV (2021) Minister Schulze: We are promoting fuels that mitigate climate change without destroying nature.

2.2 EMERGENCE OF AN EU POLICY FRAMEWORK FOR CHEMICALS & POLYMERS

Starting with the first legislative measure on chemicals, enacted in 1967, European regulation of chemicals underwent a decades-long evolution, partly similar to energy & transportation fuels regulation. Yet compared to energy policy, the control and use of chemicals has been regulated by a higher number of separate pieces of EU legislation. As a result, chemicals policy has always been more diffuse.[28]

According to the Commission's own counting, the evolution culminated in a framework of approximately 40 legislative instruments for chemicals.[29] Key pillars in this framework are the REACH, CLP, WFD, SUP, PPWD and EPR directives. Together they regulate the registration, evaluation, authorization and restriction of chemicals and polymers in the EU, the classification and labelling of chemicals, as well as the post-consumer phase of specific chemical products (see Figure 3 for a timeline showing the implementation year of these policies).

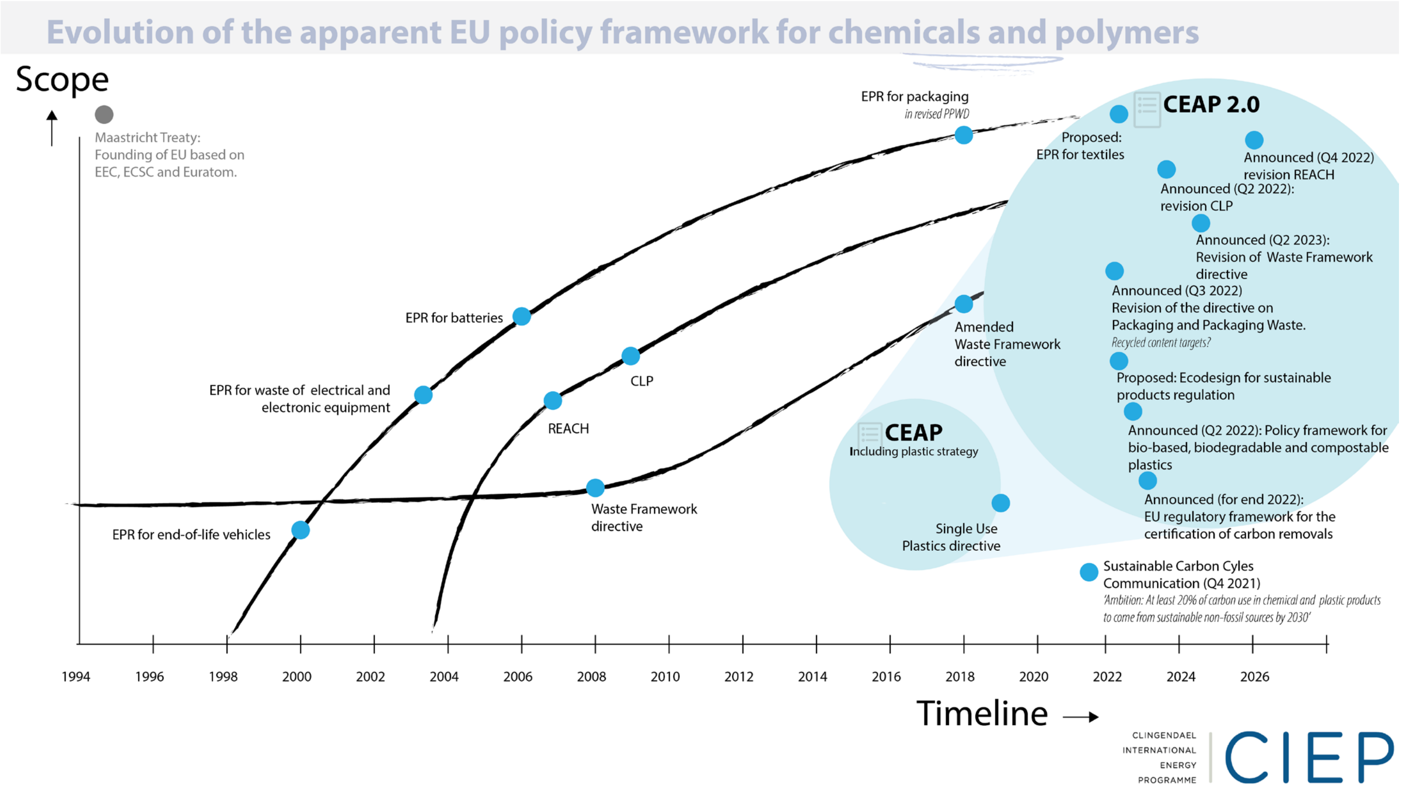

FIGURE 3. Policy timeline for the EU's apparent policy framework for chemicals and polymers

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[28] See also Stokes E., Vaughan S. (2013). Great Expectations: Reviewing 50 Years of Chemicals Legislation in the EU Journal of Environmental Law, Vol. 25, No. 3, Special Issue: 'Environmental Law: Looking Backwards, Looking Forwards' pp. 411-435.

[29] European Commission (2020). Chemicals Strategy for Sustainability.

REACH, short for Regulation on the Registration, Evaluation, Authorisation and Restriction of Chemicals, was proposed with the intention of protecting human health and the environment and came into force in 2007, replacing several older directives. At the heart of REACH is the requirement for the private sector to generate data on the intrinsic properties of certain chemical substances. These substances, together with their testing data, are registered with the European Chemicals Agency (ECHA), a regulatory body erected specifically for this purpose. Substances identified as particularly harmful to human health or the environment are either banned or are authorized by the European Commission to remain on the market for a limited time only.

CLP – the Classification, Labelling and Packaging regulation – complements REACH by providing a system for the classification, labelling and packaging of chemical substances based on the United Nations' Globally Harmonised System. It aims to harmonize communication regarding the hazard information of chemicals and thereby to facilitate global trade and promote regulatory efficiency.

As part of the EU's Chemicals Strategy for Sustainability[30] , the European Commission announced that it will propose revisions of REACH and CLP. Whereas both the current and anticipated revisions of these two regulations focus on whether and under what conditions chemical products may be placed on the European market, the Waste Framework Directive (WFD) and Extended Producer Responsibility (EPR) directives focus on the post-consumption phase of chemical and other products.

The current WFD, adopted in 2008 and amended in 2018, builds on waste legislation that has been present at the European level since the mid-1970s. The directive lays down basic waste management principles and establishes a waste hierarchy in which preventing waste is the preferred option and sending waste to landfills should be the last resort. It also sets targets to increase the preparation for re-use and recycling of waste materials, including plastics, to a minimum of 55%, 60% and 65% by weight by 2025, 2030 and 2035, respectively.[31]

During the late 1990s, EPR mechanisms were first introduced at the EU level. According to the original definition, the objective of these mechanisms is to reduce the total environmental impact of products, by making a product's manufacturer responsible for its entire life-cycle and especially for its take-back, recycling and final

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[30] European Commission (2020). Chemicals Strategy for Sustainability.

[31] The European Parliament and the Council of the European Union (2018). Directive 2018/851 amending Directive 2008/98/EC on waste.

disposal.[32] The EU introduced directives implementing EPR for end-of-life vehicles in 2000[33], for waste electrical and electronic equipment (WEEE) in 2003[34], for batteries in 2006[35], and for packaging through a revision in the packaging waste directive in 2018[36]. These directives set out how Member States can attain targets for reuse, recycling and recovery, taking into account the polluter-pays principle.

Building on among others these waste directives and chemicals legislation, the European Commission published the EU action plan for the circular economy in 2015. This action plan established an agenda and included measures covering the whole product life cycle: from production and consumption to waste management and the market for secondary raw materials and the aforementioned revision to waste legislation. In the wake of this agenda a number of directives were adopted, including the directive on single-use plastics in 2019.

Until then the policy framework for chemicals had largely revolved around protecting human health and the environment by setting conditions under which products could be placed on the market, as well as for the prevention and management of waste. The Single-Use Plastics (SUP) Directive added provisions that set recycled content targets, albeit for a very limited group of products. It limits – and in some case prohibits – placing specific single-use plastic products on the market. In addition, Article 6 of the directive introduced the target of incorporating 25% of recycled plastic in PET beverage bottles as of 2025, and 30% in all plastic beverage bottles as of 2030. [37]

In 2020 the European Commission adopted a new circular economy action plan and announced that it will propose additional mandatory requirements for recycled content and waste reduction measures for key products such as packaging, construction materials and vehicles.[38] These measures have been discussed in light of other revisions, such as that of the Packaging and Packaging Waste Directive (PPWD).

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32 Lindhqvist T. (2019). "Extended Producer Responsibility," in the proceedings of an invitational seminar at Trolleholm Castle: "Extended Responsibility as a Strategy to Promote Cleaner Products".

33 The European Parliament and the Council of the European Union (2000). Directive 2000/53/EC on end-of life vehicles.

34 The European Parliament and the Council of the European Union (2003). Directive 2002/96/EC on waste electrical and electronic equipment (WEEE).

35 The European Parliament and the Council of the European Union (2006). Directive 2006/66/EC on batteries and accumulators and waste batteries and accumulators.

36 The European Parliament and the Council of the European Union (2018). Directive (EU) 2018/852 on packaging and packaging waste.

37 The directive prohibits the placing on the market of the single-use plastic products listed in Part B of the Annex, which includes cutlery, plates and straws and of products made from oxo-degradable plastic.

38 European Commission (2020). Circular Economy Action Plan.

The Commission plans to adopt a revision of that directive in 2022.[39] For bio-based chemicals, mandatory content targets for chemicals and plastics are not expected within this time span (see Box 2). The Commission did, however, announce the publication of a policy framework on the sourcing, labelling and use of bio-based plastics, and the use of biodegradable and compostable plastics. For this framework the Commission is assessing where the use of bio-based feedstocks and of biodegradable and compostable plastics can be beneficial to the environment. As such, it can be seen as essential groundwork for potential future bio-based plastics incentives. In its most recent addition to the policy framework, announced in the Sustainable Carbon Cycles communication[40] in late 2021, the Commission shared its ambition to ensure that at least 20% of carbon use in chemical and plastic products comes from sustainable non-fossil sources by 2030.

Box 2 – Will we soon also see mandatory targets for bio-based chemicals and plastics?

For some time now, experts have noted that there are limited instruments for incentivizing bio-based products. Also, the European Commission's working group for Bio-based Products agues that 'currently the use of biomass for material purposes is only encouraged by small and isolated incentives, resulting in a situation where the use of biomass for bio-based products is disadvantaged compared to its use for energy production'[41].

One of the main aims of the EU bioeconomy strategy is to deploy innovative bio-based solutions and develop substitutes to plastics that are bio-based, recyclable and marine biodegradable[42]. This strategy amongst others includes the allocation of funds for a thematic innovation platform but doesn't contain any specific references to requirements for bio-based content in chemicals or plastics. While the European Commission indicated that it is assessing where the use of bio-based feedstock leads to genuine environmental benefits as part of the publication of the policy framework on the sourcing, labelling and use of bio-based plastics, biodegradable and compostable plastics it is unclear whether this may lead to specific bio-based content targets.

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[39] European Commission (2021). Reducing packaging waste – review of rules.

[40] European Commission (2021). Sustainable Carbon Cycles.

[41] Commission Expert Group for Bio-based Products (2014) Working Group on Evaluation of the Implementation of the Lead Market Initiative for Bio-based Products' Priority Recommendations

[42] European Commission, Directorate-General for Research and Innovation (2019). Bioeconomy: The European way to use our natural resources: Action plan 2018.

2.3 EFFECTS OF THE DIFFERENCES IN THE POLICY FRAMEWORKS FOR ENERGY AND CHEMICALS

The apparent policy framework for energy & transportation fuels differs from that for chemicals & polymers in multiple ways. Three discrepancies stand out when comparing the two frameworks. The first is of a more procedural nature, the other two substantive.

First, both policy frameworks are rapidly evolving, yet compared to the framework for energy & transportation fuels, the one for chemicals & polymers is more diffuse. The latter is characterized by a high number of regulations, directives, actions plans and strategies published on a continuous basis. This is also evident in more recent publications of policy initiatives. Whereas the Fit for 55 package bundles the publication of thirteen legislative proposals, presented as one integral whole, publications of Green Deal policy proposals for chemicals & polymers are spread out over several years. This difference is neither right nor wrong but does lead to divergent dynamics. Moreover, it points to an inherent difference in how these interrelated policy areas, which are connected through their value chains, are approached.

Second, the policy framework for chemicals & polymers initially focused primarily on protecting human health and the environment through REACH, CLP, WFD and various EPR schemes. The Circular Action Plan – particularly the Single-Use Plastics (SUP) Directive – added the objective of promoting the transition to a circular economy. With the Sustainable Carbon Cycles initiative, the European Commission goes even further by communicating the need to establish sustainable and climate-resilient carbon cycles. In doing so it places greater emphasis on emissions stemming from the entire life cycle of chemicals & polymers, effectively focusing more strongly on value chain (scope 3) emissions. Already since the early 2000s, legislation in the energy & transportation fuels framework has contained provisions that have aimed to reduce value chain emissions by stimulating the uptake of renewable fuels.

Third, and partly as a result of the aforementioned, market creation and development instruments are more established in the policy framework for energy & transportation fuels than in the chemicals & polymers counterpart (see Table 1). This is especially true for policy initiatives that focus on transportations fuels, notably RED, FQD, FuelEU and ReFuelEU (see box 1). These pieces of legislation contain articles describing how to reduce value chain emissions[43], whereas the policy framework for chemicals & polymers includes no such provisions.

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[43] Such as Article 25 in the revised REDII, which aims to ensure that the amount of renewable fuel supplied to the transport sector leads to a reduction in greenhouse gas intensity of at least 13% by 2030 compared to a baseline (see Appendix A).

TABLE 1. MARKET CREATION IN THE APPARENT FRAMEWORKS FOR ENERGY & TRANSPORTATION FUELS AND FOR CHEMICALS & POLYMERS

	Energy & transportation fuels	**Chemicals & polymers**
Market creation legislation	Strong focus: Developing markets for renewable fuels in order to replace fossil fuels, through e.g. RED, fleet-wide CO_2 emissions targets for new passenger cars and vans, FQD, FuelEU and ReFuelEU legislation	Limited focus: Developing markets for recycled plastics in order to limit waste and replace virgin materials through the SUP directive and possibly the revised PPWD
Scope	Large share of transport fuel market: · National transportation sector through RED · Maritime and aviation sector through proposed FuelEU and ReFuelEU	Small share of chemicals & plastics market: · PET beverage bottles as of 2025 through SUP · All plastic beverage bottles as of 2030 through SUP
Targets and ambitions	· Targets focused on reduction of value chain (scope 3) emissions, using a multiplier scheme (RED2) or technology-agnostic product intensity metrics (Revised RED2)	· Targets focused on uptake of recycled materials, using recycled content shares (SUP) · Ambition to ensure that by 2030 at least 20% of the carbon used in chemical and plastic products are from sustainable non-fossil sources
Maturity	Rapidly evolving policy framework with established institutions	Rapidly evolving policy framework with emerging institutions

It is currently unclear how the new non-fossil carbon ambition announced in the Sustainable Carbon Cycles initiative will be translated into EU legislation. In time, the new ambition might lead to the adoption of market creation and development mechanisms that are similar to those currently used for renewable transportation fuels.

No matter how the new non-fossil carbon ambition is translated into policy, the present-day differences between how the two policy frameworks approach renewable products are substantial. While renewable transportation fuels are steered by mature instruments that aim to fulfil targets that are also sharpening, ambitions for non-fossil carbon in the chemicals & polymers sector are aspirational objectives without any instruments to realize this ambition.

These differences are not per definition wrong. Potentially, they could even be justified from a marginal abatement cost perspective. The differences do, however, influence how the organic chemical value chain will evolve. To understand how this value chain can change, the next chapter will first discuss the available technical options to alter it, along with their most apparent drivers and barriers to implementation . While it is relevant to know the technical opportunities and limitations, the technical specificities of these options will not necessarily be the key determining factors in how the value chain will develop, as discussed in Chapter 4.

3 AVAILABLE TECHNOLOGICAL OPTIONS FOR ALTERING THE ORGANIC CHEMICAL VALUE CHAIN

The continuously evolving policy frameworks that were the focus of the previous chapter at times disguise the unambiguous nature of hydrocarbon value chains. These value chains generate transportation fuels and materials by separating molecules and converting them into chemical compounds in ways that adhere to the laws of physics and chemistry.

The basic notion that 'this also has to add up physically' has two implications. First, there is a limited set of available options. The solution space to reach the net-zero emissions and non-fossil carbon objectives in the hydrocarbon value chains is not unlimited, but it is confined by the laws of physics and chemistry. In this regard, there is no need to think outside this box. Second, understanding the options that are on the table requires some understanding of what can and cannot be done within the toolbox of organic chemistry. If we know this, the toolbox can be used to ensure that at least 20% of the carbon used in chemical and plastic products will come from sustainable non-fossil sources by 2030 and to reach the other ambition and targets set in the various pieces of legislation that were discussed in the previous chapter.

This chapter provides a brief technical background of the key options on the table for addressing the net-zero emissions and non-fossil carbon challenges in the organic chemical value chain. Rather than looking at the technical details, it zooms out to show the bigger, systemic picture. In addition to examining the technical options, it discusses the main barriers and drivers.

The origin and structure of the Northwest European refinery and organic chemistry landscape is discussed in greater detail in previous CIEP publications and will not be repeated here.[44] We take the organic chemical value chain as described in the previous publication in this series as a starting point for this chapter. In the organic

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[44] Clingendael International Energy Programme (2021). The Dynamic Development of Organic Chemistry in North-West Europe

chemical value chain, chemicals and polymers are produced by capturing naphtha or natural gas liquids from crude oil and (wet) natural gas and converting them into straight (olefins) and ring shaped (aromatics) hydrocarbons in refineries, steam crackers and propane dehydration facilities. In various chemical conversion processes these olefins and aromatics are transferred into a wide pallet of polymers and chemicals (see Figure 4).

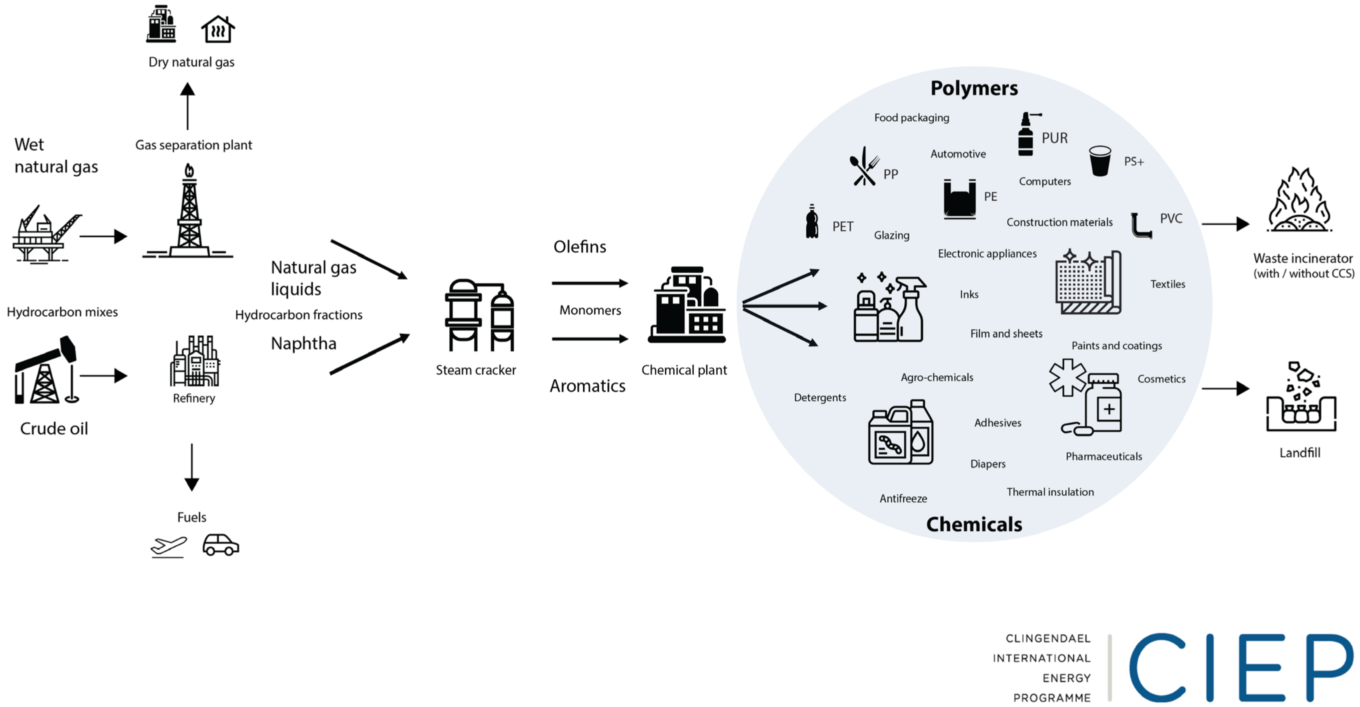

FIGURE 4. Conventional organic chemicas value chain (simplified)

Conceptually, a number of options can be used to alter this value chain. It is tempting to regard the changes that can be made to the value chain as policy levers. Yet none of the options come without side effects and negative externalities. While there is some low-hanging fruit, policy efforts in previous decades already focused on picking it.

Options to alter the organic chemical value chain can be conceptualized as follows (this list is also shown the visual representation displayed in Figure 5):

- Change what feedstocks go in:
  – The share of recycled waste used as alternative feedstock
  – The share of captured carbon used as alternative feedstock
  – The share of biomass used as alternative feedstock

- Change what products come out:
  - – The volume of products produced
  - – The types of products produced
- Change what happens with produced products:
  - – How products are used
  - – How products are discarded
- Change how products are produced:
  - – Process and energy efficiency
  - – The share of renewable energy consumption
  - – The level of direct emissions (through carbon capture and storage)

This chapter discusses these options one by one, thereby paying special attention to options that receive less attention in the policy domain.

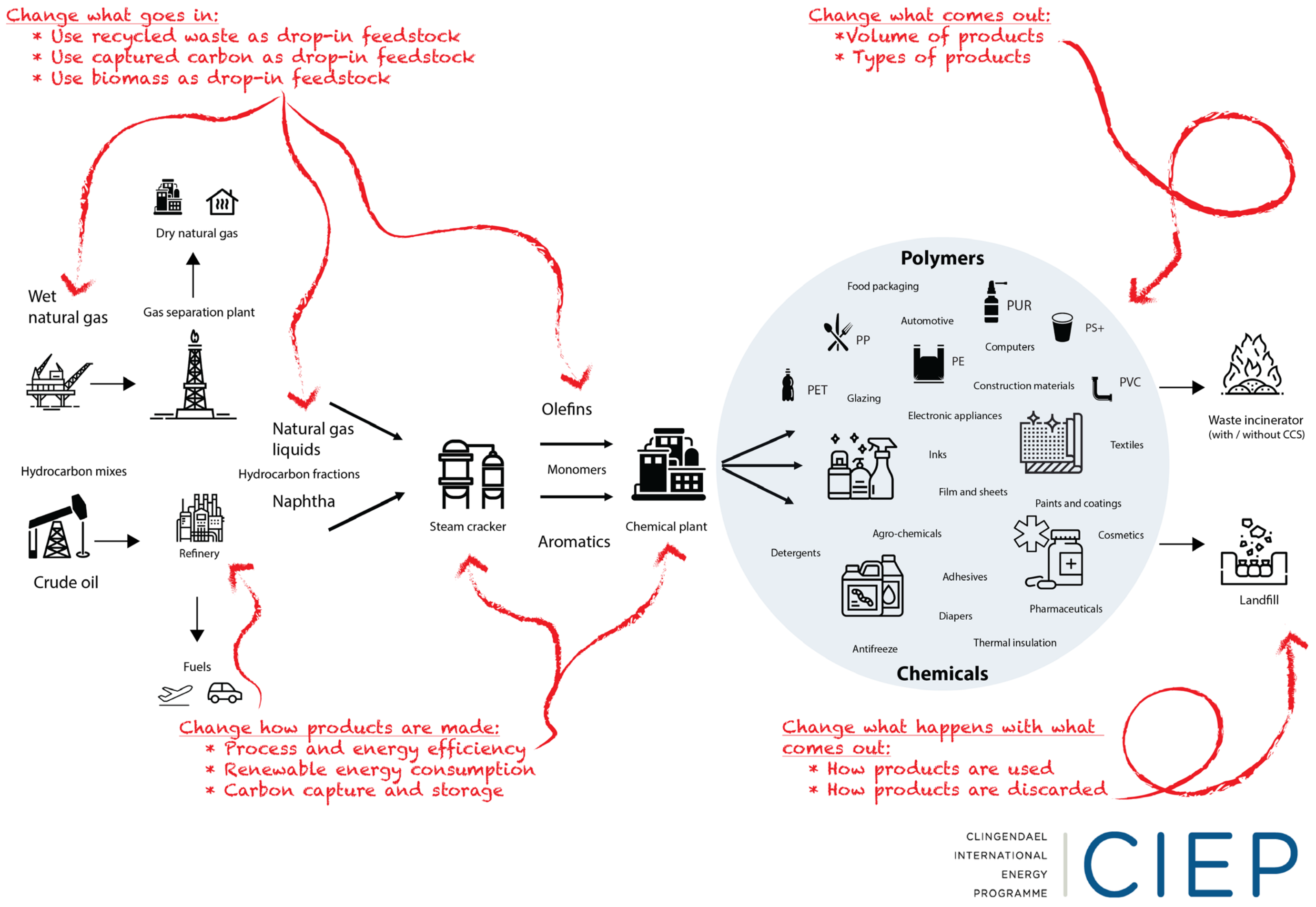

FIGURE 5. Four types of intervention measures can be deployed to alter the organic chemical value chain.

3.1 CHANGE WHAT GOES IN

Recycled waste, captured carbon and biomass can be used as alternatives to conventional hydrocarbons derived from oil or gas. Among others, they can be used as drop-ins in the existing value chain. Yet the stage at which they are fed in differs per process technology. For key technologies, the place at which they connect to the existing value chain is sketched in figures in this chapter. The figures' captions provide more detailed descriptions of key conversion technologies for the respective alternative feedstocks.

INCREASE THE USE OF PLASTIC WASTE AS DROP-IN FEEDSTOCK

To decrease the demand for virgin materials, waste streams can be recycled using mechanical and chemical recycling techniques. Mechanical recycling techniques are designed to process waste streams into 'new' materials without changing the basic chemical structure of the material. Waste streams that for waste purity or product quality reasons cannot be mechanically recycled can in certain cases be recycled chemically. In contrast to mechanical recycling, chemical recycling techniques change the chemical structure of the waste components (hence the term 'chemical'). These methods lower the demand for virgin materials by providing an alternative, recycled source of carbon to the value chain.

Figure 6 gives examples of how chemical recycling can provide alternative sources of carbon at various stages in the value chain, depending on what share of the molecular bonds are kept intact or are broken down to their smallest forms.

While recycling is often depicted as the holy grail of the circular economy, the lack of large quantities of (pure) waste streams limits the use of recycled waste as an alternative feedstock. Availability could be increased by improving sorting practices. Moreover, the use of waste as chemical feedstock could be improved by increasing imports of waste or waste intermediates (such as waste-based pyrolysis oil). This is especially relevant for the ARRRA, as a signification share of the products produced here are exported. If the loop were to be closed, waste might also need to be re-imported. However, compared to the open and relatively transparent commodity markets for chemical feedstocks and intermediates, trade in waste streams is opaque and more limited, also given the environmental restrictions and related institutional barriers.

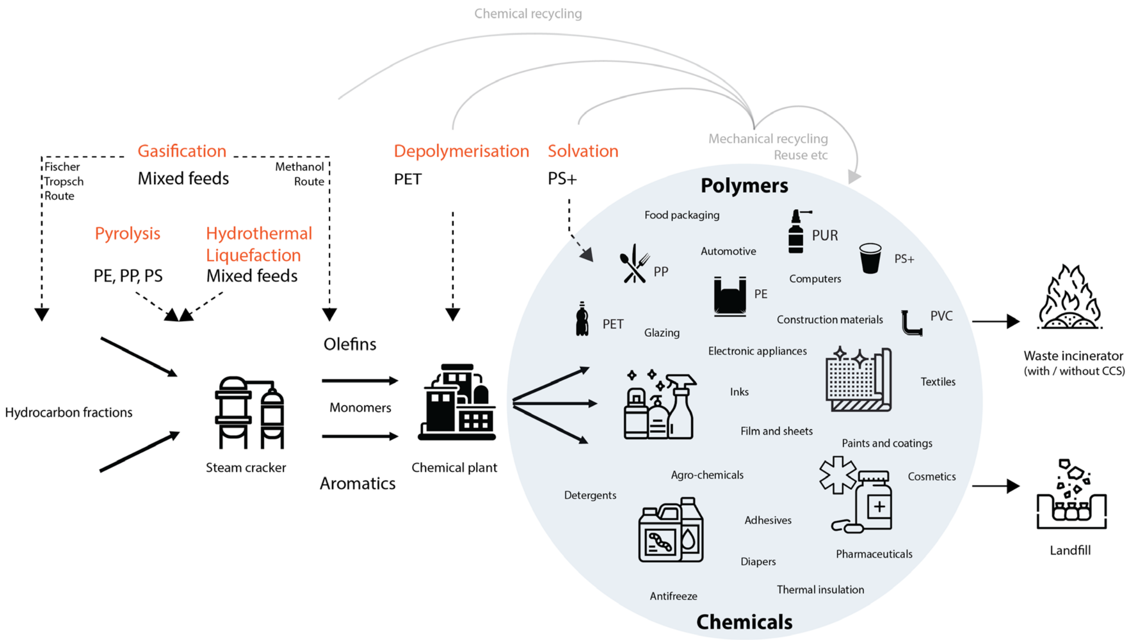

FIGURE 6. Key chemicals recycling techniques provide alternative sources of carbon

Solvation involves the selective extraction of polymers out of a relatively pure waste stream using solvents. A depolymerization process breaks down polymers into either monomers or polymer intermediates. Plastic pyrolysis pertains to the thermal decomposition of (mixed) plastics in an environment that is free of reagents such as oxygen. After treatment, the resulting pyrolysis oil could be used as a substitute for fuel and naphtha. Hydrothermal liquefaction also produces substitutes for fuel and naphtha. Gasification converts residual mixed plastic waste streams into syngas (H_2, CO and CO_2), which could be transformed into methanol or FT wax (or ethanol or ethylene) and as such could be a basis for many hydrocarbon products.

In addition, it is worth nothing that even if all institutional barriers were overcome, using chemical recycling techniques does not create a circular system in the sense that generated products become waste and can be transformed back into product with a 100% conversion factor. This is because even in a system that uses chemical recycling techniques, losses are endured. There are several reasons for this. First of all, not all products find their way into recycling streams because they may not be collected properly. Second, also in recycling and pre-processing, carbon is lost, as a certain percentage of waste is transformed into components – including tar – that cannot be reused as product. Finally, markets with high growth rates provide a particular challenge, as pure waste streams may not be available for these markets in the appropriate volumes to cover growth.

To cover the losses endured, as well as the demands of specific growth markets, new molecules need to be added to the system. Recycling cannot close the loop fully. Finding an answer to the question of how close we can get with various waste streams is the million-dollar question. It requires making assumptions about efficiency improvements that are the result of research and development projects as well as changing consumer behaviour. Yet even without having an exact answer to this question, it is clear that due to aforementioned barriers, recycling alone does not offer a full replacement to conventional feedstock production, but rather is one of a number of complementary options.

INCREASE THE USE OF CAPTURED CARBON AS DROP-IN FEEDSTOCK

Capturing and utilizing carbon is one of the alternative feedstock routes complementary to recycling. CO_2 can be captured from off-gases of industrial sites or via direct air capture.[45] Figure 7 illustrates how the carbon can be fed into the chemical value chain. Conversion techniques used to convert syngas (H_2, CO and CO_2) into chemicals are similar to those in recycling (and bio-based) routes. This reflects the notion that while useful for a policy discussion, grouping alternative conversion routes by feedstock is arbitrary from a chemical perspective.

While these techniques are promising and sometimes even depicted as 'ultimate solutions', their implementation does also face barriers. The most apparent barrier are the costs, that are high relative to other routes. As the processes are rather energy intensive, they compete with other use case of renewable energy and require many joules of renewable energy that are currently not available, requiring a further upscaling of renewable energy production. Moreover, direct air capture and carbon capture and utilization (CCU) requires further research and development to increase its technology-readiness. Using carbon captured from off-gasses does provide a route with lower barriers and potential GHG emission savings.[46] However, this route may be depicted as undesirable if the carbon is captured from processes that requires a fossil resource as input, even if it reduces emissions over the supply chain, decreases the need for additional fossil input into the system and helps promote technologies essential in the net-zero future.

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[45] Alternative feedstock routes that use CO2 captured from processes (partly) fed by biomass are discussed later in the chapter.

[46] Off-gasses are gasses produced as byproducts in an industrial process. Depending on the process, this could be the reaction product of fuel and combustion air but can also be other gasses that are not the process' main output, for example carbon monoxide (CO) produced in steam methane reforming or steel making. Using this latter type of (CO-rich) off-gas is typically preferred over using (CO2-rich) off-gas.

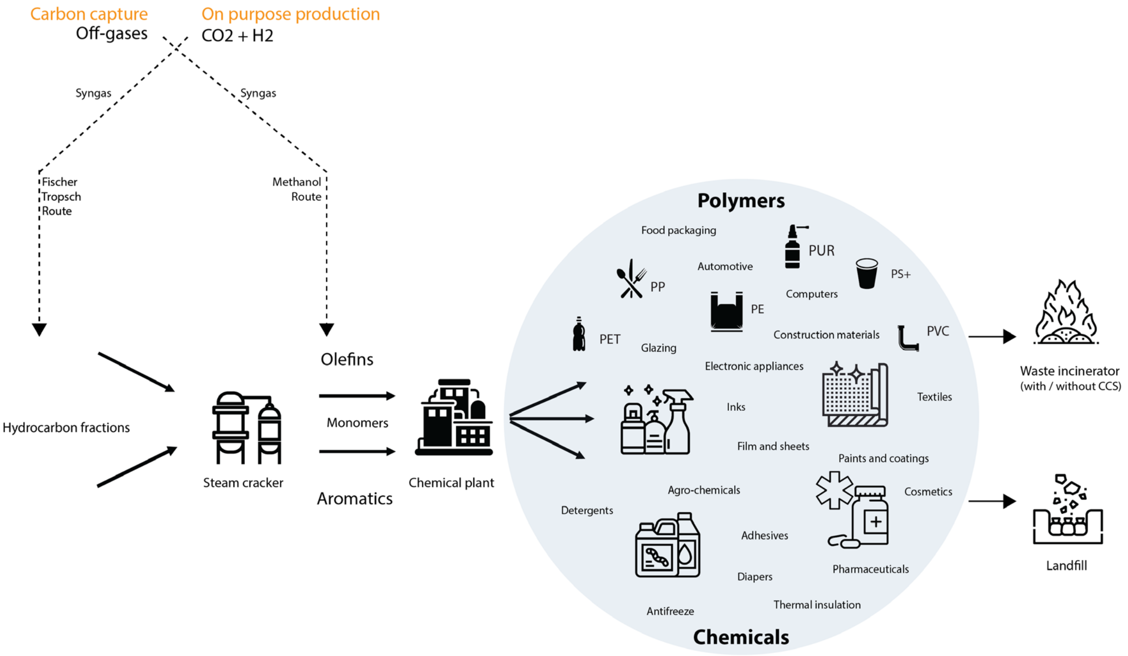

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FIGURE 7. Key carbon capture and utilization techniques provide alternative sources of carbon

The Fischer Tropsch process converts a syngas, a mixture of hydrogen, carbon monoxide and carbon dioxide, into various hydrocarbon bonds, including those in the naphtha range. Syngas can also be converted into methanol (or ethanol or ethylene). The methanol can in turn be transformed into olefins or aromatics via a methanol2olefins or methanol2aromatics process. Neither the Fischer Tropsch process nor the methanol route are new processes, but they have been in existence for a long time. The processes are sometimes referred to as power-to-liquids, a term that empasizes the opportunity to convert (renewable) electricity into transportation fuel, but to some degree disguises the need for a source of molecules.

CCU provides one of the complementary alternative feedstocks. Similar to using recycled waste as input and – as will be discussed next – biomass, its barriers to implementation are significant. Yet they can and need to be overcome if fossil inputs are to be decreased. This need for CCU has consequences for carbon capture and storage (CCS) investments. Indeed, infrastructure realized for CCS can be reused in a system relying on CCU. The prospect of using carbon as feedstock instead of just storing it makes CCS investments more robust and future-proof.

INCREASE THE USE OF BIOMASS AS DROP-IN FEEDSTOCK

Bio-based production presents a third alternative feedstock route. Molecular strings containing hydrocarbons derived from biomass can be fed into the chemical value chain at various places (see Figure 8). Similar to the other routes, molecular bonds can be kept largely intact or broken down to their smallest forms.

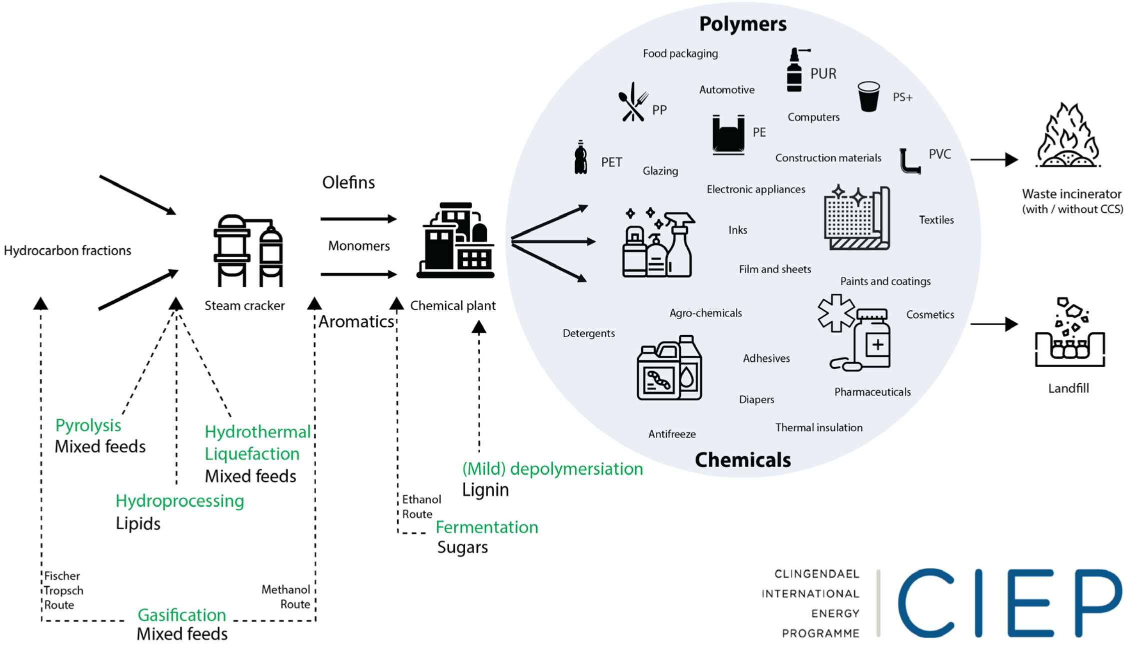

FIGURE 8. Key biomass conversion techniques provide alternative sources of carbon

Lipids are organic compounds that are insoluble in water. Their properties are similar to those of oils and fats. Lipids can be derived from various types of organisms.[47] Their biological function includes storing the organism's energy. Lipids can be hydroprocessed in a HVO or HEFA process to produce fuels and chemicals. As vascular plants contain cellulose, hemicellulose and lignin, they are classified as lignocellulosic biomass. Cellulose and hemicellulose are polysaccharides or sugars that – just as starch and other sugar-rich compounds found in plants – can be fermented to ethanol and converted to, for example, ethylene via bioethanol dehydration. Lignin is a class of complex natural polymers that provide structure to plants; they can be depolymerized to produce aromatics. Decomposing compounds by heating them in the absence of oxygen – pyrolysis – or in the presence of water – as happens with hydrothermal liquefaction – can take place with a mixed feed. This feed has to be within a specified range to produce an optimal output. A gassification process further breaks down the original structure of the mixed feed and converts it into syngas, which can be further processed to e.g. FT wax or methanol (ethanol or ethylene) for the production of hydrocarbons.

In contrast to fossil feedstocks, biomass' end-of-life emissions are carbon-neutral when sustainable biomass production guidelines and adequate forest management practices are applied. While these carbon-neutral properties are biomass's main advantage, using the resource has several co-benefits as well, among others in the realm of climate adaptation. Afforestation and reforestation can be used in areas that suffer from land degradation. These practices generate biomass as a byproduct

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[47] As organisms (plants, algae, animals, etc.) are made up of many compounds that typically can be used in many conversion processes, we here group them according to constituting compounds types (lipids, lignin, sugars) instead species (rapeseed, pine wood, sugar cane, etc.).

and can be applied in many places, including in Europe. Examples include fighting desertification in Spain and Portugal and countering soil erosion in Italy, Austria and Germany. Moreover, as forest management can go hand in hand with wildfire protection , they have the potential to bring additional benefits to local communities, alongside the extra sources of income they provide through, among others, biomass production. Growing biomass for use as drop-in feedstock can, furthermore, improve the efficiency of agriculture and food & feed production, for example by making more use of sugar cane or sugar beet byproducts. Another benefit can be found in the prospect of deploying bio-based feedstocks in combination with CCS and CCU technologies. Brining these technologies further can pave the way to increased emissions reduction or even the realization of carbon-negative projects.

The risks that should be considered when using biomass as alternative feedstocks are also apparent. Direct competition with other sectors can elevate food and feed prices, and indirect land use change as well as biodiversity loss pose serious hazards. Moreover, there are lively debates about the availability of biomass (mainly in the longer term) and related spatial planning questions.[48] Conveying a nuanced view about how these hazards are managed and risks are mitigated is difficult. Potential controversy spillover – the risk of spreading of negative public sentiment to new countries, subsectors and feedstock – is one of the key risks of the bio-based route for the chemical industry.[49]

All in all, the barriers to increasing the use of biomass as an alternative feedstock are significant but not unmanageable. The role of biomass as drop-in feedstock can best be discussed compared to other options available in the organic chemical value chain. Given the barriers that limit increases in the use of recycled waste and captured carbon, limiting the use of biomass might lead to the prolonged use of fossil feedstocks. To prevent this, the use of biomass as drop-in feedstock is essential, as is the case for the use of recycled waste and captured carbon.

3.2 CHANGE WHAT COMES OUT

Changing the products that are produced in the organic chemical value chain presents a set of solutions that is fundamentally different from the alternative feedstock options discussed above.

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[48] Biomass availability is conditional and dependent on decisions made about spatial planning. This notion is reflected in assessments of biomass availability. The outcomes of these assessments are, amongst others, greatly affected by assumptions about the potential of abandoned farm lands and the use of degraded lands. As research on the availability of biomass is omnipresent, a more detailed discussion of availability biomass is left beyond the scope of this paper.

[49] See e.g. Cuppen, E., Ejderyan, O., Pesch, U., Spruit, S., van de Grift, E., Correljé, A., & Taebi, B. (2020) When controversies cascade. Energy Research and Social Science, 68.

CHANGE VOLUME OF PRODUCED PRODUCTS

Decreasing the volume of produced products is, for obvious reasons, not the most popular intervention in business settings. Yet it would be short-sighted to say that if it were more popular, reaching net-zero and non-fossil carbon targets would be straightforward.

There are a myriad of options for decreasing the volumes of products produced. These range from the outright banning of products – as is the case for some single-use plastics through the Single-Use Plastics Directive – to price incentives, product design and recycling standards and awareness campaigns. Moreover, actions on the 'R-ladder' – refusing, rethinking, reducing, reusing, repairing, refurbishing, remanufacturing, repurposing and (mechanically) recycling – all lead to lower required volumes of new products. In many ways, these actions are the circularity equivalent to energy efficiency measures in the energy sector. Very often they are the first options to consider and implement. Simultaneously, using them to realize policy goals can be challenging, as implementation is more difficult than one might think, among others due to behavioural, social and multi-actor barriers that must be overcome.

A key aspect to consider while implementing volume-decreasing measures are replacement effects. Replacing carbon-fibre wind turbine blades or plastic car dashboards with wooden alternatives could decrease efficiency and increase life-cycle emissions. A wider use of life-cycle assessment could discourage the replacement of plastic products with products with a higher greenhouse gas emissions footprint.

Chemicals and plastics are often inexpensive, resistant and abundant. These are properties that are desirable for many functions, as they provide safety and, for example, maintain food quality and prevent food waste. Volume decreasing measures may not only increase life-cycle emissions; in some cases these measures may not be implementable at all because there are no adequate alternatives. Coming up with adequate alternatives for insultation material, adhesives, films, sheets and pharmaceuticals is challenging.

In the past few years, the number of initiatives to lower chemical and polymer consumption has grown, a development that is important but no enough to reach emissions reduction and non-fossil carbon targets.

CHANGE TYPES OF PRODUCED PRODUCTS

The bio-based drop-ins discussed earlier can replace fossil feedstocks to produce the same products. While there are benefits to producing the same product from different feedstock, it is not required. Novel types of chemicals and polymers may have properties that are superior to existing products; for example, they can be more easily recycled chemically or they can be 'safe and sustainable by design'. These novel product types can compete with their fossil-based counterparts.

In the organic chemical value chain, crude oil and natural gas are fed into refineries and gas separation plants that separate the hydrocarbon mixes that make up oil and gas into various fractions, including naphtha and natural gas liquids. In turn, these compounds are converted – or cracked – into smaller straight (olefins) and ring-shaped (aromatics) hydrocarbons that are then turned into various chemicals and polymers in chemical plants.

Polymers can be categorized into various categories base on their molecular structure. For decades, polyolefins (which are long, repeating strings of straight hydrocarbons) are the most used polymers. Polyolefins, such as polyethylene and polypropylene are resistant, abundant and cheap. For many applications, these properties are excellent. Yet these properties also make chemical recycling more difficult. As the carbon bonds don't easily break apart, chemical recycling of polyolefins is relatively energy intensive. In this regard, polyolefins are too stable. Chemical recycling of other categories of polymers, such as polyesters and polyamides, require less energy (see Box 3).

Box 3 – PEF as an alternative to PET

One of the most well-known examples of a novel product is PEF. PEF is a chemical analogue of PET, the fourth-most-produced polymer worldwide. It has a different molecular structure, and as such it has different properties. PEF can be produced from MEG and FDCA, two chemical intermediates that can be produced from biomass. PEF is marketed as a 100% plant-based, 100% recyclable and degradable plastic, with superior performance properties compared to today's widely used petroleum-based packaging materials. The ability to keep out oxygen, for example, results in longer-lasting carbonated drinks and an extended shelf life of packaged products. [50]

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[50] Avantium (2022). YXY® Technology.

Recently, changing the types of products that are produced seems to have caught momentum as a measure to reach emissions reduction and non-fossil carbon targets. Instead of assuming that relative product demand is fairly static, it would be wiser if industry road maps would explore how product palettes could change in the future, among others by studying a potential shift from polyolefins to polyester-based products. Yet it would be over-optimistic to see such a shift as a silver bullet to meeting all emissions reduction and non-fossil carbon targets. As is the case for the other measures, there are significant barriers that hinder the wider adoption of novel products.

Introducing novel chemicals and polymers can be a very time- and capital-consuming process (see Box 4). The time-to-market is long, as every segment in the value chain needs to be convinced of the superior properties of the new product. In contrast to drop-ins, novel products require new production lines that need to be dimensioned based on the evolving demand for the product, which is low at the beginning.

Box 4 – The long route to novel chemicals and polymers

Introducing novel chemicals and polymers can be a very time- and capital-consuming process, as is well illustrated by the introduction of PLA. PLA a biodegradable alternative to PS, one of the most widely used plastics. PLA was developed by DOW chemicals and Cargill in a programme co-financed by the US government.[51] According to the business developers, it took 20 to 30 years before production was profitable.[52] Scaling up production of the product takes time, a lot of testing, and especially patience and perseverance to overcome the inevitable setbacks along the way.

The significant barriers impeding the introduction of novel chemicals and polymers make the efforts of companies that pursue these routes only more impressive. At the same time, it shows that merely relying on this measure could be risky and counterproductive. This is not only because of the lengthy lead times but also because it would require the replacement of countless products and production facilities. It remains to be seen whether superior alternatives are available for all product groups and uses and if they can be scaled up in time.

[51] Block, F. And Keller, M.R. (2016). 'State of innovation'.

[52] Bio-basedpress.eu (2015). Ook groene kunststoffen hebben lange aanlooptijden.

3.3 CHANGE WHAT HAPPENS WITH WHAT COMES OUT

After leaving the chemical plant, chemical and polymers find their way to consumers in countless end products. For chemical and polymer producers this means that their products enter the post-production phase in which products are typically exported all over the world. This is especially true for products produced in the ARRRA cluster. This cluster plays a special role in Europe and the world, and its consumers are found in every corner of the globe.

Measures taken in the post-production phase of a product – such as switching from landfilling to incineration or recycling – influence the overall life-cycle emissions of a product. These emissions can be high if waste products are discarded in landfills or in the open air. They can be lower if the products are incinerated in installations equipped with CCS units or recycled, as discussed earlier. For some products, their use causes emissions of greenhouse gasses.

It is worth nothing that equipping all waste incinerators with CCS installations can be – in concept – an effective strategy for decreasing life-cycle emissions of chemicals and polymers. In fact, the crude-to-chemical plants that are currently being planned and built in the Middle East and China bank on this strategy for life-cycle emissions reduction. In these plants, oil is directly turned into chemicals and polymers. These chemicals and polymers can be incinerated with CSS to prevent GHG emissions.

While equipping incinerators with CCS installations can be an effective strategy to reduce emissions, it is not aligned with circularity concepts that aim to prevent waste and deem incineration a low value option. Moreover, a switch from storing CO_2 via CCS to using CO_2, for example using chemical recycling techniques, will eventually be required, as the availability of storage is large but not unlimited. This shows that this measure in itself is also not enough to meet both emissions reduction and non-fossil carbon targets.

Additionally, also for this route there are number of barriers, the main one being the interconnectedness and opacity of the international trade system. For companies producing commodities, it is very difficult to know which consumers will buy their products. For a company selling foam for mattresses to Ikea, it may be possible to trace in which countries their foam ends up. Yet for a company producing for the polyethylene market, this is already increasingly difficult. Understanding where and how their products are discarded *after use* is even more difficult. While in recent years policymakers have fought hard to limited the export of waste to countries where effective waste processing systems are absent, we are worlds away from effectively tracking product and waste streams.

A key complicating factor for implementing measures in the post-production phase of products is that they largely effect processes outside the direct control of producers. Effective cross-sector co-operation with the waste and recycling industry, not only in the country of production but also elsewhere, is a prerequisite for success. In addition, consumers need to be placed in a position in which they can make informed decisions on how they use and discard products. Facilitation of informed decision-making, in turn, needs co-ordinated government policy, education, and industry provision of accessible waste management services.

3.4 CHANGE HOW PRODUCTS ARE MADE

Processes in the organic chemical value chain produce greenhouse gasses. These can either be emissions resulting from the combustion of fuels or process emissions that stem from the chemical transformation of raw materials. There is plethora of options for decreasing these emissions, ranging from increasing energy and process efficiency to electrification of steam crackers, increasing renewable energy consumption and applying CCS. These measures differ from the six measures described earlier, as they focus on how products are made by increasing renewable energy consumption and limiting direct emissions. These measures do not focus on carbon embedded in products or related indirect emissions. Moreover, because increasing the share of renewable energy consumption and limiting direct emissions does not change the origin or destination of the carbon molecules, they do not bring non-fossil carbon targets any closer. As these measures are well described and discussion on the drivers and barriers to implementation of these measures are omnipresent, we do not discuss them in greater detail here.

3.5 THE EMERGENCE OF A HYBRID SYSTEM

This chapter provided a brief background on the key options for altering the organic chemical value chain. It took a zoomed-out perspective to draw the systemic picture of the value chain and the options, and discussed their most apparent barriers to implementation. The result is an overview of the solution space of the new system. This space can be seen as the perimeter in which the new system will develop. While this sketches the contours of the new system, this outcome is not as concrete as the results of a techno-economic assessment of the options.

Looking at how the value chain has developed in the past, one can argue that such pure techno-economic assessments give a false sense of certainty. The value chain was never planned but emerged based on a number of pattens, including local interactions and developments that took place outside the realm of the value chain. Also today, the factors that determine how the value chain develops are highly uncertain. This uncertainty is a result of the high number of stakeholders with different and changing interests, as well as the high number of available options that have many known, unknown, wanted and unwanted effects.

The analysis presented in this chapter shows that all available options face significant barriers to implementation. The notation that these barriers will be difficult to overcome, at least in the short- to medium term supports the argument that a hybrid system will emerge. In such a system, alternative sources of carbon would be fed in to the value chain at various places, complementing the use of oil and gas derivatives as feedstock. Based on these feedstocks, fewer and different types of products would be produced for European consumers. Both the processes to produce the products and the processes to manage waste in this system have a smaller greenhouse gas emissions footprint.

As was the case in the past, both corporate and governmental forces will try to influence the architecture of this hybrid system. Yet the exact layout will change over time and is impossible to forecast, as not all the considerations of the players nor all external factors that will influence the layout are clear. A starting point for better understanding what a future system might look like is, on the one hand, to examine the corporate and governmental vision, ambitions, targets and road maps, and on the other hand to explore how adjacent industries (e.g. those supplying and demanding carbon) expect to change. The previous chapters explained that the former is evolving rapidly.[53] Chapter 4 will focus on the latter by discussing how the value chain is affected by upstream developments in the transportation fuels sector.

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[53] See Appendix C for an indication of how key policy initiatives discussed in the previous chapter affect the organic chemical value chain as discussed in this chapter.

4 HOW THE ORGANIC CHEMICAL VALUE CHAIN IS AFFECTED BY TRANSPORTATION POLICY

The previous chapter included a discussion of the possibilities of reaching policy objectives by altering the organic chemical value chain. In earlier feedstock transitions, the chemical industry did not create new value chains itself. Instead, changes outside the chemical sector yielded feedstocks as cost-effective byproducts, and the chemical industry seized the opportunities presented by the residual streams.[54] Also in a new feedstock transition, changes outside the chemical sector can be a catalyst for change in the industry. The transportation fuels sector is one of the sectors in which developments can influence the options for players in organic chemicals production, in addition to amongst others the food & feed as well as the pulp & paper and waste management sectors. As mentioned in Chapter 2, consumption of renewable energy in the European transport sector is strongly regulated by policy, particularly the RED (see Appendix A, Development of the Renewable Energy Directive). This chapter examines how the organic chemical value chain is affected by upstream developments, largely steered by policy for transportation fuels. This is especially relevant as refineries, steam cracker operators and chemical plant owners share one value chain. The chapter sets the stage for Chapter 5, which reflects on how (sub)national governments and industry partners can respond to the non-fossil carbon ambition expressed by the European Commission.

4.1 COMPETITION FOR BIO-BASED RESOURCES

In the period between 2008 and 2020 the share of energy from renewable sources in transport rose from 4.1% to 10.2% (see Figure 9). The various provisions in the RED incentivize an uptake of biofuels consumption. In RED2, advanced biofuels are incentivized through a multiplier system. Annex IX of the directive specifies the fuel feedstocks for which the energy content counts twice towards achieving the target of a 14% share of renewable energy in the final consumption of energy in transport for 2030. In the proposed revised RED2, the multiplier system is replaced by a new incentives mechanism.

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[54] See CIEP (2021). The Dynamic Development of Organic Chemistry in North-West Europe.

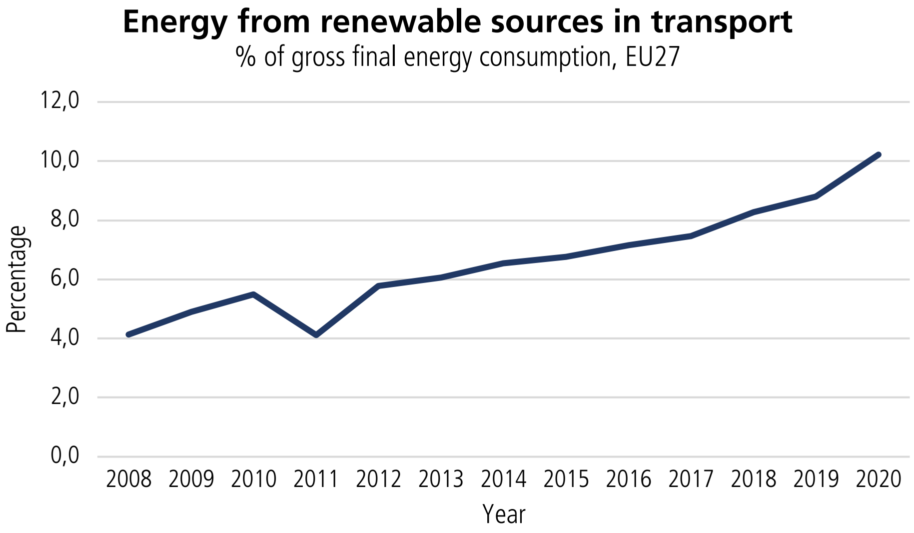

FIGURE 9. Energy from renewable sources in transport

In the period between 2008 and 2020 the share of renewable energy in transport in the EU27 rose from 4.1% to 10.2%. (Data: Eurostat)

The incentives for renewable energy consumption in transportation increase demand for resources that are used for the production of transportation fuels. In addition to feedstock for fuel production, these resources can also be used as chemical feedstocks. Examples include specific fractions of mixed municipal waste, wastes and residues from forestry and forest-based industries, used cooking oil and animal fats. Market interventions introduced in the RED to incentivize renewable transportation fuels can negatively affect the business case for chemicals and polymers production that uses non-fossil feedstocks. Where projects for low-emissions transportation fuels and low-emissions chemicals & polymers compete, RED provisions can be seen as artificial interventions in the market in favour of transportation fuels. There is, however, another side to the coin. Transportation fuels policy also pushes chemical feedstocks into the market, albeit indirectly. Describing how this happens requires some more words.

4.2 CHEMICAL FEEDSTOCKS PRODUCED AS BYPRODUCTS ARE PUSHED INTO THE VALUE CHAIN

In the past years, production capacity of Fatty Acid Methyl Esters (FAME) diesel in Europe increased as a result of transportation fuel policy. FAME is produced by processing vegetable oils, animal fats and/or used cooking oil in a process that typically produces glycerol as a byproduct. Today, glycerol is a major feedstock for bio-based polymer production, specifically for epoxy resins. According to Nova

Institute, biogenic byproducts made op 47% of total bio-based polymer production in 2019.[55] Not chemical policy, nor changing consumers behavior were the key factors that enabled this uptake. Instead, indirect effects of transportation fuel policy led to the increase in bio-based polymer production.

It is likely that the trend initiated with FAME production continues, albeit with different chemical feedstocks. The construction of an increasing number of plants for the production of renewable fuels is announced in the ARRRA (see Table 2). Demand for many of these fuels is incentivized through the RED. The majority of announced biorefinery projects rely on hydroprocessing technology to convert oils and fats into renewable diesel and aviation fuels in Hydrotreated Vegetable Oil (HVO) or Hydroprocessed Esters and Fatty Acids (HEFA) plants. Also in these biorefineries, byproducts are generated that can be used as chemical feedstock, particularly renewable naphtha and renewable propane.[56] The volume of chemical feedstocks that is produced differs per process technology and feedstock, and thus per project. Yet they are significant. Industry sources speak of renewable naphtha production being around 5% of total output.[57] Industry reports suggest an renewable naphtha output between 1 and 7% (percentage by weight).[58]

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[55] Nova Institute (2020). Market development, tends and prospects.

[56] In some cases, these products are also referred to as bionaphtha or biopropane. Here we use the terminology renewable naphtha and renewable propane.

[57] See, among others, S&P Global (2022). Europe’s nascent bionaphtha market gearing up to serve demand for cleaner fuels and petchems.

[58] See Dwarsverband (2016). Haalbaarheid van deoxygenatie van oliën/vetten tot bionafta in stilstaande biodieselfabrieken.

TABLE 2. COMMERCIAL PRODUCERS OF RENEWABLE NAPHTHA IN THE ANTWERP ROTTERDAM RHINE RUHR AREA

Name	Location	Technology	Status	Start of production	Renewable fuel volumes (metric tons / year)	Input
Neste	Rotterdam, Netherlands	Hydroprocessing	Online	2014	1.400.000	Used cooking oil, Animal fat waste, Vegetable Oils, etc
Neste	Rotterdam, Netherlands	Hydroprocessing	Announced FID	H1 2026	1.300.000	To be announced
Shell	Rotterdam, Netherlands	Hydroprocessing	Announced FID	2024	820.000	Waste in the form of used cooking oil, waste animal fat and other industrial and agricultural residual products
Shell	Rheinland, Wesseling, Germany	Bio Power-to-Liquid (Gasification + FT)	Pre-FID	2025	100.000	Green hydrogen, Wood-based residue
UMP	Rotterdam, Netherlands	Hydroprocessing	Pre-FID	tbd	500.000	Vegetable & animal fats & oils and energy-rich waste streams

In addition to renewable transportation fuels produced from biomass in HVO or HEFA plants, also the use of synthetic fuels is stimulated through transportation fuels policy. Synthetic fuels can be derived from captured carbon and are produced in Fischer Tropsch plants (also referred to as ‘e-refineries’). Among others, provisions in the ReFuelEU policy for sustainable air transport, proposed as part of the Fit for 55 package, incentivize synthetic fuel use through blending mandates.[59],[60] As the production of Fischer Tropsch fuels is more energy- as well as capital-intensive, these mandates are not expected to lead to investments in commercial Fischer Tropsch plants before 2030. Yet synthetic fuel production is expected to go up in market outlooks for the post-2030 period (see Box 6) and is deemed relevant in all key

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[59] European Commission (2021). Proposal for a regulation ensuring a level playing field for sustainable air transport.

[60] Discussions about the proposal are currently ongoing, see e.g. Euractive (2022). Lawmaker proposes raising EU green jet fuel target to 100% by 2050.

energy scenarios published by the European Commission as well as International Energy Agency (see Appendix D, Low-carbon liquid fuels in energy scenarios).

Similar to biorefineries relying on hydroprocessing technology, Fischer Tropsch plants produce byproducts in the naphtha range. Today, Shell operates one of the few commercial-sized Fischer Tropsch plants in the world that converts natural gas into liquid products such as transportation fuels, motor oils and chemicals. According to a company report, over 20% of hydrocarbons produced in this process are in the naphtha/gasoline range.[61] Naphtha produced in Fischer Tropsch plants is highly suited for use as cracker feedstock.[62] Fischer Tropsch plants, incentivized by transportation fuel policy, might also push renewable naphtha into the organic chemical value chain, similar to FAME and HVO/HEFA plants.

The exact volumes of renewable naphtha and other byproducts that could be produced in these refineries depend on the process technologies that are deployed and feedstocks that are used. As illustrated in Box 5, renewable naphtha production, incentivized through SAF blending mandates, can be significant and can contribute to reaching non-fossil carbon targets.

Box 5: Proposed SAF blending mandate could stimulate renewable naphtha production

As part of the Fit for 55 package, the European Commission proposed blending mandates for sustainable aviation fuels (SAF) in its ReFuelEU Aviation proposal.[63, 64] Various market participants explored the potential effects of these mandates. One of these market participants is SkyNRG, a SAF producer.[65] According to the company's latest market report, EU and UK SAF mandates for the year 2050 stipulate a European SAF demand of approximately 40 Mt.[66] Among others, approximately 18.5Mt of synthetic kerosine (produced in combined gasification

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[61] Shell (2018a). 'The road to sustainable fuels for zero emissions mobility: status of, and perspectives for, power-to-liquids fuels.' Paper presented at the 39th International Vienna Motor Symposium as referenced by Concawe (2019). A look into the role of e-fuels in the transport system in Europe (2030–2050) (literature review).

[62] According to Sasol, another operator of a commercial-sized (fossil based) Fischer Tropsch plant, its gas-to-liquid naphtha is highly paraffinic, with virtually no aromatics or sulfur and negligible metallic contaminants. See Sasol (2022). Gas-to-liquids products: Naphtha.

[63] European Commision (2021). Proposal for a regulation ensuring a level playing field for sustainable air transport.

[64] Discussions about the proposal are currently ongoing see e.g. Euractiv (2022). Lawmaker proposes raising EU green jet fuel target to 100% by 2050.

[65] SkyNRG (2021). A market outlook on sustainbale aviation fuel (July 2021).

[66] SkyNRG (2022). A market outlook on sustainbale aviation fuel (May 2022).

and Fischer Tropsch plants as well as power-to-liquid facilities) is needed to meet this demand.[67]

If one assumes that future Fischer-Tropsch plants will produce between 10% and 25% of their hydrocarbons in the naphtha range, 18.5Mt of synthetic kerosine production would correspond to a production of between 1.85 and 4.63 Mt of synesthetic naphtha. Similarly, between 0.13 and 0.26 Mt of renewable naphtha would be generated in a scenario in which from 2030 onward 2.6 Mt of SAF is produced in HVO/HEFA processes that produce between 5% and 10% renewable naphtha.[68] Combined, this would result in a renewable naphtha production of between 1.98 and 4.89 in 2050 that is stimulated by SAF blending mandates.

Volumes in this range are modest compared to the present-day (2020) consumption of fossil naphtha of over 30 mt.[69] If we however compare them to current levels of renewable naphtha production these volumes are rather substantial. In 2019 Neste, UPM, and ENI produced a combined volume of renewable naphtha of between 0.1 – 0.15 Mt/year in Europe for use as a chemical feedstock, according to Nova institute.[70]

The exact volumes of renewable naphtha and other byproducts that could be produced as a result of blending mandates are uncertain. They are highly dependent on plant capacities, the process technologies deployed, and the share of renewable naphtha produced in these plants. A better understanding of the exact size of the renewable naphtha volumes that are induced by blending mandates requires a more extensive, quantitative research exercise. Yet even in the absence of such studies, it is clear that transportation fuels policy – including SAF blending mandates – is an influencing factor in the development of the organic chemical value chain and can contribute to meeting non-fossil carbon targets.

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[67] As derived from Figure 1 on page 16 of the backgound analysis of SkyNRG (2022). A market outlook on sustainbale aviation fuel (May 2022).

[68] The 2.6 Mt SAF produced in HVO/HEFA plants is relatively low, among others because it reflects the cap placed on waste fuels and an exclusion of vegetable oil production on degraded lands and oil from cover crops.

[69] Eurostat (2022). Supply, transformation and consumption of oil and petroleum products.

[70] Nova institute (2020). Market developments, trends and prospects.

4.3 MULTIFACED EFFECTS OF TRANSPORTATION FUELS POLICY

The effects of transportation fuels policy on the development of the organic chemical value chain are multifaceted. On the one hand, fuels policy increases competition for renewable feedstocks, making it more challenging for players in the chemical industry to compete. On the other hand, fuels policy enables investments in bio- and e-refineries that produce chemical feedstocks as byproducts. Transportation policy both obstructs and incentivizes non-fossil carbon use in the organic chemical value chain.

This dual relationship between transportation fuels policy and the development of the organic chemical value chain has three implications. First, in absence of specific mechanisms to increase non-fossil carbon use in chemicals and polymers, the uptake of renewable carbon in the organic chemical value chain is driven to a large extent by transportation fuels policy. Second, this relationship means that if policymakers aim to increase the uptake of non-fossil carbon above levels that are directed by transportation policy, additional chemicals & polymers policy will be required. Third, developing and implementing chemicals & polymers policy will not mean the organic chemical value chain will become independent of developments of the transportation sector. On the contrary, as an important supplier of carbon, the transportation sector will continue to influence the developments in the organic chemical value chain. Policy mechanisms developed to reach climate targets in the transportation sector will influence the workings of policy mechanisms to increase non-fossil carbon use in chemicals and polymers and vice-versa. The next chapter uses these observations to reflect on how (sub)national governments and industry partners can respond to the non-fossil carbon ambition expressed by the European Commission.

5 THE WAY FORWARD

At this moment, the ambition to ensure that at least 20% of carbon used in chemical and plastic products comes from sustainable non-fossil sources by 2030 should be seen as an aspirational objective expressed by the European Commission without any instruments to realize it. While technical options to reach these ambitions are available, they do not come without serious barriers, supporting the argument that in an evolving EU policy landscape, with mature transportation fuels policy mechanisms, the ARRRA is developing into a hybrid cluster for the production of chemicals and polymers.

Building on the conclusions from the previous chapters, this chapter considers how (sub)national governments and industry partners in the ARRRA may respond to new non-fossil carbon ambitions. Before highlighting two possible responses, it is important to emphasize that at the time of writing, the European Commission has not yet translated its ambition into a proposed piece of legislation. Also, the European Parliament and Council have not had the opportunity to respond to the ambition, let alone come up with potential strategies to reach it. Moreover, as there is currently a discussion ongoing about what sources of carbon qualify as renewable, the scale of the challenge is yet unclear.[71] For these reasons of uncertainty, the effort of considering how (sub)national governments and industry partners can respond should be seen as an analytical exercise that yields a number of considerations which could be taken into account, not as a forecast nor recommendation for future actions.

National governments and lower levels of governments (such as the Belgium state of Flanders and the German state of North Rhine-Westphalia)[72] in the ARRRA could, in several ways, respond to the non-fossil carbon ambition. In this chapter two possible options are discussed, namely attracting new refinery investments and introducing

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[71] What the 'at least 20% of carbon use' ambition exactly means in terms of additional non-fossil carbon sources that need to be developed is currently largely unclear. One of the reasons for this is that there is no shared understanding about the current level of 'sustainable, non-fossil carbon use in chemicals and plastics'. From the European Commission's communication, it is for example unclear whether recycled waste also qualifies as sustainable non-fossil carbon. If we nevertheless want to place the ambition in perspective, in 2020 Nova-Institute and COWI estimated that the current average renewable carbon share in the European chemicals and plastics industries lies between 20 and 25%, with 15% coming from biomass and 5-10% from recycling, suggesting that depending on how discussion progress, reaching the ambition does not have to be very challenging. See Nova Institute (2020). Market development, trends and prospects.

[72] Collectively referred to as (sub)national governments.

an additional, harmonized policy mechanism as a potential way forward. As the two options are not mutually exclusive, they could be implemented alongside each other. This chapter concludes with a discussion of how the development of integrated carbon plans for the regions could benefit the cluster. By crafting such plans along the lines of the various hydrogen strategies developed for the region, (sub)national governments together with industry representatives can align policy instruments and provide direction and certainty for producers, consumers and other value chain partners.

5.1 ATTRACTING NEW REFINERY INVESTMENTS

As discussed in the previous chapter, demand for renewable transportation fuels incentivized by transportation fuels policy enables bio- and e-refinery investments, which can lead to an increased uptake of renewable feedstocks for the chemical industry. As is typical for refineries, also bio- and e-refineries produce chemical feedstock as byproducts.

To reach a non-fossil carbon ambition for chemicals and plastics, it can be beneficial to increase efforts to attract new bio- and e-refinery investments to clusters with existing steam crackers and chemicals and polymers production. As the key centre of refining and chemicals production in Europe, this specifically applies to the ARRRA. Bio- and e-refinery investments can be made by both established and new entrants to the cluster. They can consist of investments in newly built assets – such as HVO/HEFA plants or Fischer Tropsch facilities – and investments to repurpose existing assets, for example building new pre-processing units to enable the co-processing of renewable feedstock in existing refinery assets. It is furthermore important to emphasize that these investments can be made in addition to investments in chemical recycling. As discussed in Chapter 3, investments in chemical recycling are important but should be seen as one of a number of complementary drop-in feedstock options that by themselves do not offer a replacement to conventional feedstock.

Having refineries, chemical plants and industrial gas producers in close proximity comes with several (cost) benefits. For example, locating bio- and e-refineries close to chemical plants decreases the transportation costs of byproducts that are produced in these refineries and used in chemical plants. In addition, synergies could be enjoyed in the form of exchange of heat and technical gasses, including hydrogen. Moreover, existing assets, including processing units and tank storages, could be repurposed. The benefit of establishing renewable naphtha production close to steam crackers and chemical production increases when changing price-cost and incentive structures alter the balance between blending and feedstock use of renewable naphtha (see Box 6). By establishing bio- and e-refineries close to chemical plants, renewable feedstocks can become available for chemical feedstock use in an earlier stage of development than would be possible if these refineries were built outside existing chemical clusters.

Box 6: Using renewable naphtha where it creates most value

By serving multiple markets, a typical refinery owner enjoys trading and arbitrage opportunities and increases the robustness of its investments. The volume of renewable naphtha that is produced and used as chemical feedstock depends on multiple factors that reflect where the naphtha creates most value. These factors are site- and portfolio-specific.

As is typical for oil-based refineries, output in bio- and e-refineries is optimized based on dynamic feedstock prices and the relative value of refinery products. As a result, the volume of renewable naphtha that is produced is flexible. Moreover, as (renewable) naphtha can either be used as a blending component or chemical feedstock, the share of (renewable) naphtha that is used as chemical feedstock also depends on the value created by using it as feedstock compared to that of blending it in transportation fuels.

Given the many factors that influence renewable naphtha production and use, assessing how much additional non-fossil carbon will be used as a result of attracting new bio- and e-refinery investments is difficult and requires a more extensive analysis that uses site-specific data. From refinery investments, as well as from announcements by steam cracker and chemical plant operators, it nevertheless becomes clear that renewable naphtha is (expected to be) used for both feedstock and blending purposes.

This is reflected by, on the one hand, large chemical players including LyondellBasell[73], Dow[74], Ineos[75], Sabic[76], BASF[77] and Borealis[78], which have

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[73] LyondellBasell (2019). LyondellBasell and Neste announce commercial-scale production of bio-based plastic from renewable materials.

[74] Dow (2019). Dow and UPM partner to produce plastics made with renewable feedstock.

[75] Ineos (2022). INEOS and UPM Biofuels announce supply agreement for renewable raw materials to make plastic.

[76] Sabic (2019). Sabic demonstrates leadership in sustainable packaging solutions at K 2019.

[77] BASF (2021). Plasticizers for the PVC industry are now also available based on renewable and chemically recycled feedstock.

[78] Borealis (2021). Renewably-sourced feedstock being tested at Borealis cracker in Stenungsund, Sweden.

announced that they are using or testing renewable naphtha as feedstock for their plants. Also, TotalEnergies shared that it will use the 50,000 metric tons of renewable naphtha that it will be producing, starting in 2024 at its converted Grandpuits site, to produce bioplastics.[79] On the other hand, Preem uses renewable naphtha to produce gasoline that is sold under its Evolution brand. This gasoline contains 10% renewable naphtha, 5% ethanol and 1% ETBE.[80] In addition, Shell announced that the renewable naphtha it will produce in its 820,000 metric ton/year biorefinery, which is currently under construction, will not immediately be used as feedstock. Instead, it will first be used in the Pernis refinery, while in the future it is expected to be used as feedstock for the chemical industry .[81] Over time, changing price-cost and incentive structures could change the balance between blending and feedstock uses of renewable naphtha.

Attracting bio- and e-refinery investments to clusters with chemical plants can lead to an accelerated uptake of renewable feedstocks in chemical plants. Conversely, having chemical plants in close proximity to bio- and e-refineries is also beneficial for these refineries. Chemical demand creates an easy to reach, additional outlet for refinery products, such as renewable naphtha, creating increased optionality and improved arbitrage opportunities. Locating bio- and e-refining capacity close to chemical demand centres contributes to making refinery investments robust, especially considering that these biorefineries produce hydrocarbons that are essential for the longer-term feedstock transition.

There are various ways to attract bio- and e-refinery investments to the ARRRA. Developing integrated carbon plans can be an approach to algin policy and create the conditions in which such investments can take place. Before we discuss the development of integrated carbon plans, the next section discusses how an additional policy instrument may be implemented to increase non-fossil carbon use in in chemical and plastic products.

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[79] TotalEnergies (2022). Grandpuits: a zero-crude platform by 2024.

[80] S&P Global (2022). Europe's nascent bionaphtha market gearing up to serve demand for cleaner fuels and petchems.

[81] Petrochemi.nl (2021). Shell bouwt fabriek voor biobrandstoffen in Pernis.

5.2 IMPLEMENTING AND ALIGNING AN ADDITIONAL POLICY MECHANISM

As discussed in the previous chapter, increasing the use of non-fossil carbon above levels established by transportation policy would require additional chemicals & polymers policy. There is a broad spectrum of policy mechanisms that could be implemented to increase non-fossil carbon use in chemicals and plastics. These include subsidies, tax incentives, standards, tradable permits and hybrid instruments.

For the design of a non-fossil carbon policy mechanism, policymakers may take inspiration from existing market creation and development instruments that are used to increase the uptake of renewable fuels. To increase the use of renewable fuels and meet both EU and national targets, Germany and the Netherlands use an obligations and tradable credit system.[82] The introduction of a similar system could be explored to increase the use of non-fossil carbon in chemicals and plastics (see Box 7).

Box 7: Using an obligations and tradable credit system to increase non-fossil carbon use

One of the market creation and development mechanisms that could be explored to increase the use of non-fossil carbon in chemicals and polymers is the development of an obligations and tradable credit system. Implementing such an instrument for non-fossil carbon use could contribute to creating more stable demand and, as such, increase certainty for potential producers, exporters and consumers of renewable chemical feedstocks.

Compared to a subsidy scheme, an obligations and a tradable credit system has the advantage that it is budget-neutral for public parties. Such a system may focus on suppliers that deliver chemical feedstocks to local markets. In this way, the number of participating companies could be limited and the administrative load for consumers of chemical feedstocks could, in potential, be reduced.

While implementing an obligations and tradable credit system has a number of clear benefits, it also comes with a number of questions that need to be answered. First, there needs to be agreement on which markets are included in the system and which are not. This applies to both the geography and the

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[82] In June 2022, the Dutch government announced that it is exploring the opportunity to use a obligations and credit system, similar to the existing one for renewable fuels, to ensure that the country meets the expected binding target for the use of low-carbon hydrogen in industry, see Rijksoverheid (2022). Ontwerp Beleidsprogramma Klimaat.

chemicals & polymers submarkets. The European Commission envisions that the 20% non-fossil carbon use ambition applies to chemicals and plastics production in all Member States. In contrast to the different policy instruments that were implemented in Belgium, Germany and the Netherlands to increase renewable fuel consumption and reach EU targets, these countries may consider implementing the non-fossil carbon use ambition for chemicals and plastics using a harmonized system. Aligning policy instruments in the ARRRA may be beneficial, given the integrated nature of the cluster.

Another area where clarity is required at the EU and/or (sub)national level is which chemicals & polymers submarkets should be included in an obligations and tradable credit system. This question is especially relevant given the diverse nature of the chemicals and polymers sector. Furthermore, the establishment of an effective and univocal certification system for non-fossil carbon (feedstocks and products) is a prerequisite that needs to be met before such a system could be implemented. Finally, implementing an obligations and credit system that focuses on suppliers that deliver chemical feedstocks to local markets has the benefit of not effecting prices of products that are exported. It would, nevertheless, be good to study potential (indirect) effects of any new policy instruments on the competitiveness of the cluster, especially in the current times of relatively high inflation and price volatility.

Independent from the decisions made to implement a non-fossil carbon ambition, it would be good to provide clarity and direction on how carbon is and will continue to be supplied and demanded in our society going forward. This can be done by establishing integrated carbon plans. Such integrated carbon plans, or any other formal communications that fulfil a similar purpose, could include provisions on attracting bio- and e-refining investments and the development and alignment of policy instruments in the ARRRA. The manner in which value chains are currently developed for hydrogen provides an example of how such plans could be established.

5.3 DEVELOPING INTEGRATED CARBON PLANS

As discussed in the previous chapters, energy & transportation policy and chemicals & polymers policy have long been developed relatively independently of each other. This can be seen, among others, in economy-wide emissions reduction strategies and circular economy policies that show limited interdependence. It is understandable that EU, national and subnational policy experts divide the problems and policy dossiers they encounter over different departments. Similarly, it can at times be logical to develop policy on a sector level. Nonetheless, this approach conflicts with an emerging need to develop new value chains that transcend sector boundaries. The result of inconsiderate sector policy is a rather siloed approach in which interrelated parts of the same value chain are approached as unconnected entities and multiple departments chase the same molecule with different policy plans.[83]

That such a siloed approach is not a given can be observed from how the attitude towards hydrogen has changed in the past years. As CIEP and IEA reported, many countries in Northwest Europe published hydrogen strategies, while at the same time countries co-operated on a joint strategy for Northwest Europe.[84] Players working on hydrogen development increasingly realize the importance of making sure the whole value chain – from production to conversion, transportation, storage and consumption – is considered in public and private development plans.

An approach similar to the one used for the hydrogen value chain could be used for the development of carbon value chains. Independent from decisions made to implement a non-fossil carbon ambition, it would be good to provide clarity on how carbon is currently used in our society and give direction on how this might change in the future. By developing integrated carbon plans, (sub)national governments could provide insights on the future direction, align policy to reach agreed objectives and establish the conditions in which investments in new value chains can be made. Such a plan could include provisions on attracting bio- and e-refining investments, as well as the development of a harmonized policy instrument for non-fossil carbon use.

(Sub)national governments may find the building blocks for their integrated carbon plans in the various road maps developed for sectors that require and supply carbon in their operations.[85] Yet the key to the success of these integrated carbon plans is found in the integration of these road maps. In addition to the transportation fuels sector and the chemicals & polymers sector, it would be good to consult public and private parties in the food & feed as well as the pulp & paper and waste management sectors, as these sectors are also main suppliers and offtakers of carbon. In

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[83] To bridge this gap the Dutch government published a number of 'horizontal policy agendas' in June 2022, through which it aims to address challenges that transcend sector boundaries. The circular economy is one of the themes for which a horizontal policy agenda was announced. See Rijksoverheid (2022). Ontwerp Beleidsprogramma Klimaat.

[84] IEA and CIEP (2021). Hydrogen in Northwest Europe.

[85] For the chemical industry these include: CEFIC (2019). Molecule Managers A journey into the Future of Europe with the European Chemical Industry; SUSCHEM (2020). Sustainable Plastics Strategy; Plastics Europe (2022). ReShaping Plastics; VCI (2019). Roadmap Chemie 2050; Essenscia (2019). Chemie & life sciences: dé formule voor meer welvaart en meer welzijn; VNCI (2018). Chemistry for climate; VNCI (2021). Van Routekaart naar Realiteit.

developing their plans, (sub)national governments would be wise to look for public-private co-operation, as accounting for the multitude of challenges observable in the various carbon supplying and demanding sectors is challenging.[86] Moreover, as Northwest Europe will not be able to supply sufficient carbon itself, developing integrated carbon plans should also focus on managing import streams of carbon, in various forms. Finally, as discussed in previous chapters, not all technologies available for altering the organic chemical value chain are market-ready. Especially many CCU techniques and specific bio-based routes require research and development to increase their technology readiness levels. Providing public co-financing for promising carbon projects that are close to being market-ready but which in practice turn out to be difficult to bring to a financial close should be considered. This action could contribute to collectively realizing a diverse portfolio of carbon projects in various stages of development and enable the value chain to continue to evolve.

Industry partners in the ARRRA can assist in the process of finding agreement on integrated carbon plans by effectively explaining how the transition pathways available for the chemical industry relate to various developments and challenges from outside the sector. These developments include the changing supply patterns of (renewable) chemical feedstocks from the sectors for transportation fuels, food & feed as well as the pulp & paper and waste management sectors. Hereby, it is important to refrain from applying a too-siloed perspective and instead consider changes in the value chain on a system level. Moreover, and as discussed in Chapter 3, industry partners should consider exploring transition pathways that are based on changing product ranges. Pathways that represent a shift from polyolefins to polyester-based products can be studied, in addition to pathways based on drop-in feedstocks.

By accounting for these considerations, (sub)national governments and industry partners may live up to the many challenges they are faced with, while maintaining and advancing the coherence of the ARRRA cluster. This is especially relevant now that an accelerating energy and feedstock transitions coincides with an energy crisis caused by the war in Ukraine. In this setting, preserving the vitality of the chemical industry, as key converter of carbon compounds, is nothing less than imperative.

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[86] For many of these sectors, ample public-private co-operation initiatives as well as policy programmes are already present or are currently being developed. How these initiatives and programmes can be translated into a coherent investment environment with aligned policy instruments that reflect the needs of all essential value chain partners is less clear. Here, lessons learned from the integrated value chain approach used for hydrogen can be applied to value chains relying on other molecules, such as carbon.

6 CONCLUSION

While the number of hydrogen policies and projects in Northwest Europe is rising quickly, surprisingly little attention is focused on the question of how carbon may be sourced in a net-zero world. Organic chemicals production is one of the sectors that uses carbon as a primary element and that relies on some source of carbon for its emissions reduction strategies. Belgium, the Netherlands and western Germany are home to the organic chemical cluster referred to as the Antwerp, Rotterdam, Rhine, Ruhr Area (ARRRA). This area represents Europe's largest cluster for the transformation of hydrocarbons into organic chemical products.

The development of this cluster is affected by many EU policy initiatives. The latest addition was announced as part of the Sustainable Carbon Cycles communication in late 2021. In this communication the European Commission announced that it aspires to having at least 20% of the carbon used in chemical and plastic products be from sustainable non-fossil sources by 2030.

This new ambition and related policies under development have the potential to bridge the long-standing gap between policy developed for energy & transportation fuels and that for chemicals & polymer production. Yet how this ambition will be met is currently unknown. Moreover, it is unclear how the organic chemical value chain in the ARRRA – and the players active in it – can advance in a continuously evolving EU policy landscape. This paper aims to contribute to filling these knowledge gaps by subsequently discussing how the new ambitions fit into the wider EU policy landscape, by considering the technical options that are available for reaching the new ambitions and by exploring how the value chain is currently affected by transportation fuels policy. This paper concludes by suggesting areas for further action for (sub)national governments and industry partners active in the ARRRA.[87]

When comparing the EU policy frameworks for chemicals & polymers with the policy framework for energy & transportation fuels, three points stand out. First, while both frameworks are rapidly evolving, the policy framework for chemicals & polymers is more diffuse compared to its energy & transportation fuels counterpart. In the

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[87] This paper uses '(sub)national governments in the ARRRA' to refer to the Dutch national government, the government of the Flemish Region of Belgium and the government of the German state of North Rhine-Westphalia. These (sub)national governments concern themselves with the ARRRA cluster, among others in the Trilateral Chemical Region initiative, also see Clingendael International Energy Programme (2021). The Dynamic Development of Organic Chemistry in North-West Europe.

chemicals & polymers framework, a high number of regulations, directives, actions plans and strategies are published on a continuous basis. This demonstrates an inherent difference in how the interrelated policy areas are approached. Considering that the policy areas are connected through shared value chains, this discrepancy necessarily has consequences.

Second, the policy framework for energy & transportation fuels has already focused on reducing value chain (scope 3) emissions since the early 2000s. At that time the primary focus of the policy framework for chemicals & polymers was on protecting human health and the environment. The introduction of the Single-Use Plastics (SUP) Directive and, now, the Sustainable Carbon Cycles initiative places greater emphasis on emissions that stem from the entire life cycle of the chemicals & polymers. While the stronger focus on these emissions is relevant, it will not lead to an overnight change in the prevailing dynamics within the cluster.

Third, market development instruments are more established in the policy framework for energy & transportation fuels, partly as a result of the aforementioned. Specifically, provisions in the various adaptions of the Renewable Energy Directive (RED) and Fuel Quality Directive (FQD) are translated into functioning national schemes that lower life-cycle emissions by increasing the uptake of renewable transportation fuels. Examples are the obligations and tradable credit systems implemented in Germany and the Netherlands. On the chemicals & polymers side, the SUP directive has been implemented into national law. Yet the share of chemicals and polymers covered is relatively limited.

Through the Sustainable Carbon Cycles initiative, the European Commission both widens its scope in terms of including more products – all chemical & plastic products instead of just packaging – and aims to increase the uptake of non-fossil carbon instead of just recycled feedstocks. Despite the larger scope, these ambitions for chemicals & polymers are still aspirational objectives without any instruments to realize them, while the transportation fuels sector is steered by mature instruments aimed to fulfil targets that are also rising. Depending on the way the new ambitions are translated into policy, they will have profound implications on how the organic chemical value chain in the ARRRA (and the rest of the EU) will evolve.

While the exact way of implementing the ambition has yet to be decided, the available options to alter the value chain can be clearly distinguished. In the organic chemical value chain, four different types of intervention measures can be identified (see Figure 10). EU policy makes use of all these levers. Recently, there has been increased interest in changing what feedstocks go into the value chain, as can be observed, among others, in the non-fossil carbon ambition.

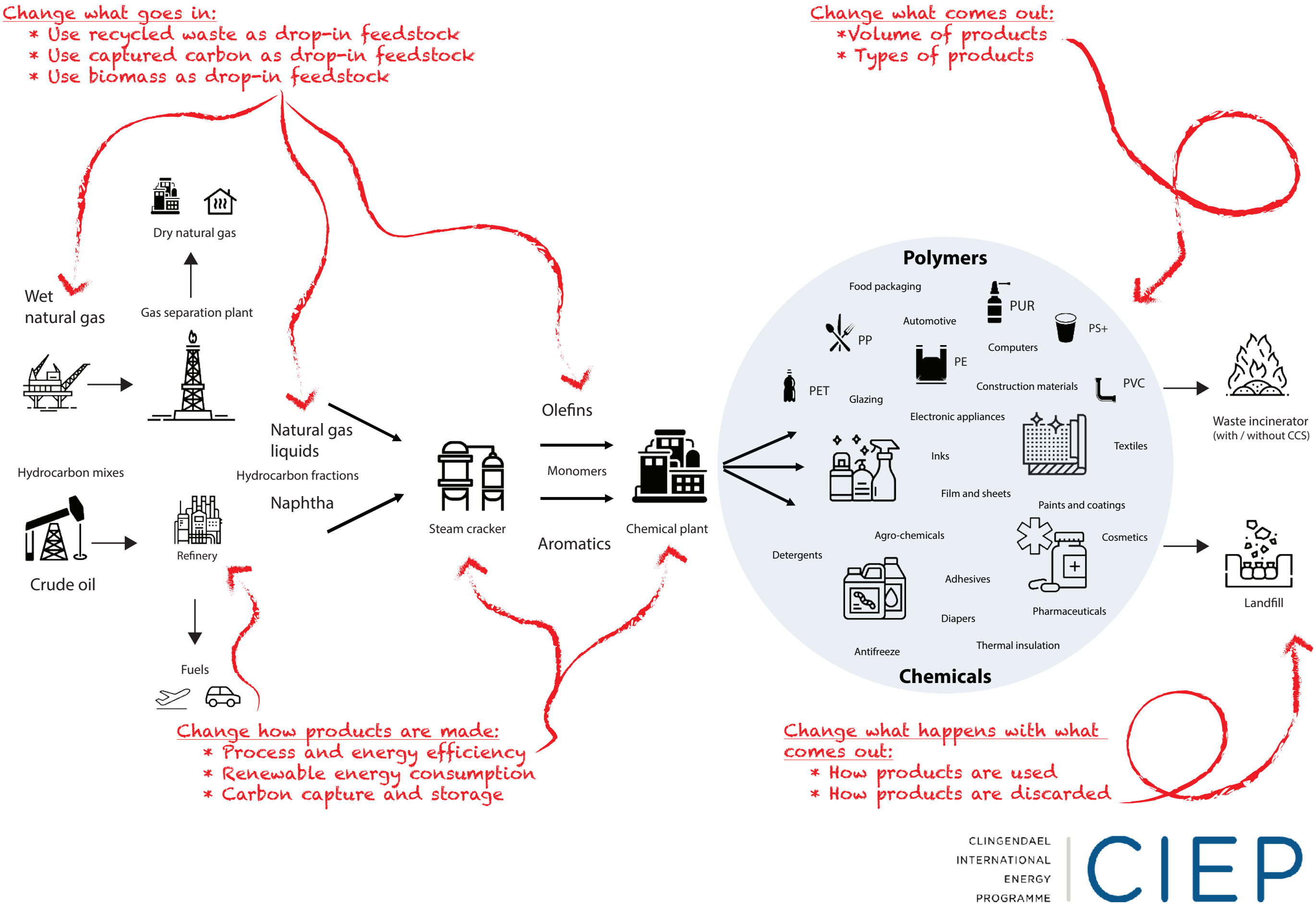

FIGURE 10. Four types of intervention measures can be deployed to alter the organic chemical value chain. Recycled content and non-fossil carbon targets and ambitions, included in new legislation, affect what feedstocks go in and products come out of the value chain. These policies reflect a shift from using policy instruments to steer how products are made and discarded to changing what goes into and what comes out of the value chain.

There are many process technologies available to change feedstocks from oil and gas derivatives to renewable feedstocks and, as such, to reach non-fossil carbon use ambitions. Carbon can be sourced from recycled waste, off-gases, the air and biomass and subsequently fed into the organic chemical value chain following the routes shown in Figure 11 (see page 73). Yet while the laws of chemistry and physics determine the technical limits of the available process technologies, technical specificities alone do not define how the ARRRA chemical cluster will change going forward. Therefore, a wider perspective is needed.

All available options for changing the organic chemical value chain face significant implementation barriers. As shown in this paper, these barriers are often of a non-technical nature and will, at least in the short- and medium term, be difficult to overcome. This supports the argument that over time, a hybrid system will emerge. In such a system, alternative sources of carbon will be fed in the value chain at various places, complementing the use of oil and gas derivatives as feedstock. Based on these alternative feedstocks, fewer and different types of products will be produced for European consumers. Both the processes to produce these products and the processes to manage waste in this system have a smaller greenhouse gas emissions footprint.

What the exact architecture of this hybrid system will look like over time is impossible to forecast, as not all the considerations of the players nor all external factors that will influence the layout are clear. What is clear, however, is that, as indicated, the described hybrid system is emerging in a policy landscape that has established policy mechanisms for the uptake of transportation fuels but no comparable mechanisms for increasing non-fossil carbon use in chemicals and polymers. This has important implication for the emergence of this hybrid system.

The current uptake of non-fossil carbon in the organic chemical value chain is not driven by chemicals & polymers policy. In contrast, it is driven to a large extent by transportation fuels policy. The effects of policy-induced developments in the transportation fuels sector on the organic chemical value chain are multifaceted. On the one hand, fuels policy increases competition for renewable feedstocks, making it more challenging for players in the chemical industry to compete. On the other hand, fuels policy enables investments in bio- and e-refineries that produce chemical feedstocks as byproducts. In this way, transportation policy both obstructs and incentivizes the use of non-fossil carbon in the production of chemicals and polymers.

There are several ways in which policymakers in the ARRRA could respond to a non-fossil carbon use ambition while at the same time accounting for these multifaceted effects of transportation fuels policy. First, (sub)national governments may consider to increase efforts to attract bio- and e-refinery investments. These investments could be made by both established and new entrants to the cluster. They could consist of investments in newly built assets, such as HVO/HEFA plants or Fischer Tropsch facilities, and investments to repurpose existing assets, for example building new pre-processing units to enable the co-processing of renewable feedstocks in existing refinery assets. These investments could furthermore complement investments in chemicals recycling.

Second, if policymakers aim to increase the uptake of non-fossil carbon above levels directed by transportation policy, additional chemicals & polymers policy will be required. For the design of a non-fossil carbon policy mechanism, policymakers may take inspiration from existing instruments used in the region to increase the uptake of renewable fuels. Development of a similar market creation and development mechanism could be explored to increase the use of non-fossil carbon in the production of chemicals and polymers. Implementing such an instrument could contribute to creating stable demand and, as such, increase certainty for potential producers, exporters and consumers of renewable chemical feedstocks.

Independent of the decisions regarding the implementation of a non-fossil carbon ambition, it would be good to provide clarity and direction on how carbon is and will continue to be used in our society. This can be done by establishing integrated carbon plans for the region. Such integrated carbon plans, or any other formal communications that fulfil a similar purpose, could include provisions on attracting bio- and e-refining investments and the development and alignment of policy instruments in the ARRRA. In crafting integrated carbon plans, (sub)national governments and industry partners can take inspiration for the value chain approach that has been used to develop hydrogen strategies over the past years.

Based on the presented analysis, this paper suggests the following areas for further action:

National and sub-national policymakers in the ARRRA may consider:
- Complementing existing hydrogen strategies with integrated carbon plans. Providing insight into how carbon is used in society today as well as direction on how this might change in the future can create certainty for producers, consumers and other value chain partners, especially if policy instruments are designed accordingly.
- Recognizing that chemical feedstocks produced in bio- and e-refineries can benefit the feedstock transition in the ARRRA and, as such, contribute to circular economy concepts. Attracting investments in bio and e-refineries, in addition to chemical recycling plants, can be a key step towards simultaneously meeting energy transition, feedstock transition and to some extent security of supply objectives.
- Promotion of an additional, harmonized policy mechanism, especially if an increased uptake of non-fossil carbon, above levels that are directed by transportation policy, is aspired to. Such an instrument could be similar to instruments used to increase the uptake of renewable transportation fuels in the region.

- Including promising non-fossil carbon projects in public funding schemes to help them come to a financial close. Collectively realizing a diverse project portfolio of carbon projects can contribute to a value chain that continues to evolve.

At the same time, industry partners in the ARRRA may consider:
- Explaining more effectively how the transition pathways available to the chemical sector relate to developments and challenges from outside the sector, thereby refraining from applying a too siloed perspective and instead considering the transitions at a systems level.
- Exploring transition pathways based on changing product ranges, including variants that represent a shift from polyolefins to polyester-based products. These pathways can be studied in addition to transition pathways that are based on drop-in feedstocks.
- Working together with policymakers on developing integrated carbon plans and making investment opportunities and their wider societal benefits explicit.

By accounting for these considerations, (sub)national governments and industry partners could contribute to maintaining and advancing the coherence of the ARRRA cluster. Closing the carbon loop presents a major challenge for the chemical sector. The success of this effort largely depends on the implementation choices that will be made in the period going forward. That these choices now have to be made in the context of a war in Europe and an increasingly heated debate about sanctions, and in the midst of an energy and feedstock crisis, makes them all the more relevant. In this context, it is crucial to acknowledge that preserving the vitality of the chemical industry, as key converter of carbon compounds, is nothing less than imperative.

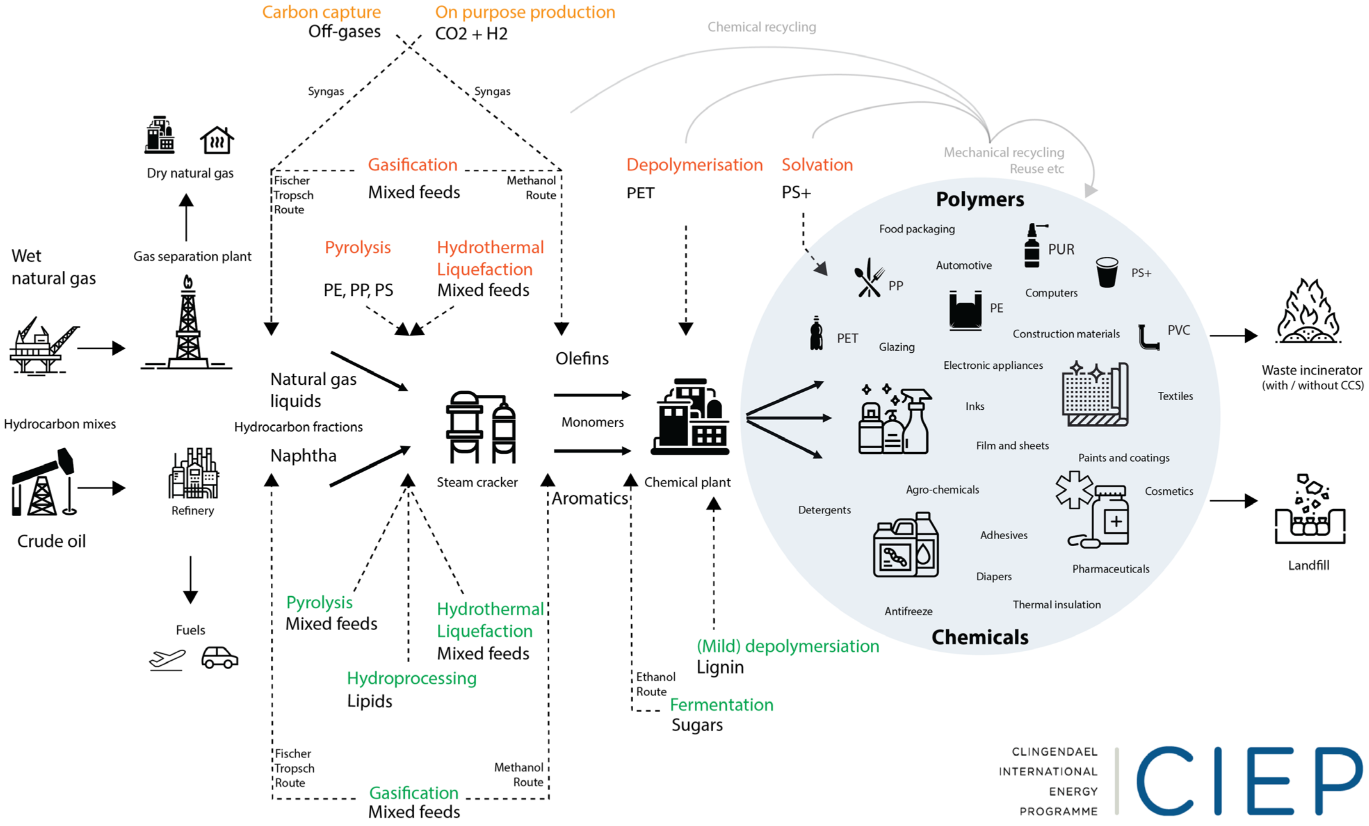

FIGURE 11. The organic chemical value chain, including key drop-in feedstock routes, arranged by carbon origin

In addition to carbon from oil and gas derivatives (in black), carbon sourced from recycled waste (red), biomass (green) or captured carbon (Yellow) can be fed into the organic chemical value chain. A wide palette of process technologies can be used to convert carbon from these sources into appropriate drop-in feedstocks. These include pyrolysis and hydrothermal liquefaction of mixed (biomass and/or plastic waste) feeds, as well as the hydroprocessing of lipids in an HVO or HEFA process. These three routes produce chemical feedstocks with properties similar to fossil-based naphtha. Gasification of mixed (biomass and/or plastic waste) feeds can be used to generate syn-gas that in turn can be converted into longer hydrocarbons - including naphtha - in a Fischer Tropsch process, or into methanol, which can be converted into olefins and/or aromatics. The Fischer-Tropsch and methanol routes can also be used based on carbon captured from off-gases or the air. An additional route that can be used is the fermentation of sugars, to produce ethanol that, among others, can be used to produce ethylene. Depolymerization can be used to break down polymers, including lignin and PET, into monomers or polymer intermediates, for example aromatics and TPA and MEG. Solvation processes can be allocated, for example to extract polymers from polystyrene waste streams. In addition to changing what goes in to the value chain by increasing the use of these drop-in feedstocks with the aforementioned processes, a number of other measures can be used to alter the value chain of organic chemicals. A discussion of all available measures, including their key drivers and barriers, can be found in Chapter 3.

7 APPENDICES

APPENDIX A – DEVELOPMENT OF THE RENEWABLE ENERGY DIRECTIVE

On 23 April 2009, the European Council and Parliament set out the goals that European Member States should achieve in terms of renewable energy consumption for the year 2020, in the first Renewable Energy Directive (RED)[88]. The general objective of the RED was that 20% of the EU's gross final energy consumption should come from renewable sources. The 2009 RED repealed Directive 2003/30/EC that officially started the harmonization of regulatory and fiscal promotion of biofuels at the European level.[89]

Arguing that the starting points – the renewable energy potential and the energy mix of each Member State – vary, the 20% target was translated into individual targets for each Member State (e.g. 13% renewable energy consumption in 2020 for Belgium, 18% for Germany and 14% for the Netherlands). The directive also set a 10% target for energy from renewable sources consumed in transport. In contrast to the overall target, this transport target was set at the same level for all Member States, reflecting that transport fuels are more easily traded. To assure that all goals were met, Member States were to adopt national renewable energy action plans. The RED was amended multiple times and, among others, the ILUC directive placed stricter targets to limit indirect land use change that could result from increased use of biofuels.[90]

Nine years later, on 11 December 2018, a new renewable energy directive was published: RED2[91]. It established a binding EU-level renewable energy target for 2030 of at least 32%. The targets were to be collectively delivered by Member States on the basis of voluntary national contributions, instead of mandatory targets as had been the case for the first RED.

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[88] The European Parliament and the Council of the European Union (2009). Directive 2009/28/EC on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC.

[89] The European Parliament and the Council of the European Union (2003). Directive 2003/30/EC on the promotion of the use of biofuels or other renewable fuels for transport.

[90] The European Parliament and the Council of the European Union (2015). Directive 2015/1513 amending Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources.

[91] The European Parliament and the Council of the European Union (2018). Directive 2018/2001 on the promotion of the use of energy from renewable sources (recast).

RED2 specifies a binding sectorial target of a 14% share of renewable energy in final energy consumption in transport by 2030. The use of specific fuels in transport sectors is incentivized through a multiplier system. Annex IX part A specifies the feedstocks for the production of advanced biofuels and biogasses for which the energy content counts twice towards achieving the targets. These fuels are set to increase to at least 3.5% of final consumption of energy in the transport sector by 2030. The list in this annex includes, among others, algae, straw and various biomass waste streams such as animal manure and palm oil mill effluent. Biofuels produced from feedstocks that are specified in Annex IX part B also count double toward the 14% target, though their potential contribution is capped at 1.7%. This list contains used cooking oil and various animal fats. Furthermore, the maximum contribution of food-based biofuels (sometimes referred to as first-generation biofuels) is capped at maximum 7%, and fuels produced from feedstocks with high indirect land-use change risks are to be phased out by 2030. Criteria for the certification of biofuels with a low indirect land-use change risk are laid out in a separate delegated act.[92]

The announcement of a new 55% GHG reduction goal for 2030, and the following inclusion of the goal as a legally binding target in the EU climate law, spurred an update of all EU climate and energy legislation.[93] This culminated in the Fit for 55 package, which was published on 14 July 2021 and also included a proposal for a revision of RED2.[94] Not only is the higher level of ambition reflected in an updated 2030 EU target of at least a 40% share of energy from renewable sources, the targets' metrics and the methods by which they can be achieved are also changed. In the revision the binding sectoral target of 14% renewable energy to be consumed in the transport sector by 2030 and the multiplier system are replaced (although a 1.2 times multiplier remains intact for aviation). Instead, Member States should ensure that the amount of renewable fuels supplied to the transport sector lead to a greenhouse gas intensity reduction of at least 13% by 2030 compared to a baseline. Calculating the greenhouse gas intensity reduction takes place using predefined emissions savings per fuel type and without the multipliers introduced in RED2. The high ambitions could give room for more biofuels consumption. At the same time, the sub-target for advanced biofuels in 2030 was lowered from 3.5% to 2.2%. The revision does add a new sub-target that for fuels of non- biological origin of at least

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[92] European Commission (2019). Commission Delegated regulation supplementing Directive (EU) 2018/2001.

[93] The European Parliament and the Council of the European Union (2021). Regulation 2021/1119 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law').

[94] European Commission (2021). Proposal for a directive amending Directive (EU) 2018/2001 of the European Parliament and of the Council, Regulation (EU) 2018/1999 of the European Parliament and of the Council and Directive 98/70/EC of the European Parliament and of the Council as regards the promotion of energy from renewable sources.

2.6% of energy supplied to the transport sector by 2030. Fuels of non-biological origin include, for instance, renewable hydrogen and synthetic fuels.

In response to the war in Ukraine, the European Commission proposed another amendment to the RED2. As part of the RED2 revision that was proposed under the Fit for 55 package, the Union's renewable energy target was already raised from 32% to 40%. In the amendment published on 18 May 2022, the Commission argued that '*given a radical change in the market conditions for fossil fuels used in power, heating and transport, including as concerns increased prices and the need for the EU to phase out its dependence on energy imports from Russia, it is necessary to raise the 2030 target for renewables to 45% so that they better contribute to this objective as well as to having competitive energy prices.*' [95]

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[95] European Commission (2022). Proposal for a directive amending Directive (EU) amending Directive (EU) 2018/2001 on the promotion of the use of energy from renewable sources, Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency.

APPENDIX B – THE EU POLICY FRAMEWORK ON ENERGY & TRANSPORTATION FUELS AND THE FIT FOR 55 PACKAGE

In 2019 the European Green Deal was announced as one of the 'headline ambitions' for the newly formed European Commission. It encompassing an ensemble of cross-sector and interrelated policy interventions.

To transform the announced high-level ambition into a set of concrete policy measures, the European Commission first assessed the impacts of raising its climate ambitions, by means of the Climate Target Plan (CTP). The new ambitions were subsequently translated into a legally binding target of net-zero greenhouse gas emissions by 2050 and an intermediate, EU-wide 2030 target of 55% reduction compared to 1990 levels.

With the publication of the Fit for 55 package on 14 July 2021, the European Commission made a next step to concretize these ambitions. The package includes proposals for 13 new, revised or updated pieces of legislation. It adds and alters several policy instruments in the energy & transportation fuels policy framework, as discussed in this chapter. Among others, the package includes rules for a new emissions trading system for the building and transportation sectors, a proposal for a Carbon Border Adjustment Mechanism, a revision of the existing EU emissions trading system, as well as updated energy taxation rules. It furthermore proposes new targets in an updated Effort Sharing Regulation; an updated Land Use, Land Use Change and Forestry regulation; revised Renewable Energy and Energy Efficiency directives; as well as through the FuelEU and RefuelEU legislation on clean maritime and aviation fuels. Moreover, it proposes new guidelines for new passenger cars and new light commercial vehicles, as well as for infrastructure for alternative fuels. Lastly, it uses revenues and regulation to promote innovation, build solidarity and mitigate impacts for the vulnerable in society, notably through the new Social Climate Fund and enhanced Modernization and Innovation Funds.

APPENDIX C – HOW KEY POLICIES AFFECT THE VALUE CHAIN

In the Sustainable Carbon Cycles initiative, the European Commission expressed its ambition to ensure that at least 20% of carbon use in chemical and plastic products will come from sustainable non-fossil sources by 2030. This announcement can be seen as part of a larger shift from using policy to steer how products are made and discarded to changing what goes into and what comes out of the organic chemical value chain. From the perspective of producers of chemicals & polymers, the EED, RED and EU-ETS are examples of directives that stipulate the conditions under which chemical & polymer products can be produced, while the WFD and various EPR schemes govern how products are discarded. SUP and REACH contain provisions that affect what comes out of the organic chemical value chain.

Figure 12 shows how key policy initiatives in the policy framework for chemicals & polymers – as discussed in chapter 2 – intervene in the organic chemical value, as discussed in chapter 3.

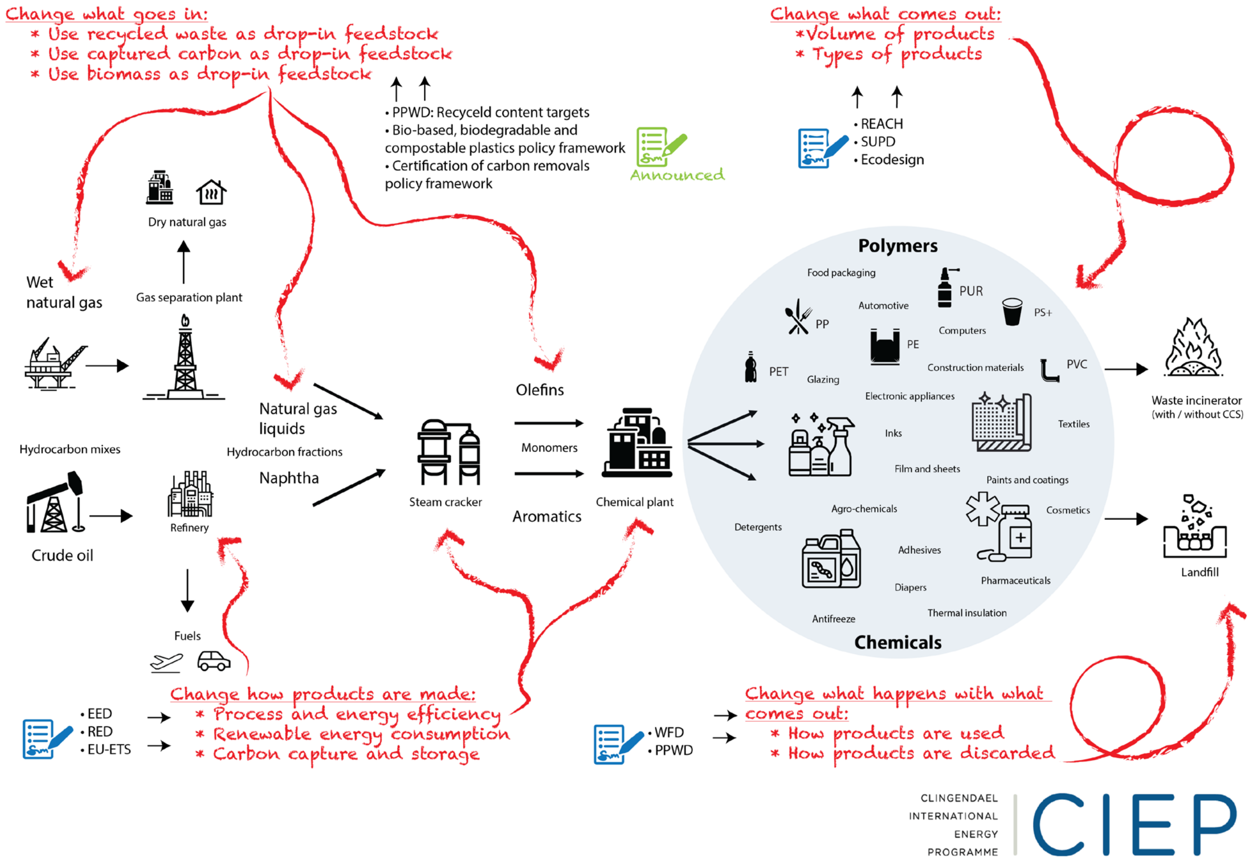

FIGURE 12. Key EU policies and their primary type of intervention in the organic chemical value chain.

APPENDIX D – LOW-CARBON LIQUID FUELS IN ENERGY SCENARIOS

Energy scenario studies published by the International Energy Agency and the European Commission show a clear role for biofuels and e-fuels. The IEA's net-zero emissions (NZE) scenario, arguably the most ambitious global net-zero emissions scenario to date, illustrates that reaching net-zero emissions requires low-emission fuels where energy needs cannot easily or economically be met by electricity.

Liquid biofuels meet 14% of global transport energy demand in 2050 in this scenario, up from 4% in 2020. Hydrogen, ammonia and synthetic hydrocarbon collectively meet a further 28% of transport energy needs by 2050. Synthetic oil demand grows from virtually zero to 2 EJ in 2040 and 5 EJ in 2050. The latter is equivalent to over a third of all energy demand for aviation in 2050, or the total hydrogen demand in industry in that year.[96]

Also, scenario studies published for policy making by the European Commission, including those published for the Fit for 55 package, reflect a prominent role for various forms of liquid fuels, especially post-2030.[97] The share of e-liquids and biofuels ranges between approximately 69 Mtoe in the 1.5 LIFE scenario and 87 Mtoe for the P2X scenario (see Figure 13). In all 2050 scenarios, biofuels and e-fuels collectively represent between 34% and 43% of total transport sector fuel demand.

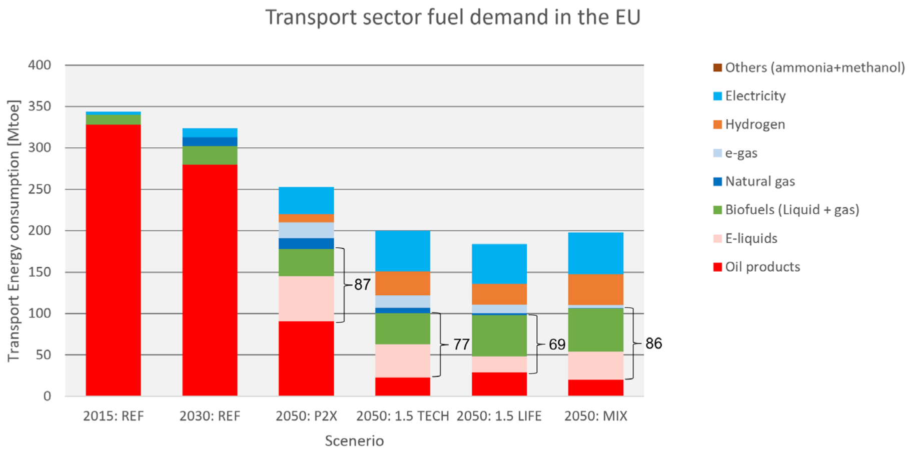

FIGURE 13. European Commission scenarios for energy consumption in transport (incl. international aviation and maritime) based on PRIMES[98]

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[96] See IEA (2021). Net Zero by 2050 A Roadmap for the Global Energy Sector.

[97] See European Commission (2021). Impact Assessment Report p. 77 – 469.

[98] Selected scenario for energy consumption in transport: 2015: REF; 2030: REF and 2050: MIX scenarios derived from European Commission (2021). Impact assessment report revised RED.

2050: P2X, 2050: 1.5 TECH and 2050: 1.5 LIFE scenarios derived from European Commission (2018). A Clean Planet for All.

Meeting this demand requires huge investments in e-refineries and biorefineries, including potential investments in the co-processing of renewable fuel feedstocks in conventional refineries. The Dutch industry association for liquid fuels, VNPI, estimates investment costs for process installations at European refinery sites to be between 76 and 92 billion euros. With these investments the total CO_2 reduction potential would be met through the use and local production of low-carbon liquid fuels in a 1.5 scenario. Additional investments between 36 and 556 billion euros are required outside refinery gates. In particular, increasing the capacity of renewable electricity requires high investments.[99]

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[99] VNPI (2022). Zijn Low Carbon Liquid Fuels nodig voor de decarbonisatie van het transportsysteem in 2050?

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