POLICY OPTIONS TO CREATE LEAD MARKETS FOR CLEAN, SUSTAINABLE AND CIRCULAR FEEDSTOCKS IN THE CHEMICAL INDUSTRY

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SUMMARY

Reaching the EU's climate targets requires cutting emissions across its entire economy. While low-carbon energy and notably electrification can significantly reduce emissions in many sectors, the chemical industry faces a specific challenge: Around half of its emissions arise from industrial processes linked to chemical reactions and feedstock use. For chemical products, carbon is, and will remain, an essential building block – yet more than 90 % of it is currently fossil-based. Defossilising feedstock requires a fundamental transformation of the industry's value chains, i.e. a (gradual) shift towards alternative carbon sources such as sustainable biomass, recycling and captured CO_2.

This CEPS report examines alternative carbon pathways from both a technological and a market perspective, with a particular focus on both methodological and policy frameworks required to make this transformation happen. To contribute to this debate, the report reviews a range of policy options to generate demand for alternative carbon sources currently under discussion for the chemical industry, including voluntary labelling, public procurement and mandatory targets as well as certification or credit-based mechanisms.

The analysis suggests that no single policy instrument is likely to be sufficient on its own to drive the transition. Instead, a mix of measures will be needed to incentivise investment in alternative carbon pathways at scale, with scope to become more stringent or be complemented by additional tools over time. Without robust market signals, for example in the form of a lead market framework, the transformation towards defossilised feedstock will not happen – putting the translation of European technological leadership into investment and scale up at risk.

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EXECUTIVE SUMMARY

The EU chemical industry accounts for around 3-4 % of EU net greenhouse gas emissions. Around half of these emissions stem from industrial processes linked to chemical reactions and feedstocks. Carbon is used as an essential building block, most of which is currently derived from fossil sources (over 90 %). Reducing the industry's climate impact requires a gradual shift towards alternative feedstocks. These include carbon sourced from sustainable biomass, recycling and captured CO_2 from industrial processes or the atmosphere.

The report, which takes stock of the technological and market conditions for alternative carbon pathways, identifies deployment challenges, and reviews the methodological foundations and policy options to create demand identifies the following findings:

Technologies and markets

Technologies are increasingly available – market-driven demand is not. Across the pathways analysed in this report, the technologies to substitute the use of virgin fossil carbon with recycled, bio-based or CO_2-derived feedstock are available in principle. The central constraint lies in the cost competitiveness of these alternatives, driven particularly by insufficient economies of scale. Creating credible demand signals is therefore central to enabling investment in alternative carbon feedstocks and associated infrastructure.

State of policy

Clarity on the problem to be solved is critical. Policies that aim to address material-related emissions need to focus on the core challenge – namely the transition away from fossil carbon towards alternative carbon sources. While these efforts are closely interlinked with the ambition to reduce industrial emissions, they are not identical. Clearly and consistently differentiating carbon origin, i.e. (virgin) fossil vs. non-fossil based, in relevant policies will become increasingly important to enable and guide the feedstock transition.

The EU policy framework for alternative carbon is evolving but requires continuous harmonisation efforts – instruments to create demand can support this. At the policy level, the EU has articulated its vision for the chemical industry, notably through its emphasis on establishing sustainable carbon cycles and feedstock diversification. However, the regulatory framework underpinning this transition is developing across multiple policies, including circular economy, bioeconomy and industrial carbon management. While efforts exist to link these domains, most visibly between circular and bioeconomy policies, regulatory coherence remains a challenge across alternative carbon pathways. Demand-creation instruments can play a role in connecting policy areas by promoting a mix of alternative carbon sources. Targeted measures for specific pathways can be justified in the early stages of the transition. Over time a technology-neutral approach could improve coherence and cost efficiency.

Tools to support demand creation instruments

An evolving accounting framework is required that combines early-stage pragmatism with a roadmap towards greater robustness. The effectiveness of any instrument to create demand depends on clear definitions and robust methodologies. At present, no official EU-level framework exists that comprehensively covers alternative carbon pathways. Instead, policies build on different methodologies and standards developed for different purposes, such as quantifying embedded carbon, tracking carbon flows, or certifying sustainability characteristics. While these provide an important starting point, the wide range of methodologies creates uncertainty. Therefore, an evolving accounting framework will be necessary. In the early stages of the transition, a pragmatic approach to differentiating carbon by origin through chain-of-custody models, such as mass balance, will be necessary to enable scaling up where physical segregation is not economically or technologically feasible. While stakeholder views differ on which approach best balances robustness with administrative feasibility at scale, any solution should be implemented with a clear pathway towards greater robustness over time, without delaying the deployment of demand-creation instruments As alternative carbon pathways scale up, physical segregation should become increasingly viable and could ultimately enable the phase-out of some interim accounting approaches to reduce administrative burden without compromising robustness.

Policy options to build lead markets

Credible and mandatory market signals are the starting point for instruments to create demand – speed and scale will determine success. Demand-creation measures must both reach sufficient scale and provide credible long-term signals to influence investment decisions in alternative feedstocks, new production routes, and infrastructure within this decade. A range of demand-creating policy options have been brought forward, including by the European Commission and industry. Stakeholder views on these options diverge on some design elements. Nonetheless, there is broad agreement on two points: maintaining the status quo is unlikely to trigger the transition at the required pace, and near-term pragmatic instruments are needed to kick-start it. Current initiatives by the European Commission on mandatory targets and voluntary labelling combined with public procurement, were widely seen as a pragmatic starting point, but will unlikely be enough to reach sufficient scale. Whatever instruments are ultimately used, they must be complemented by an enabling framework, that encompasses the entire EU climate, environment and energy policy framework.

The policy window to scale existing instruments and develop further approaches is now. The proposed Industrial Accelerator Act introduces a provision enabling the European Commission to adopt Union-level demand-side measures for products derived from sustainable carbon sources. Since the specific instruments have yet to be defined, this creates an opportunity to explore how existing approaches could be strengthened and scaled up across product groups and value chains, as well as whether additional mechanisms could complement the emerging policy framework. A phased approach could be the best way to balance requirements for speed, scale and robustness in demand creation instruments. Such an approach could include extending existing measures such as mandatory targets in the short to medium term and further exploring the integration of proposed certification or credit-based mechanisms, provided they can be made workable across the value chain, address stakeholder concerns and align with the existing EU regulatory framework. The final section of this report presents recommendations for the way forward.

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1. INTRODUCTION

By setting the goal to reach climate neutrality by 2050, alongside intermediate targets for 2030 and 2040, the EU has established a clear direction for the clean transition of its economy. These targets aim to cut greenhouse gas emissions by 55 % by 2030 and 90 % by 2040, compared to 1990 levels.

Meeting these milestones requires deep emissions cuts across all sectors. Energy-intensive industries play a central role in this effort and are at the core of the Clean Industrial Deal, which sets out the EU's approach to reducing industrial emissions. While electrification and a growing share of low-carbon electricity will be essential, some sectors will also require complementary solutions to meet EU climate targets.

The chemical industry – a cornerstone of the European economy and the world's second largest chemical producer by revenue – is a case in point[1,2]: It accounts for around 3-4 % of the EU's total net greenhouse gas (GHG) emissions[i][3]. Around half of these emissions are linked to fuel combustion, where emissions reductions will mainly depend on decarbonising the energy mix[4]. The other half comes from industrial processes, specifically emissions from chemical reactions and the transformation of feedstocks during production and product use[5]. Additional material-related emissions occur at the end of life of chemical products, for example through incineration or degradation in the waste management sector. Addressing these non-energy emissions throughout the life cycle of chemicals and derived materials will require changes in production routes, and notably feedstocks, including the scaling up of new technologies and alternative materials.

Although technological progress has enabled substantial reductions in some material-related GHG emissions, such as in the case of nitrous oxide (N_2O)[6], the production of chemicals remains structurally dependent on carbon as a fundamental building block of many products – and will continue to do so in the future. Consequently, material-related carbon dioxide (CO_2) emissions cannot be fully eliminated across the life cycle, making full *decarbonisation* of the sector infeasible in practice. Given that the overwhelming share of carbon used in the EU chemical industry is fossil-based (over 90 %), these emissions continue to contribute to global warming by adding additional CO_2 to the atmosphere[7]. The transition of the chemical industry towards climate neutrality will therefore require reducing the use of fossil carbon as feedstock, complemented by the scaling up of low-carbon energy.

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[i] Author's calculation based on EU-27 greenhouse gas emissions 2020-2023 data from the European Environment Agency data viewer, using Common Reporting Framework categories 1.A.2.c (fuel combustion in chemicals) and 2.B (chemical industry – industrial processes and product use), expressed as a share of total EU net emissions.

Acknowledging this reliance on carbon, policy discussions increasingly frame the transition of the chemical industry in terms of *defossilisation* rather than *decarbonisation* alone. Defossilisation entails the gradual replacement of fossil carbon with carbon derived from alternative sources, including sustainable biomass, recycled carbon from waste streams, and captured carbon from industrial processes or atmospheric CO_2[8]. These pathways do not eliminate life-cycle emissions but they can reduce the industry's reliance on virgin fossil carbon in the near to medium term. Over time, they could also enable a shift away from both virgin *and* secondary fossil carbon, such as recycled fossil carbon or fossil-based captured CO_2 – moving the chemical industry closer to full defossilisation.

Alternatives to virgin fossil carbon exist in principle but they vary in terms of technological maturity and commercial viability. As of 2023, only an estimated 5.5 % of the carbon used in chemicals and derived materials in the EU came from biomass, 4 % from recycling, with no measurable contribution from captured CO_2[9] – highlighting the considerable gap that must be closed to reach the large-scale adoption of alternative carbon[ii] in the EU chemical industry.

Closing this gap will require substantial investment in new technologies, production capacity and infrastructure, including biorefineries, waste collection and recycling systems, and carbon capture, transport and utilisation clusters. Such investment decisions ultimately depend on the existence of a robust business case, including reliable future demand for alternative carbon products. This has been acknowledged by the European Commission in its 2025 Chemical Action Plan, noting that 'investments in non-fossil feedstocks and low-carbon technologies are often constrained by the lack of off-takers, making it difficult for frontrunner companies to reap the green premium[iii] and capitalise on investments'.

To address this, the European Commission intends to 'design incentives to build a viable business case for the clean transition of the EU chemical industry'[10]. A key instrument under consideration is the concept of so-called lead markets – which aim to stimulate demand for novel clean technologies and products through regulatory frameworks and

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[ii] In the absence of an official EU definition, this report uses the term *alternative carbon* to refer to carbon sourced from sustainable biomass, recycling, or captured CO_2 from industrial processes or the atmosphere. Notably, both recycled carbon and captured carbon may originate from either fossil or biogenic sources. The term *virgin fossil carbon* is used to distinguish newly extracted fossil carbon from recycled or captured fossil carbon or CO_2. Where the term *fossil carbon* is used without further specification, it refers to fossil carbon irrespective of whether it is used as virgin feedstock, recycled, or captured as CO_2. This definition broadly aligns with the concept of 'renewable carbon', originally developed by the nova-Institute and subsequently adopted and further developed by the Renewable Carbon Initiative, a coalition of companies and industry stakeholders.

[iii] The *green premium* refers to the additional cost associated with producing or using a more sustainable product or input compared to its conventional, fossil-based alternative, reflecting higher production costs, for example due to a lack of economies of scale or higher raw material and clean energy costs.

incentives in selected markets. As set out in the Clean Industrial Deal, the objective of these lead markets is to 'drive economies of scale, reduce costs, and make sustainable alternatives more accessible to consumers and businesses alike'.

Measures relevant for the EU chemical industry encompass a broad range of instruments to support lead market creation. As set out in the Chemical Action Plan or the 2025 EU Bioeconomy Strategy, these include tools such as revised public procurement criteria, voluntary labelling schemes, and buyer alliances, as well as product-specific measures for selected product groups, notably recycled or bio-based content requirements.

This report aims to provide an overview of the main concepts[iv] to highlight differences and similarities across scope, design and underlying mechanisms as well as stakeholder perspectives on central issues. Topics include administrative complexity, implementation timelines, the robustness of the resulting business case, regulatory alignment, and – as cross-cutting issue – potential cost implications of policies designed to create demand for alternative carbon in the EU chemical industry.

Overview of the report

With the aim of examining the role of carbon and transition pathways away from virgin fossil carbon, this reports starts off by analysing the current technological and market readiness of alternative carbon, maps the evolving EU policy context, and discusses policy options for demand creation to support the transition of the chemical industry.

Section 2 reviews the technological maturity, feedstock availability and market conditions of alternative carbon. Section 3 integrates these developments in the broader EU policy context, with particular attention paid to the emerging debate on instruments to create lead markets. Section 4 examines the methodological foundations for carbon accounting, tracking and sustainability assessments. Section 5 outlines principles and the enabling framework for effective demand creation instruments in the context of alternative carbon feedstocks. Building on this foundation, the section then discusses selected policy options, enriched by stakeholder perspectives. Cost implications along the value chain and for consumers are considered as a cross-cutting issue. The report concludes by synthesising the main findings and highlighting avenues for implementing and further developing instruments for demand creation to drive the transition in the chemical industry.

[iv] Relevant policy instruments being implemented or considered by the European Commission as well as selected proposals by industry stakeholders are described and analysed in Section 5.

Data basis of the report

This report draws on extensive desk research and insights from stakeholders gathered through a combination of expert interviews and a stakeholder workshop involving industry and business, civil society organisations, experts as well as the European Commission. Where differences between the different stakeholder groups occurred, they are highlighted.

Limitations of the report

This report takes a high-level policy perspective on how instruments to create demand in the context of the evolving debate on lead markets could support the scale-up of alternatives to virgin fossil carbon in the EU chemical industry. It does not provide detailed value-chain assessments or a review of the wider policy mix, but offers a structured overview of policy options to best scale up alternative carbon sources in the EU chemical industry.

2. TECHNOLOGICAL AND MARKET READINESS OF ALTERNATIVE CARBON PATHWAYS

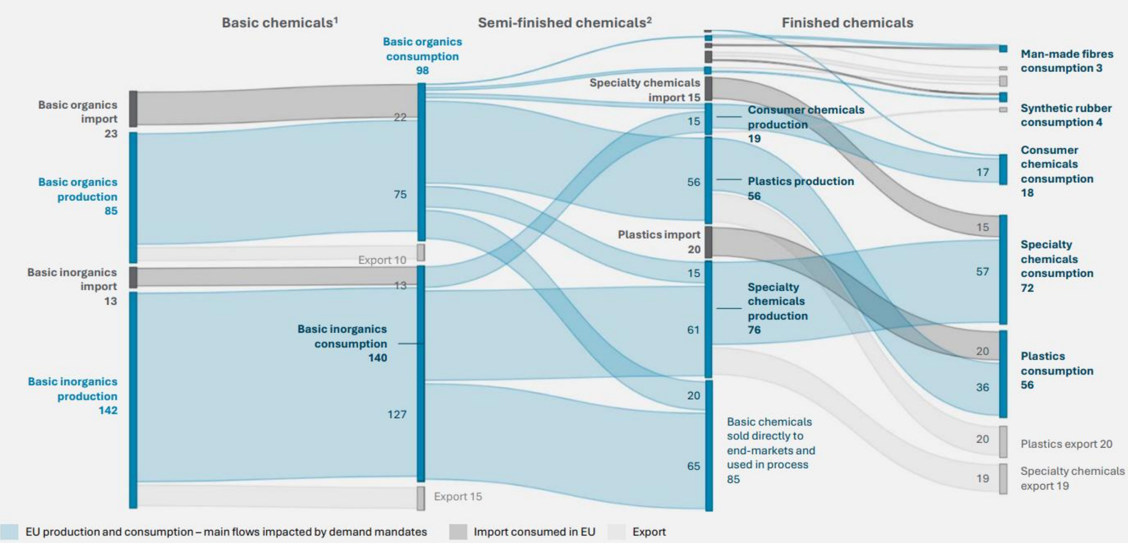
The transition of the EU chemical industry away from fossil carbon depends on the availability of new technologies and scalable markets for alternative feedstocks. The most relevant sources, including sustainable biomass, recycled carbon and captured CO_2, are at various stages of development and deployment. The following sections briefly explain the role of carbon in EU chemical value chains before reviewing the technological and market readiness of each alternative carbon pathway in the EU chemical industry.

2.1. CARBON IN CHEMICAL VALUE CHAINS

The chemical industry transforms raw materials into a wide range of products through complex value chains (Figure 1). Production starts with primary organic and inorganic feedstocks. Organic feedstocks account for approximately 41 % of material consumption and consist mainly of fossil-based hydrocarbons, notably crude oil (typically in the form of naphtha) and natural gas. These feedstocks are converted into 'basic' chemicals, such as ethylene and propylene. Basic chemicals then serve as essential 'high-volume, low-value' building blocks for downstream chemical production[11].

Just seven of these basic chemicals, supply over 90 % of all downstream organic chemical production globally[12]. In the EU, basic chemicals derived from both organic and inorganic feedstocks account for approximately 58 % of chemical output by value, illustrating their central role in the value chain[13].

Figure 1. Consumption and trade flows of chemical production, EU-27, 2023 (in million tonnes).



Source: Deloitte (2025)[14].

Note: '1) Organic chemicals are carbon-based chemicals, generally containing hydrocarbons; Inorganic chemicals are not carbon-based, e.g. salts, minerals, metals and alloys; 2) Assumed that consumption of (semi-)finished chemicals are first fulfilled with imports, and then by EU basic chemicals production. Remainder of basic chemicals classified as 'Chemicals used within the process, yield loss, other'[15]

These basic chemicals feed into often widely branched, multi-stage chemical production processes and ultimately consumer and industrial products. Many organic basic chemicals derived from hydrocarbons are transformed into plastics, synthetic fibres, rubbers, solvents, and other materials used across sectors, such as fertilisers[16]. Plastics and fertilisers together represent the two largest product segments within hydrocarbon-based chemical value chains[17].

The chemical value chain is highly integrated and by-products from one process often become feedstock for another, creating a vast network from raw feedstocks to finished goods. This entails that virtually every manufacturing sector – from textiles and electronics to cosmetics and pharmaceuticals – relies to some extent on upstream chemicals[18].

To reduce dependence on fossil-based chemicals, the industry can shift to alternative carbon feedstocks, including sustainable biomass, recycling, and captured CO_2, to reduce , or in the longer term even potentially fully substitute, the use of virgin fossil carbon[19].

These pathways differ in their underlying mechanisms and climate impact. Biomass takes up CO_2 from the atmosphere while it grows, and this carbon is typically released again when bio-based products are used or reach end-of-life. Recycling and captured CO_2 can rely on either fossil or biogenic carbon. When fossil-derived materials or emissions are recycled or captured, they reduce the need for virgin fossil carbon. By contrast, recycling biogenic carbon, capturing CO_2 from biogenic sources, or directly from the atmosphere can, in principle, allow for the full substitution of virgin fossil carbon.

2.2. EMERGING ALTERNATIVES TO VIRGIN FOSSIL CARBON

2.2.1. Sustainable biomass

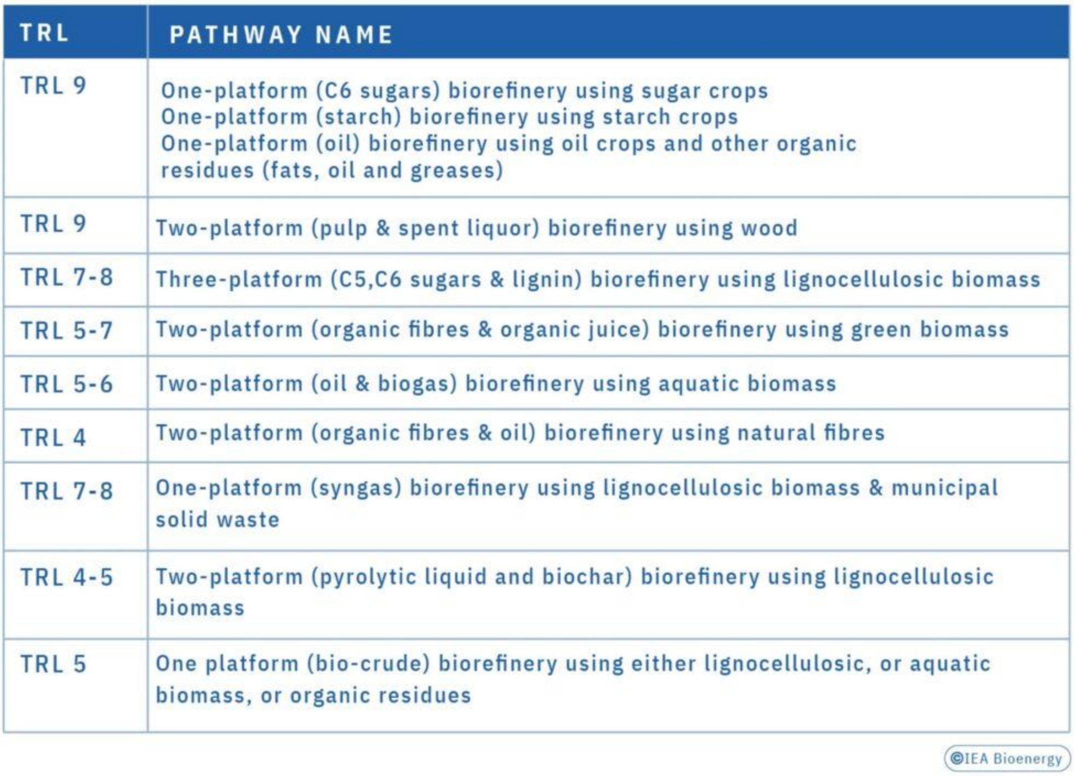
Biomass is currently the most used alternative carbon feedstock in the EU chemical industry, and is likely to continue playing a major role in the coming decades[20,21]. Increasing the share of carbon sourced from sustainable biomass in chemicals requires investment in biorefinery capacity and production efficiency, including for emerging technologies that process waste and residual biomass. Such investments, in turn, depend on market frameworks that help address the persistent cost gap between bio-based and fossil-based products. This scale-up also needs to be supported by a shift in biomass allocation towards material applications.

Technological readiness

Technologies to convert biomass into chemical feedstocks are relatively mature for certain value chains in the industry. Traditional ‘first-generation’ biorefineries that use food or feed crops to produce chemical building blocks and bio-based polymers, for example by processing sugar crops, starches or oils, are deployed at commercial scale in the EU[22,23].

At the same time, research and innovation are increasingly focusing on using biomass residues and waste streams, broadening the feedstock base for bio-based materials and products. However, while some biorefinery technologies that use residues and waste are moving towards early commercial deployment, many are still at an early stage of development[24,25].

Figure 2. Overview of Technology Readiness Levels of selected biorefinery technologies.



TRL	PATHWAY NAME
TRL 9	One-platform (C6 sugars) biorefinery using sugar crops One-platform (starch) biorefinery using starch crops One-platform (oil) biorefinery using oil crops and other organic residues (fats, oil and greases)
TRL 9	Two-platform (pulp & spent liquor) biorefinery using wood
TRL 7-8	Three-platform (C5,C6 sugars & lignin) biorefinery using lignocellulosic biomass
TRL 5-7	Two-platform (organic fibres & organic juice) biorefinery using green biomass
TRL 5-6	Two-platform (oil & biogas) biorefinery using aquatic biomass
TRL 4	Two-platform (organic fibres & oil) biorefinery using natural fibres
TRL 7-8	One-platform (syngas) biorefinery using lignocellulosic biomass & municipal solid waste
TRL 4-5	Two-platform (pyrolytic liquid and biochar) biorefinery using lignocellulosic biomass
TRL 5	One platform (bio-crude) biorefinery using either lignocellulosic, or aquatic biomass, or organic residues

©IEA Bioenergy

Source IEA (2023)[26].

At present, 479 biorefinery plants producing chemicals are operating in the EU. Of these biorefineries, over 70 % are at commercial stage, 21 % are in pilot phases and around 7 % are at R&D stage[27]. New EU-based biorefinery projects illustrate business interest in scaling up emerging technologies, such as the wood-based biorefinery developed by UPM in Leuna, Germany[28]. Commercial challenges remain, as shown by the closure of Clariant's cellulosic ethanol plant in Romania after difficulties in scaling up production and ongoing financial losses[29,30].

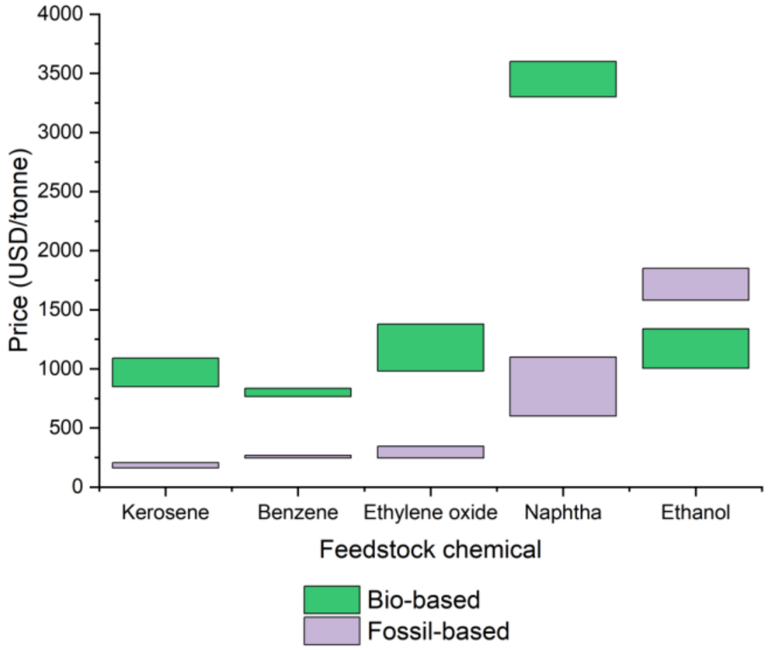
Market readiness

A range of bio-based chemicals and plastics is already commercially available in the EU. Examples include bio-polyethylene or polylactic acid, which are typically marketed as 'bio-based' or 'plant-based' alternatives to fossil-based products[31]. However, they continue to serve niche segments. Bio-based and bio-attributed plastics, for instance, accounted for only about 1 % of total plastics production in the EU in 2024[32].

While the market share of bio-based and bio-attributed plastics has gradually increased in recent years, economic factors continue to hinder their wider uptake. Evidence from recent modelling and market data shows that bio-based products are generally associated with substantial cost premiums compared with fossil-based equivalents, sometimes in the order of 150 % or more[33]. This is consistent with other studies indicating that bio-based feedstocks are typically between around one and more than four times more expensive than their fossil-based counterparts (Figure 3). The largest cost differentials are seen with commonly used feedstocks such as naphtha and kerosene, whereas bio-ethanol is already close to cost competitiveness in some applications.

Bio-based feedstocks and products are often more expensive because they are produced on a smaller scale and require more energy and materials. Biomass generally has lower carbon density, meaning more feedstock and processing input is required per unit output which affects their cost competitiveness. Fossil-based products, in contrast, benefit from highly integrated production systems, and the fact that their environmental impacts are not fully priced in[34,35,36].

Figure 3. Price ranges of bio-based in comparison to fossil-based feedstocks.



Source: Collett, K.A. et al (2023)[37].

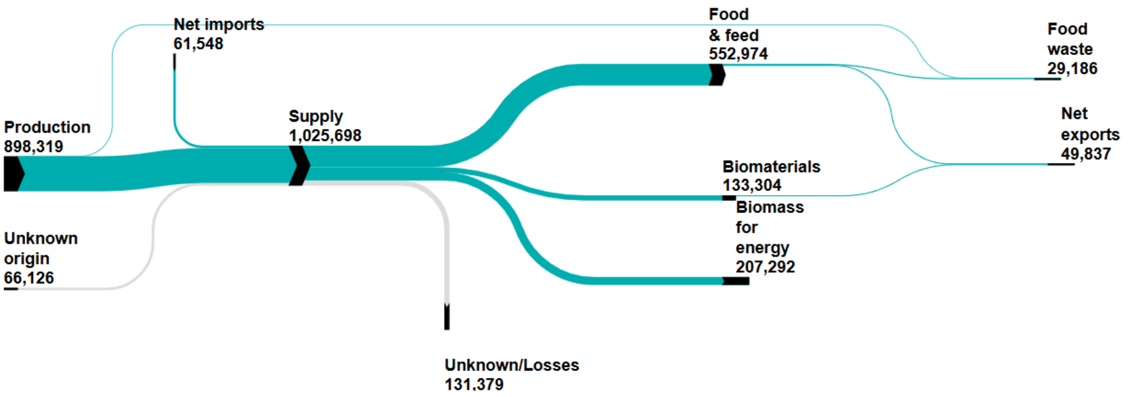
Scaling up production and achieving economies of scale are important to improve the competitiveness of bio-based products. This also requires a sufficient and reliable supply of biomass for use as feedstock in chemicals and related materials.

In absolute terms, the EU mobilises a biomass supply of around 1 billion tonnes of dry matter per year, mainly from domestic production and complemented by limited net imports (Figure 4). The largest share comes from agriculture (63 %), only a smaller share is sourced from forestry (24 %), with the rest being imported or of unknown origin. Most of this biomass is used for food and feed, which account for more than half of total use, followed by energy generation. Only a smaller share is currently used for material applications, including chemicals.

Looking ahead to 2050, projections suggest limited scope to expand domestic biomass supply in the EU[38]. Scaling up the supply of bio-based carbon in the chemical and derived materials sector therefore becomes a question of how much existing biomass is mobilised and allocated to material applications, combined with greater use of woody biomass as well as residues and biowaste. Recent EU policy initiatives promote a biomass-use hierarchy that prioritises food and feed security and gives preference to material applications over energy uses (see Section 3.2.1).

The use and scaling up of cultivated biomass for material applications in this transition remains a topic of debate. Some industries argue that access to a broad range of sustainably sourced biomass, including agricultural crops, is necessary to support the transition[39]. Environmental organisations, by contrast, emphasise ecological limits and caution that increasing biomass demand risks exceeding sustainable supply[40,41]. This tension is reflected in scenario projections, which indicate that higher bio-based shares are achievable only under high-productivity agricultural scenarios and not under business-as-usual conditions once food, feed and biofuel demand are taken into account. The scenarios incorporate both agricultural crops as primary feedstocks and residues and biowaste streams, although the modelling suggests that the latter remain constrained in volume[42].

Figure 4. Volume of biomass flows by type, EU, 2022 (in thousand tonnes).



Source: JRC (2025)[43].

2.2.2. *Recycled carbon*

Recycled carbon currently meets around 4 % of carbon demand in EU chemicals and derived materials, making it the second most widely used alternative carbon pathway,[44]. Large amounts of waste are generated each year, but only part of this material can be effectively collected and processed. Different recycling routes exist, but they vary in how easily they can supply feedstock to chemical value chains. Many face high costs for collection, sorting, decontamination and energy, as well as limited economies of scale. As a result, recycled materials often struggle to compete with virgin fossil-based products, which limits their uptake.

Technological readiness

Two main recycling pathways are relevant in the EU: mechanical and chemical recycling. Mechanical recycling involves processing waste without altering its chemical structure, enabling materials to be re-used for similar purposes. It is the most common form of recycling and is widely used commercially across the EU[45]. However, mechanical recycling has its limitations. It typically requires clean, well-sorted waste streams. Recycled materials also degrade over successive cycles, which limits their reuse to lower-quality applications, in a process known as *downcycling*[46].

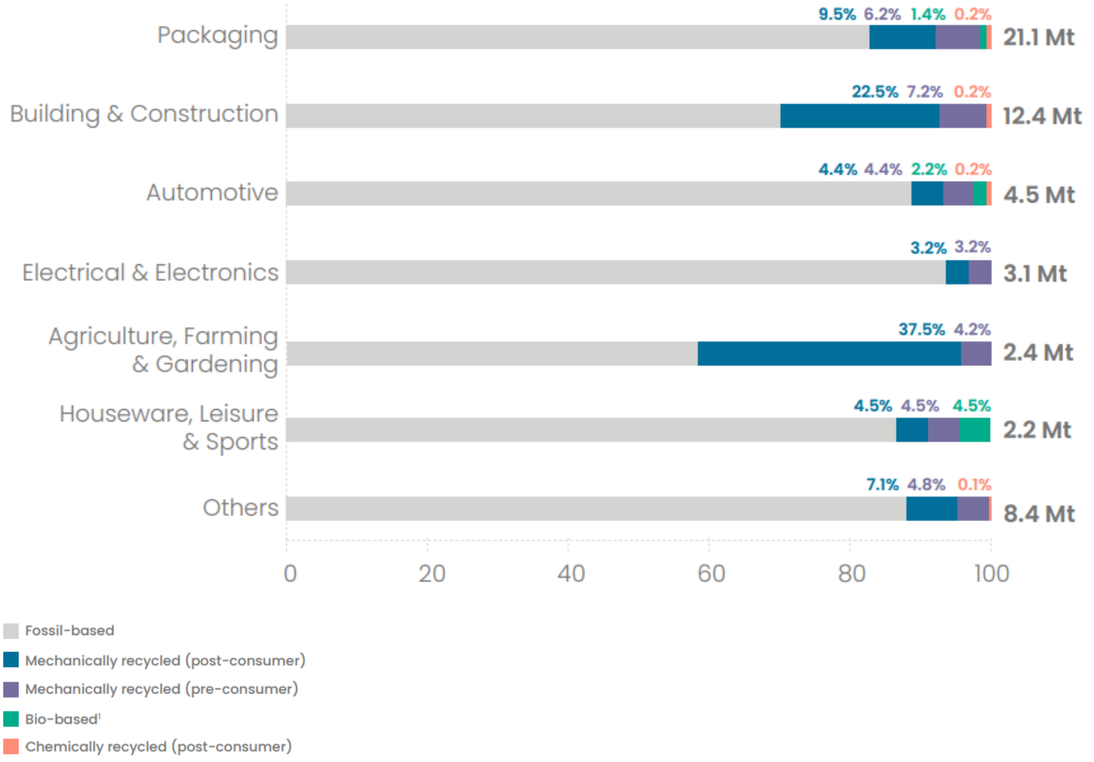
Mechanical recycling does not truly ‘free up’ the carbon to produce new basic chemicals. For example in the case of plastics, mechanical recycling typically involves the sorting, washing, shredding and re-melting of plastic waste into secondary polymers, which are then used mainly in lower-value applications[47]. As a result, mechanical recycling can contribute to reducing demand for virgin fossil carbon only temporarily by extending the lifespan of carbon for certain applications – but it does not reintroduce carbon as a ‘new’ feedstock that can be flexibly used across chemical value chains[48].

Chemical recycling, on the other hand, breaks down waste material into its chemical components, allowing the recovered carbon to be used in a manner comparable to virgin feedstock[49]. Technologies such as pyrolysis and gasification are approaching or are in some cases available for commercial deployment. While gasification currently offers higher scalability potential, it requires less pre-treatment and can process a higher variety of waste streams – though typically producing lower quality outputs than pyrolysis[50]. At the same time, both gasification and pyrolysis are energy-intensive due to their reliance on high-temperature thermochemical processes and require the scaling-up of capital-intensive facilities to provide a relevant contribution to carbon feedstock supply for the chemical industry[51][52].

Market readiness

In theory, recycled carbon offers a substantial feedstock volume, given the significant amount of waste containing carbon produced each year. Taking plastics as an example, approximately 32 million tonnes of (post-consumer) plastic waste was collected in the EU in 2022 alone – with the overwhelming share being fossil-based[53] (Figure 5). However, recycling rates in the EU remain constrained by various factors including insufficient collection rates and limited sorting and pre-treatment capacity to deliver waste streams to recycling sites at scale in a suitable form. In practice, not all collected waste can be recycled, as contamination, mixed materials and insufficient sorting quality lead to further losses at the sorting and pre-treatment stage. As a result, only about 27 % of the collected plastic waste in 2022 was recycled while the largest share was either incinerated with energy recovery (50 %) or landfilled (24 %) – leaving the effective supply of feedstock for recycling processes substantially below actual waste generation volumes[54].

Figure 5. Volume of plastics in conversion by recycling method, EU27+3, 2022



Source: PlasticsEurope (2024) [55]

Looking at the cost competitiveness of recycled materials, scrap polyethylene traded at around EUR 330 per tonne versus roughly EUR 1 444 for virgin polyethylene in the EU in 2023[56]. Yet at the product level, recycled polymers can cost as much or more than virgin competitors. For example, S&P Global noted European recycled hard plastic pellets selling at about EUR 480 per tonne above virgin plastic, and recycled bottle plastic around EUR 1 680 per tonne (almost EUR 700 higher than virgin bottle plastic)[57].

This is explained by high costs for collecting, sorting, and decontaminating waste plastics, as well as the lack of economies of scale and integrated logistics in the recycling sector, which operates on smaller, less efficient systems compared to petrochemical producers[58,59]. Additionally, quality and performance constraints limit recycled plastic use in certain applications, which limits demand despite cheaper raw material. Meanwhile, virgin plastic prices have been declining due to global overcapacity (driven by increased supply from China and the US) and weak demand, making new fossil-based plastics even cheaper[60] .

For chemical recycling, current estimates suggest that plastics produced via pyrolysis-based recycling may cost up to twice as much as those based on virgin fossil feedstocks. Price parity is expected only when chemical recycling reaches a substantial share of the market (of 20-30 %)[61]. At present, the deployment of chemical recycling remains very limited, with only 0.1-0.2 % of plastics waste being processed in this way[62]. Recent decisions by major industry players to cancel or delay planned recycling investments, citing cost and competitiveness concerns, underline the challenges associated with scaling both mechanical and chemical recycling capacity in the EU[63].

2.2.3. *Captured CO_2*

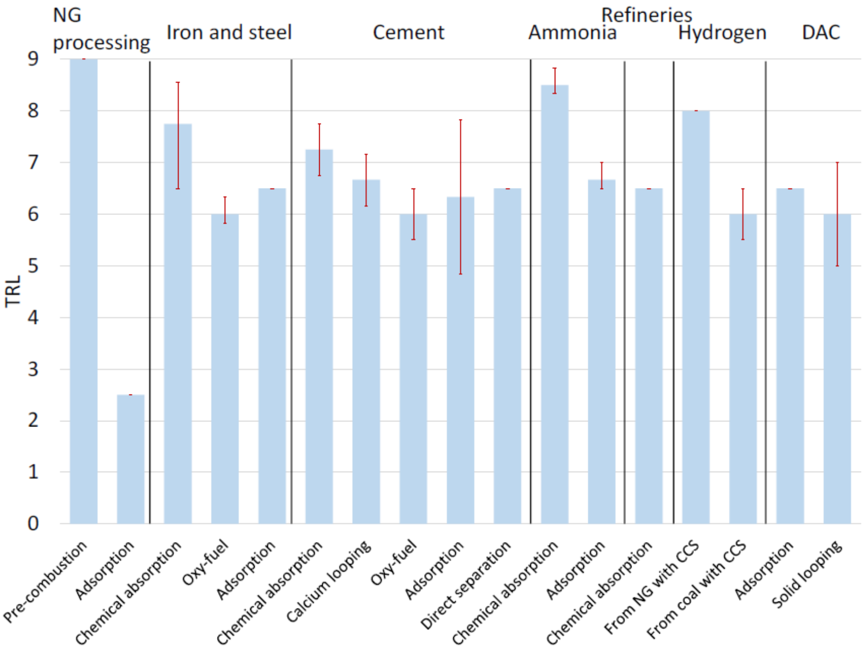
The CCU value chain combines CO_2 capture, transport and utilisation technologies, each of which is at a different stage of development. While several CO_2 capture and utilisation technologies are technically mature or approaching commercial readiness, overall deployment of CCU remains limited. This reflects a combination of high costs, energy requirements and infrastructure constraints, such as the lack of large-scale CO_2 transport networks. As a result, most CCU applications in the EU remain at demonstration or early commercial stages.

Technological readiness

On the capture side, CO_2 capture technologies are advancing, driven by growing policy interest in using CCS as carbon removal to contribute to EU climate neutrality objectives, including in the Commission's Industrial Carbon Management Strategy, the EU ETS Directive, Net-Zero Industry Act and the Carbon Removals and Carbon Farming Regulation.

From a technological perspective, several capture methods – including absorption, adsorption, and membrane technologies – are relatively mature. However, their use in industrial applications remains limited. According to the Joint Research Centre, only carbon capture from natural gas processing is deployed at full commercial scale, while applications in most other industrial sectors remain at demonstration or early commercial stages (Figure 6). Its use in ammonia, hydrogen and iron/steel production are among the use-cases closest to full commercial deployment after natural gas processing.

Figure 6. Average Technology Readiness Level of carbon capture technologies by emission source.

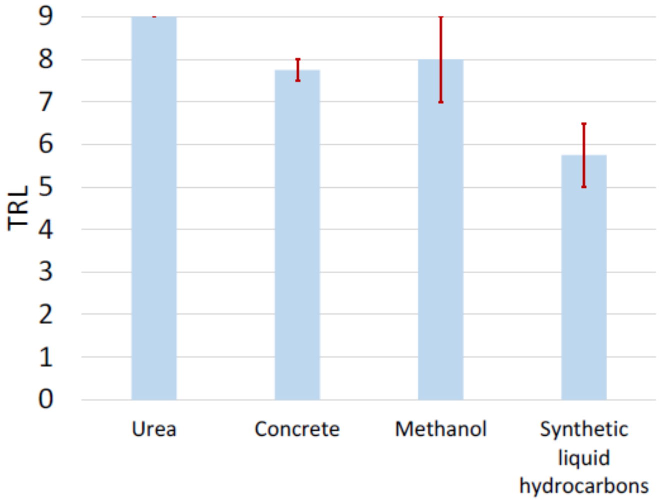


Source: JRC (2024 [64].

A CO_2 transport network is a critical enabler for both CCU and CCS in the EU. Transport technologies themselves are considered technologically mature and can draw on experience with pipelines and shipping of hydrocarbons[65]. However, the JRC highlights that Europe currently lacks a dedicated, large-scale CO_2 transport network. Existing pipelines and shipping routes are limited in scale and largely serve niche markets such as in the food and beverage industry. This constrains the flexibility and scalability of CCU value chains, including for chemical applications that could otherwise benefit from aggregated CO_2 supply across industrial clusters[66].

The utilisation step – converting captured CO_2 into a product – shows wide variation in technological and market readiness. According to the JRC, CO_2 utilisation encompasses a diverse set of technologies, ranging from established processes to early-stage concepts, with different levels of technology readiness and market prospects (Figure 7). Urea production and CO_2-based methanol synthesis are the most mature applications, and are already integrated into existing industrial value chains. In contrast, mineralisation pathways, such as embedding CO_2 into concrete or aggregates, are approaching commercial readiness while the production of synthetic hydrocarbons, including so-called synthetic fuels, generally remains at pilot or demonstration scale[67].

Figure 7. Average Technology Readiness Level of carbon utilisation technologies by application.



Source: JRC (2024).[68]

Market readiness

From a market perspective, the Joint Research Centre finds that, despite strong growth in announced Carbon Capture, Utilisation and Storage (CCUS) projects globally, the EU has seen relatively few final investment decisions across the full value chain, including CCU. Most European projects involving CCUS receive some form of public support[69]. Public investments serve as both funding and as a de-risking measure for initial private investments. Looking at projects funded by the Innovation Fund, there is a strong emphasis towards geological storage with 26.6 million tonnes of captured CO_2 per year of projects in storage, compared to 4.9 million in utilisation[70].

One reason for the limited deployment of CCU is its cost structure. CO_2-based value chains face, at least, a double cost hurdle: the cost of capturing CO_2 and the cost of converting it into products, with additional transport costs arising where capture and utilisation processes are not located at the same site.

Even for mature capture technologies, deployment is constrained by energy requirements, costs and scalability. Cost estimates vary widely depending on capture source and technology, ranging from around EUR 10-30 per tonne of CO_2 for highconcentration industrial streams, as in ammonia production and natural gas processing, to EUR 25-120 per tonne for other applications, such as cement or iron and steel[71]. The wide range in costs reflects differences in how mature CO_2 capture technologies are. Some options are already in use, while others are still under development and much more expensive, with costs also varying across sectors due to different production processes and capture options.

Similarly for the utilisation step, the Joint Research Centre underlines that many CCU technologies are energy-intensive and often require additional inputs (including hydrogen for synthetic hydrocarbons), which contributes to high capital and operating costs and increases dependence on access to low-carbon electricity[72].

CO_2 transport costs vary widely by mode, scale and distance, ranging from around EUR 2-7 per tonne for large onshore pipelines, to over EUR 25 per tonne for small or offshore pipelines, and roughly EUR 19-34 per tonne for ship-based transport over longer distances[73].

As a result, earlier estimates from the International Energy Agency suggest that products produced with captured carbon, such as synthetic methane, methanol or liquid fuels, cost several times more than conventional fossil alternatives[74]. This is confirmed in more recent EU-level analyses by the Joint Research Centre that conclude that most CO_2 utilisation pathways remain significantly more expensive than incumbent fossil-based production routes. Cost estimates for CO_2-based products again show very wide ranges, strongly influenced by capture and energy costs, with reported production costs for products such as methanol reaching EUR 300-2500per tonne, well above conventional benchmarks [75].

Looking ahead, the Joint Research Centre estimates that costs for capture and utilisation could decline over time as technologies mature and scale, supported by falling costs, for example of renewable electricity, and learning effects in CO_2-capture technologies. The extent of this remains uncertain. Similarly, the development of shared CO_2 transport infrastructure and industrial hubs could reduce unit transport costs through higher utilisation rates and economies of scale. Nevertheless, under current technological and market conditions, high capture, conversion and transport costs remain a major barrier to near-term CCU deployment[76].

2.3. ROLE OF ALTERNATIVE CARBON PATHWAYS DURING THE TRANSITION

The main challenge for alternative carbon pathways is less a lack of technology than costs and market conditions. As fossil-based and alternative carbon-based products typically perform similarly, price becomes the central differentiating factor for customers. Many alternatives to virgin fossil-based carbon products and materials are already available or close to market, yet they are not deployed at scale. This limits economies of scale and undermines their cost competitiveness.

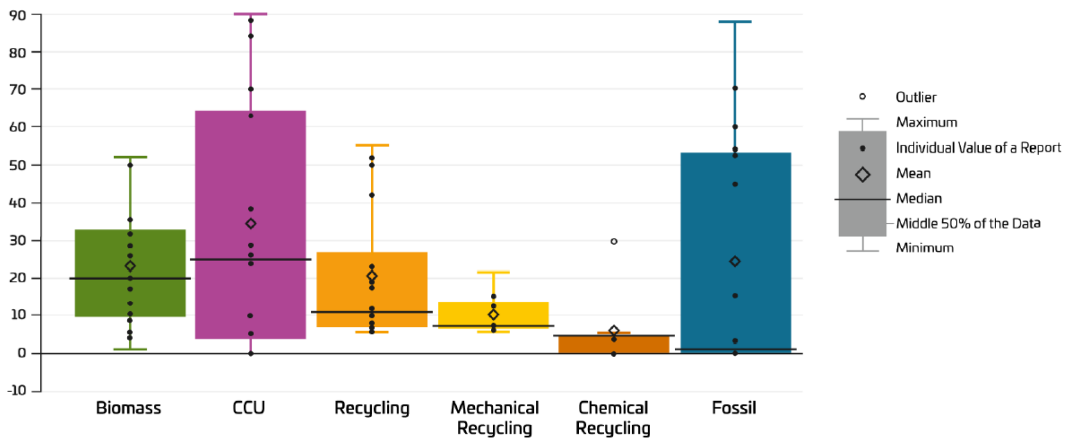
Each alternative carbon source also faces specific constraints. Sustainable biomass is limited by the availability and allocation of feedstock. There is continued interest in using biomass from waste and residues but this requires investment in scaling up emerging technologies.

Recycling is widely seen as a cornerstone of the transition, particularly mechanical recycling and, over time, certain chemical recycling routes, which could play complementary roles. Mechanical recycling is commercially established but typically requires relatively clean waste streams and can face quality limitations in some applications. Chemical recycling can process more complex or mixed waste streams and reintroduce carbon into chemical value chains, although several technologies remain at an early stage and involve high investment and energy costs .

The role of captured CO_2 varies across industrial applications. Central barriers to scale-up persist, notably compounding cost challenges: the cost of capturing CO_2, the cost of converting it into usable products, and, where capture and utilisation sites are not co-located, additional transport expenses. These processes are typically energy-intensive and depend on access to competitive low-carbon electricity, while dedicated transport and supporting infrastructure remain limited.

Overall, while scaling up alternative carbon sources can reduce the need for fossil carbon, stakeholders consistently point out that no single option is sufficient on its own. The different pathways need to fulfil complementary functions – for example, biomass can compensate for material losses in recycling processes by supplying virgin feedstock into the system. The transition will therefore require a mix of biomass, recycled carbon and captured CO_2, even though stakeholder views differ on the future contribution of each pathway (Figure 8).

Figure 8. Projected composition of carbon feedstock in a net zero chemical industry in 2050.



Source: Renewable Carbon Initiative (2024)[77].

Note: Based on 16 net zero scenarios from 9 analysed reports.

3. EVOLVING POLICY FRAMEWORK FOR ALTERNATIVE CARBON FEEDSTOCK

The regulatory framework for the EU chemical industry for the transition towards alternative carbon has been evolving in recent years across multiple policy areas, including bio- and circular economy and industrial carbon management.

3.1. A VISION FOR THE EU CHEMICAL INDUSTRY

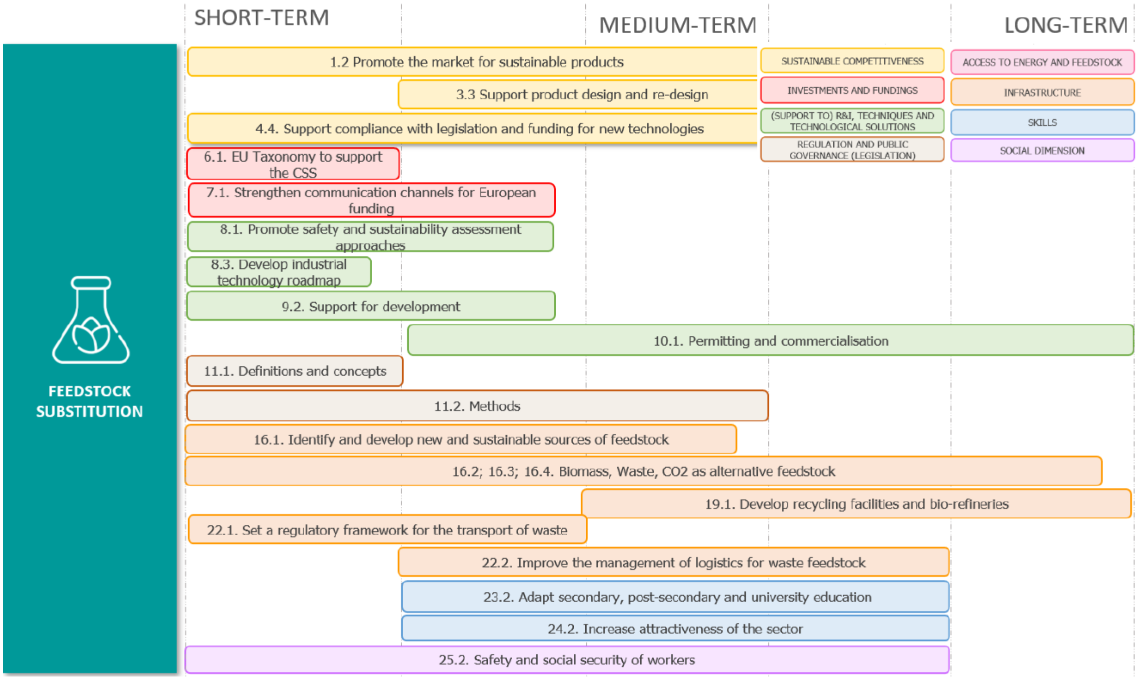
The European Commission first formulated a comprehensive vision for the role of alternative carbon in the EU economy in the 2021 Sustainable Carbon Cycles Communication – with the ambition to establish 'sustainable and climate-resilient carbon cycles.' Relevant for the EU chemical industry, this included the shift from virgin fossil-based to alternative carbon sources, including waste streams, sustainable biomass and captured CO_2. To promote this shift, the Communication announced the ambition that 'by 2028, any tonne of CO_2 captured, transported, used and stored by industries should be reported and accounted by its fossil, biogenic or atmospheric origin' and set an 'aspirational' target whereby 'at least 20 % of the carbon used in the chemical and plastic products should be from sustainable non-fossil sources by 2030.'

Building on this vision, the European Commission developed a Transition Pathway for the Chemical Industry through a multi-stakeholder consultation process that was published in 2023. The outlined pathway frames the transformation of the chemical sector as a long-term, stepwise process, aligned with the EU's climate neutrality objective. It also recognises the sector's structural dependence on both energy *and* carbon-based feedstocks. As a large share of emissions is linked to the carbon embedded in chemical products, the transition pathway emphasises on diversifying feedstocks and progressively moving away from virgin fossil inputs, namely recycled materials, biomass, and captured CO_2 – in line with the 2021 Sustainable Carbon Cycles Communication.

To support this, the Transition Pathway proposes several measures integrated in a long-term roadmap (Figure 9). Under the task to 'identify and develop new and sustainable sources of feedstock', the roadmap includes setting targets for 'renewable/non-fossil content,' harmonising certification for sustainable biomass, defining 'non-fossil sources' and developing a 'methodology to calculate the share of total feedstock in carbon sources.'

Taken together, these strategy documents and the accompanying roadmap provide the EU's vision and a set of actions across the short, medium and long term. Regulatory frameworks to guide the transition are spread across different EU policies, namely bioeconomy, circular economy and industrial carbon management.

Figure 9. Roadmap for feedstock substitution in the 'Transition Pathway for the Chemical Industry'.



Source. European Commission (2023)[78].

3.2. STATUS OF POLICY

3.2.1. Bioeconomy

For carbon sourced from sustainable biomass, the central strategy is the updated Bioeconomy Strategy, released in November 2025. It sets out the vision of large-scale deployment of bio-based products 'such as construction materials, biochemicals, textiles, fertilisers and plant protection products and plastics' as 'fossil-free alternatives' across Europe by 2040. The strategy frames the EU bioeconomy as a central driver of future industrial competitiveness, economic growth and resilience. It emphasises its potential contribution to strategic autonomy by reducing reliance on 'imported fossil-based products.'

For the EU chemical industry, an important aspect is the emphasis on replacing fossil-based materials and products with alternatives from 'renewable biomass sources' by increasing their use in 'packaging, automotive components and industrial applications.' Examples mentioned include bio-based plastics and polymers or fibre-based packaging materials made from biomass, such as 'starch, lignin or algae.'

The vision for a large-scale deployment of bio-based products and materials is integrated with an emphasis on enhancing the 'efficient use' of biomass in the EU. In the case of biomass, this implies the prioritisation of using biomass to ensure food and nutrition security followed by material uses that substitute fossil-based inputs and enable longer-term carbon storage. According to this, energy use should be largely limited to residual and secondary biomass streams, in contrast to the current biomass allocation in the EU (Section 2.2.1). To support this shift, the Strategy recommends integrating efficient use principles in existing policy frameworks, including Common Agricultural Policy Strategic Plans, National Energy and Climate Plans, Cohesion Policy and national bioeconomy strategies.

To stimulate uptake of sustainable biomass, the Bioeconomy Strategy places strong emphasis on lead market creation and identifies priority markets for bio-based materials and products, including plastics and polymers, fibre-based packaging, chemicals, construction materials and textiles. As an 'enabler for bioeconomy lead markets' the strategy highlights public procurement and voluntary industry alliances. In this context, it refers to the planned revision of the Public Procurement Directives (scheduled for 2026) to potentially integrate guidelines that incentivise the procurement of bio-based materials and products by public entities. This is complemented by the plan to establish a Bio-based Europe Alliance, a voluntary coalition of EU companies committing to collective offtake of bio-base materials, products and applications. The alliance is envisaged as a demand-aggregation platform, with the objective of mobilising up to EUR 10 billion in demand by 2030.

For certain product groups, the strategy considers integrating bio-based content requirements into EU product regulations. For example, under the Packaging and Packaging Waste Regulation (PPWR), the Commission plans to 'support the recognition and uptake of bio-based plastics and novel materials, in complementarity with recycled content targets' in 2027 (See also Section 3.1.2). For bio-based polymers, the strategy also foresees an assessment of introducing EU-level definitions and certification approaches to incentivise further scale up.

For materials embedded upstream in complex industrial value chains, notably bio-based chemicals, the Bioeconomy Strategy signals the possibility of introducing bio-based content requirements for selected downstream products. In this case, final products placed on the EU market, such as plastics or rubbers, might in the future be required to contain a minimum share of bio-based carbon to create demand upstream.

Demand creation in other product groups and materials, such as bio-based textiles and construction materials, is envisaged to be supported primarily through a revision of product standards and transparency measures, including under the Ecodesign for Sustainable Products Regulation (ESPR) and the Construction Products Regulation (CPR).

According to the Strategy, the European Commission is also developing a methodology for carbon storage in buildings, planned for 2026, under the Carbon Removals and Carbon Farming framework, to certify long-lasting biogenic carbon stored in construction products and buildings (See also Section 3.1.2). This is complemented by measures to enhance transparency for investors and consumers on the environmental and circularity benefits of bio-based materials, including through the enhancement of Product Environmental Footprint (PEF) methodologies recommended by the EU to assess the environmental impact of products.

Notably, the Bioeconomy Strategy features circularity as a ‘core principle’ to keep bio-based carbon within use and minimise the need for virgin material. This highlights the strong link to circular economy policies which form the guardrails for the sourcing of recycled carbon in the EU.

3.2.2. Circular economy

The main reference point for material circularity policies at EU-level is the second Circular Economy Action Plan, adopted in 2020. It sets out a broad list of initiatives across product groups and value chains, combining recycled-content requirements with product rules on design, recyclability and end-of-life treatment. The measures for demand creation of secondary raw materials are integrated in several pieces of product-specific legislation. These include, for example, the Packaging and Packaging Waste Directive (PPWD), Single-Use Plastics Directive (SUPD), Batteries Directive (now replaced by the 2025 Batteries Regulation), and the End-of-Life Vehicles Directive (ELVD).

Many of these frameworks have been or are currently being updated, in several cases including new or more stringent targets for recycled content. The new Packaging and Packaging Waste Regulation (PPWR), for example, introduces binding minimum recycled-content targets for plastic packaging, ranging from 10-35 % by 2030 and increasing to 25-65 % by 2040, depending on packaging type. Similar targets exist under the new Batteries Regulation and are foreseen in the proposed End-of-Life Vehicles Regulation (ELVR), which includes minimum recycled plastic content requirements for new vehicles. Further measures are expected under the forthcoming Circular Economy Act in 2026 with the objective ‘to establish a Single Market for secondary raw materials, increase the supply of high-quality recycled materials and stimulate demand for these materials within the EU.’

Notably, EU rules defining 'recycling'[v] (as set out in the Waste Framework Directive) exclude energy recovery and the reprocessing of waste into materials intended to be used as fuels or for backfilling. In practice, many recycled-content requirements and verification approaches have so far been built primarily around mechanically recycled material, while harmonised EU calculation rules for *chemically* recycled content have been less developed.

This creates challenges for certain chemical recycling routes. Some processes produce intermediate outputs that can be used either as fuels or as chemical feedstock. In such cases, it is often unclear how to distinguish and account for the share that is not used as fuel. As a result, it can be difficult to determine, in a transparent and consistent way, which part of the output qualifies as 'recycled content' under existing EU definitions. Industry actors have highlighted this uncertainty as a barrier to investment in chemical recycling[79].

Against this background, the European Commission launched a public consultation in 2025 to collect stakeholder inputs on mass balance and allocation methodologies that can enable the tracing and accounting of chemical recycling content. Building on this consultation, the Commission proposed new implementing rules towards the end of 2025 that would allow, under certain conditions, chemically recycled content to count towards recycled content obligations using 'mass-balance allocation rules', initially for recycling targets for plastic beverage bottles under the Single-Use Plastics Directive[80] (See also Section 4.1).

3.2.3. *Industrial carbon management*

With regard to capturing CO_2 from industrial processes or the atmosphere, the European Commission adopted the Industrial Carbon Management Strategy (ICM) in 2024. The Strategy acknowledges the role of Carbon Capture for Utilisation (CCU) in products, such as 'synthetic products, chemicals or fuels,' as a potential complementary pathway to the capturing of carbon from industrial processes or the atmosphere for permanent storage (CCS).

In the early stages, CCU is expected to rely on a mix of CO_2 sources. Over the longer term, however, the Industrial Carbon Management Strategy points to greater climate benefits from using CO_2 from biogenic sources or directly from the atmosphere. Under certain

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[v] Definition from the Waste Framework Directive: '"recycling" means any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations.'

conditions, these sources could avoid adding new carbon to the atmosphere and therefore deliver greater climate benefits than using CO_2 captured from fossil-based processes.

The Strategy further outlines the possible role of CCU for substituting feedstock in carbon-dependent sectors such as the chemical industry but acknowledges that the current EU policy framework predominantly incentivises CO_2 use in fuels as opposed to other applications – notably through EU ETS provisions supporting certain aviation fuels and through ReFuelEU Aviation and FuelEU Maritime rules.

For other applications, CO_2 utilisation is not yet fully supported by EU regulatory frameworks. For example, under the current ETS, when an industrial installation captures CO_2 and sells it for use, the capturing installation is still required to surrender ETS allowances as if the CO_2 had been emitted.

The 2026 ETS review is planned to, among others, review the incentives and disincentives for CCU in this context and 'assess whether the CO_2 potentially released from non-permanent CCU products and fuels should be accounted at the point of emission to the atmosphere ('downstream accounting') or when the CO_2 is initially captured ('upstream accounting').' The review will also assess whether an inclusion of municipal waste incineration installation and 'other waste management processes, in particular landfills' should be included in the EU ETS to consider if this 'could help recognise non-permanent CCU as a pathway to reduce surrender obligations by pricing emissions downstream.'

Another relevant framework for CCU is the Carbon Removals and Carbon Farming Certification Regulation, adopted in 2024. The regulation established the first EU-wide voluntary certification framework for carbon removals, carbon farming, and storage of carbon in products. Under the Regulation, the European Commission is mandated to develop certification methodologies, specifying how eligible activities are quantified, monitored and verified. However, its scope for carbon stored in products remains limited to carbon stored for at least 35 years[vi], or that is permanently chemically bound[vii]. Consequently, carbon stored in chemical products with a shorter lifespan are outside of the scope of the framework.

[vi] Definition from the CRCF: 'carbon storage in products' means any practice or process that captures and stores atmospheric or biogenic carbon for at least 35 years in long-lasting products, allows on-site monitoring of the carbon stored and is certified throughout the monitoring period.'

[vii] Definition from the CRCF: 'permanently chemically bound carbon in products' means carbon chemically stored within a product with the result that it does not enter the atmosphere under normal use of the product, including any normal activity taking place after the end of life of the product, in accordance with Article 12(3b) of Directive 2003/87/EC.'

3.3. EVOLVING POLICY PERSPECTIVE ON THE TRANSITION

The EU policy framework increasingly reflects the understanding that the transition of the chemical industry cannot be approached in the same way as energy systems. Given the sector's continued reliance on carbon as an essential material feedstock, policy attention is shifting towards the defossilisation of the material base of chemicals by replacing virgin fossil carbon with alternatives.

This shift spans several policy areas, reflecting the cross-cutting nature of alternative carbon pathways. Initial efforts to connect these domains are already visible, for example between bioeconomy and circular economy policies (Section 3.2.1). These linkages will remain central, particularly for creating demand for individual alternative carbon pathways.

Industry stakeholders acknowledged that technology-specific approaches may be appropriate in the early phases of the transition. Over time, more technology-neutral frameworks may become more important, notably from a certainty and cost-efficiency perspective.

At the same time, stakeholders emphasised the need to enhance the conceptual clarity of alternative carbon pathways in EU policies. This includes accounting systems to differentiate carbon primarily by its original source, whether fossil, bio-based or atmospheric, because each has different climate impacts. This distinction is especially relevant for recycling and CCU. In both cases, the origin of the carbon should remain the central point of differentiation. The process through which carbon is converted or reused, such as recycling or CCU, can be treated as a secondary characteristic.

4. BUILDING THE TOOLS TO SUPPORT DEMAND CREATION

Developing and implementing effective demand-creation instruments for alternative carbon through policy instruments requires robust methodological tools to quantify, track and verify carbon flows across complex chemical value chains. In recent years, various approaches have emerged in this context. This section reviews the main methodological building blocks that are currently used or under discussion at EU level and explores their respective roles in supporting demand creation for alternative carbon.

4.1. DIFFERENT TOOLS FOR DIFFERENT PURPOSES

The need for greater conceptual clarity and robust accounting systems to underpin the transition of the chemical industry has been increasingly recognised at EU level. In 2022, the European Parliament's Committee on Industry, Research and Energy highlighted the absence of a coherent EU framework for alternative carbon sources and called on the European Commission to develop a framework for the differentiation of carbon types by origin and methodologies to quantify the share of sustainable non-fossil carbon in plastics and chemicals[81]. This was subsequently reflected as an action point in the industry roadmap of the Transition Pathway for the Chemical Industry (Section 3.1). As of now, different methodologies and initiatives exist to quantify embedded carbon, track the origin of carbon as well as to assess the sustainability characteristics of materials.

Quantifying carbon in products

To date, life-cycle assessments are commonly used to assess climate and broader environmental impacts of products. To quantify climate impacts in terms of GHG emissions, industry practice typically relies on Product Carbon Footprint (PCF) methodologies, as defined by international standards such as ISO 14067:2018 and the GHG Protocol Product Life Cycle Standard[82][83]. At EU level, the European Commission has developed its own framework, the Product Environmental Footprint (PEF), complemented by product-specific Product Environmental Footprint Category Rules[84] [85].

These frameworks establish system boundaries that define the life-cycle stages and the calculation rules for estimating climate (and/or environmental) impact, with the aim of improving the consistency and comparability of results. A central distinction between them lies in their scope – while PCFs focus on GHG emissions, PEF adopts a broader perspective, covering additional environmental categories such as water use, land use and resource depletion alongside climate impacts.

Notably, neither PCF nor PEF methodologies *measure* how much carbon is physically contained in a material itself (e.g. carbon atoms in biomass). Instead, both methods *estimate* the GHG emissions *associated* with a product over its entire life cycle, including raw material extraction, production, use and end-of-life. These emissions are expressed as CO_2-equivalent values and are quantified using emission factors and life-cycle inventory data rather than direct measurement of carbon content. Although they do not rely on direct measurement, these approaches provide a structured and widely recognised basis for assessing a product's climate impact when grounded in established life-cycle standards and robust underlying data.

While PCF and PEF methodologies likewise do not physically *track* carbon across value chains to distinguish carbon by origin, they nevertheless influence the differentiation of products based on alternative or virgin fossil carbon through their modelling of life-cycle emissions. Two special cases – for biogenic carbon and recycled carbon – are discussed in the boxes below (Box 1 and 2).

Box 1. Quantifying carbon – the case of biogenic carbon

For **bio-based products**, a key methodological issue concerns how biogenic CO_2 flows are treated across the life cycle. When biomass grows, it captures CO_2 from the atmosphere, which is typically released later during product use, degradation or end-of-life treatment such as incineration. If uptake and release are balanced, this cycle can be considered climate neutral over the life cycle.

In life-cycle assessments, these dynamics are often reflected through the –1/+1 approach, where carbon uptake during biomass growth is counted as a negative emission at the beginning of the life cycle and an equivalent positive emission when the carbon is later released[86]. A similar logic can in principle apply to CO_2 captured from the atmosphere and used as feedstock in CCU processes. In this case, however, achieving climate benefits depends strongly on the availability of low-carbon energy, given the high energy demand of capture and conversion (see Section 2.2.3).

Several major life-cycle standards, including ISO 14067:2018 and the GHG Protocol Product Life Cycle Standard, require biogenic carbon to be reported separately from fossil carbon and allow or apply the –1/+1 accounting approach[87,88]. The GHG Protocol also requires removals to reflect the actual biogenic carbon content of the product and explicitly includes CO_2 captured from the atmosphere[89].

However, accounting rules differ across standards (Table 1). The EU's PEF, for example, also reports biogenic emissions separately but applies a 0/0 approach, under which biomass-related carbon sequestration and subsequent emissions are excluded from the carbon footprint. This approach has been criticised by industry stakeholders and practitioners for limiting the differentiation of bio-based products from fossil-based alternatives[90, 91].

Table 1. Overview of provisions on accounting for biogenic carbon in leading life-cycle assessment standards and guidelines

Biogenic Accounting Approach[viii]	+1/-1	0/0	EF method [ix]	No provisions/ not relevant
ISO 14040/-44				■
ISO 14067	■			
PEF			■	
EPD (ISO 14025 and EN 15804)	EN 15804			ISO 14025
GHG Protocol (Product level)	■			
Pathfinder	■			
Together for Sustainability	■			
JRC's plastics LCA method			■	
RED III		■		

Source: Own figure based on Renewable Carbon Initiative (2025)[92].

Box 2. Quantifying carbon – the case of recycled carbon

For **recycled carbon**, a central question is how the environmental impacts of a material should be distributed between its first and subsequent life cycles. A range of approaches is used in practice, including *cut-off* approaches to *avoided-burden* approaches[93].

[viii] All approaches assessed in this table refer to product- or product-pathway-level accounting. ISO 14040/44 are general LCA standards but are considered here as the methodological basis for product-level applications.

[ix] Corresponding to the 0/0 approach.

To illustrate, under a cut-off approach, the recycled plastic is treated as entering the new life cycle without inherited fossil emissions and only the emissions from the recycling process are included in the new PCF. By contrast, under an avoided-burden approach, recycling at end-of-life can generate a credit for the avoided production of virgin plastic, depending on assumptions including on avoided virgin material and quality losses.

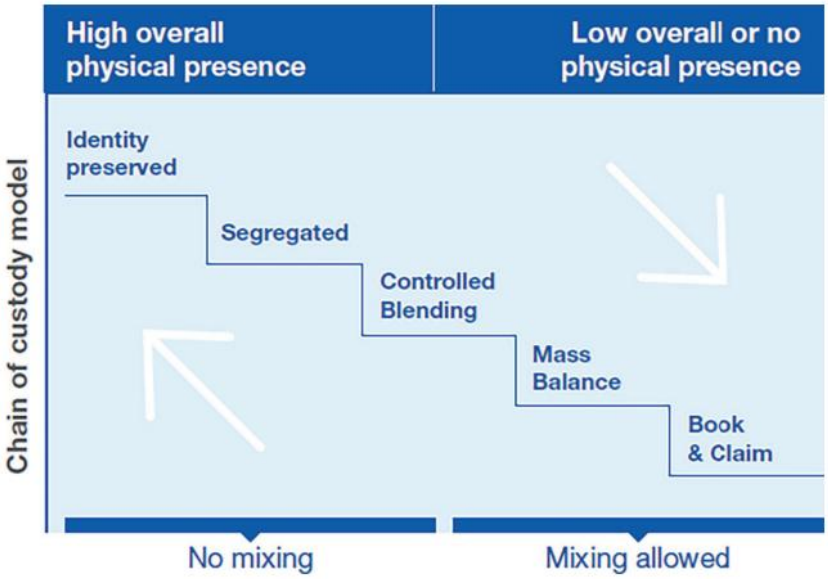
International standards, such as ISO 14067 and the GHG Protocol Product Standard, allow different approaches for modelling recycling, including the abovementioned cut-off and avoided-burden methods, while the EU's PEF primarily applies its own formula ('Circular Footprint Formula') that combines elements of both approaches. However, recent methodological reviews underline that guidance is often limited and uneven across standards, which affects comparability across products[94]. A related unresolved issue is whether biogenic carbon uptake from a previous life cycle should be counted in the footprint of a recycled product, given the risk of double counting removals across multiple cycles[95].

Differentiation of carbon by origin

Existing life-cycle assessment methods are designed to quantify climate and environmental impacts rather than to physically track carbon through complex value chains. Consequently, they do not enable differentiation of carbon by origin, which is a central requirement for distinguishing alternative from virgin fossil carbon. Differentiating their origin in materials and products therefore requires additional mechanisms, typically referred to as chain-of-custody models.

Chain-of-custody models (ISO 22095:2020) range from ensuring traceability through strict physical separation (i.e. identity preserved) to allocating attribute claims through accounting rules decoupled from physical material flows (i.e. book-and-claim) (Figure 10). In between hybrid approaches exist, such as mass balancing.

Figure 10. Chain-of-custody methods, based on ISO 2205:2020.



Source: Krljuš et al. (2024)[96]

Such models are required to support demand-side instruments in the chemical industry due to the specific characteristics of carbon and chemical value chains. Once carbon is used in chemical production, its origin is difficult to determine at the product level, particularly where different carbon streams are mixed, as carbon from different sources can be indistinguishable in practice[97]. While certain distinctions, such as between fossil and biogenic carbon, can, in principle, be made through methods such as radiocarbon analysis, this is generally limited to physical carbon flows and does not resolve the broader challenge of tracing carbon across complex value chains. As chemical value chains are highly integrated, maintaining full physical separation between alternative and fossil carbon throughout production would be costly and impractical, particularly in the early stages of the transition when volumes of alternative carbon remain limited[98].

In practice, the only workable options during the transition are chain-of-custody models that allow at least some degree of physical mixing and rely on accounting systems that record material inputs and outputs over time. These approaches make it possible to integrate alternative carbon feedstocks into large-scale chemical production without the need for separate production lines. Two main models are discussed: book-and-claim and mass balance.

In a book-and-claim system, producers of alternative carbon feedstocks generate certificates or credits for a defined attribute, such as one tonne of bio-based plastic produced. These certificates are recorded in a registry and can be purchased by downstream users. By purchasing a certificate, a company can claim the use of alternative carbon, even if the physical material it uses does not itself contain that carbon. Book-and-claim systems are already used in other sectors in the EU, most notably in electricity markets through Guarantees of Origin for renewable energy, reflecting the fact that once electricity is injected into the grid, it is no longer physically traceable from a specific producer to an individual consumer[99].

Mass balance approaches also allow the physical mixing of sustainable and conventional feedstocks, but link sustainability claims more directly to the production process. Under mass balance, the amount of alternative carbon attributed to products is limited by the amount of alternative carbon introduced into the system, within a defined system boundary and over a specified time period. Accounting rules ensure that output claims do not exceed inputs, even though individual molecules in the final product cannot be traced. A central issue within mass-balance systems concerns how recycled or alternative carbon content is allocated across production outputs (Box 3).

Mass balance accounting is already implemented through established voluntary certification schemes, notably ISCC PLUS and REDcert[2]. These schemes include third-party verification, certified bookkeeping systems, defined balancing periods, and safeguards to prevent double counting. However, a review of the leading standards underlines that clear guidance on mass balance within common life-cycle assessment methodologies is often missing[100]. Against this backdrop, mass-balance methodologies are currently being further developed by the European Commission in the context of recycling, notably to enable the tracing and accounting of chemically recycled content under product-specific legislation for certain plastics (See also Section 3.1.2).

Box 3. Two ways of sharing recycled content a mass-balance systems

In mass-balance systems, recycled or bio-based material can be mixed with fossil material during production. The question is how the recycled share is counted and assigned to the final products.

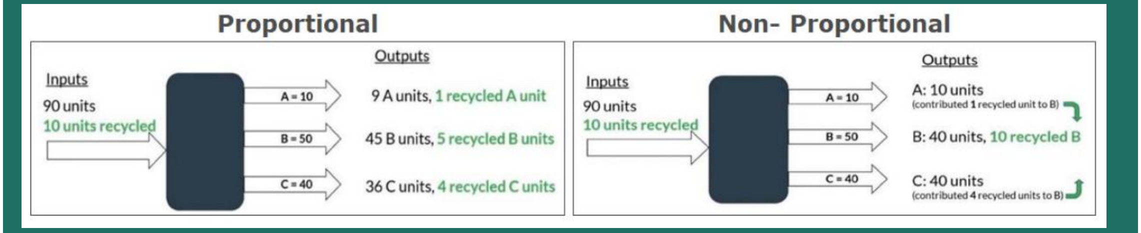
There are two main approaches (Figure 11):

Proportional allocation spreads the recycled material across all products coming out of the process. Each product receives a share of recycled content that reflects how much of the total output it represents. In other words, every product is assigned *some* recycled material attribute, in proportion to its size.

Non-proportional allocation, by contrast, allows all the recycled material to be assigned to one product (or a small number of products). The remaining products are then counted as fully fossil-based. This gives producers more flexibility to concentrate recycled content in specific products.

In both cases, the total amount of recycled material remains the same. What changes is only how the ‘recycled’ attribute is distributed across products.

Figure 11. Illustration of ways to share recycled content in mass balance systems



Source. JRC (2023)[101].

Sustainability of carbon

While the methodologies described above provide a foundation to quantify and track carbon, they do not in themselves determine whether carbon is sourced *sustainably* – an attribute which is repeatedly highlighted for chemicals and their feedstocks in EU policy documents [x]. Assessing sustainability requires additional criteria that address environmental impacts beyond greenhouse gas accounting, including land use, resource efficiency, competing uses and long-term climate effects

In the EU, sustainability requirements for some alternative carbon feedstocks are already developed for certain applications. For example, for biomass used for energy purposes under the Renewable Energy Directive (RED II) and its amending Directive (RED III)[102]. These frameworks link eligibility for policy support to compliance with criteria on biomass sourcing and GHG emissions.

By contrast, biomass used as a material feedstock in chemicals and derived products is not yet covered by an equivalent horizontal regulatory framework, as highlighted by the Renewable Carbon Initiative[103]. However, existing EU policy instruments increasingly reference sustainability principles of the Renewable Energy Directives in non-energy contexts. In particular, the EU Taxonomy Delegated Regulation and the Policy Framework on Bio-based, Biodegradable and Compostable Plastics explicitly mention these criteria as a relevant benchmark for assessing the sustainability of biomass in material applications, pointing to an emerging alignment across policy areas.

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[x] See for example, the EU Chemical Action Plan or the Bioeconomy Strategy.

4.2. DEVELOPING ROBUST AND WORKABLE ACCOUNTING SYSTEMS

The transition to alternative carbon requires reliable systems to measure, track and verify carbon flows and sustainability claims. Such systems are essential for demand creation policies to ensure effectiveness and credibility.

At the same time, industry stakeholders point out that alternative carbon pathways are already subject to extensive accounting and certification requirements, while fossil carbon does not face comparable obligations. This difference can create additional costs and administrative burdens for alternative carbon pathways, particularly in the early stages of scale-up. It therefore raises the question of how to design robust but practical systems that maintain integrity without slowing down the transition. Pragmatic solutions for a number of challenges need to be found for this, integrated in a roadmap to increase robustness over time.

While life-cycle approaches such as PCFs play an important role in assessing climate impacts, methodological differences and data limitations are likely to persist, at least for some time. Results depend strongly on data quality and methodological choices, which can affect comparability between products. To support the shift in feedstocks, a consistent differentiation of carbon pathways is needed, taking into consideration their specific characteristics in relation to their carbon footprint.

Approaches to track carbon origin, rather than accounting of life-cycle emissions alone, are required for the transition to alternative carbon and for the functioning of related lead market instruments. Where physical tracing is not feasible, chain-of-custody models, such as balance accounting, have emerged as a practical approach. Physical segregation of alternative and fossil feedstocks is often not possible at scale in chemical processes, especially during the transition phase, or only at high administrative and cost burden.

At the same time, book-and-claim and mass balancing approaches carry the inherent risk of potentially misleading claims. An example being non-proportional attribution approaches that allow limited volumes of alternative carbon to be marketed as fully ‘recycled’ or ‘bio-based’ products, even if this is technologically not feasible. One way forward could be to implement mass balance systems with strict safeguards, transparency for consumers, clearly defined system boundaries – preferably at EU level – and explicit phase-out conditions as technologies mature and more granular accounting becomes feasible.

Current implementation of mass balance through existing certification schemes seems to be complex and as a result, costly. In particular, certification requirements aimed at midstream and downstream companies, covering individual production sites, warehouses and value-chain partners risk creating additional administrative burdens. The higher the complexity, the higher the cost for alternative carbon. One solution could be simplified, legally anchored mass balance rules, potentially based on company-level or facility-level accounting of carbon inflows and outflows, while maintaining safeguards against double counting and greenwashing. As alternative carbon pathways scale up, possibly physical segregation may become increasingly viable and could ultimately represent the most robust approach, provided it is economically and technologically manageable.

Taken together, there appears to be a broad convergence on chain-of-custody models, particularly mass balance, as a necessary, but transitional, accounting approach. The framework can also be designed to evolve over time, as more granular tracking and verification become technically and economically feasible. While different opinions exist on risks and implementation challenges, there seems to be shared recognition that the design and use of chain-of-custody models must be closely aligned with their underlying purpose – to support the shift towards alternative carbon feedstocks as the primary objective.

5. POLICY OPTIONS FOR LEAD MARKET CREATION

In the context of the ongoing policy debate on lead markets in the EU chemical industry, a range of instruments to create demand is being considered by the European Commission, alongside additional proposals put forward by industry actors. This chapter reviews the principles and enabling framework for effective lead markets and examines existing and emerging policy options in this context.

5.1. PRINCIPLES AND ENABLING FRAMEWORK

To inform a structured review of existing and emerging policy options, a range of principles and tools to underpin effective lead market instruments can be considered. While stakeholder views differed on specific instruments, there was broad convergence on the conditions under which demand creation measures could influence investment decisions and support the transition towards alternative carbon in the EU chemical industry.

A central objective of lead markets is to trigger private investment. In order for this happen, the regulatory framework needs to be credible and provide a robust long-term outlook that holds the promise of commercial demand both in the EU and globally. A clear transition pathway for the EU chemical industry to underpin a robust long-term business case for alternative carbon was considered to be a central driver of investment.

Speed emerged as another important aspect in light of the need to reduce GHG emissions as fast as possible. Stakeholders underlined that effective measures at scale for market pull will ideally need to become operational by the second half of this decade. Investment decisions will need to be taken now, not only to meet EU and global climate change objectives but also to maintain a resilient EU materials industry. There is a trade-off between complexity and speed.

In parallel, scale matters too. While there is a case to be made for example for pilots – comparable with pilot auctions for the Industrial Decarbonisation Bank – it is important to ensure that demand reaches scale very quickly. Investment will not be triggered through marginal demand.

Industrial stakeholders highlighted that demand-side instruments will need to be mandatory, primarily to create long-term predictability. In order to generate robust investment signals, rules for lead markets, notably the incentive will need to be mandatory. Multi-billion investment decisions are not likely to be taken on the basis of rules that are applied voluntarily.

At the same time, lead markets are a complement and not a silver bullet. Lead markets cannot be a substitute for other policies, notably support for scale-up and early deployment of innovative technologies, such as for example batteries or steel. The objective of lead markets is to make a project investable by creating demand. Lead markets are not independent of energy prices and costs, restrictions, functioning markets, carbon leakage protection, trade policies, for example to address global overcapacity and dumping, subsidies, or support for innovation or infrastructure policy. Many stakeholders insist on regulatory alignment of the different tools, coherence as well as transparency.

Commonly agreed approaches for quantifying carbon embedded in products are a central element of an enabling framework for lead market instruments to be effective. However, consistent carbon footprint metrics are not sufficient to guide the transition towards alternative carbon in the chemical industry alone. The objective should be foremost to progressively shift away from virgin fossil carbon. Therefore, additional methodologies are required that allow embedded carbon to be quantified *and* carbon content to be differentiated by origin, complemented by sustainability criteria that assess the environmental impacts of the relevant products and materials beyond GHG emissions (See also Section 4).

5.2. EXISTING AND NEW INSTRUMENTS

To date a number of policy options are already being used to stimulate demand, such as labelling, public procurement or mandatory targets. For the specific case of alternative carbon, certification or credit-based approaches have been added to the list.

Voluntary labelling and public procurement are among the main tools considered in the EU's broader strategy to support lead markets for clean products and materials. As outlined in the Clean Industrial Deal, combining voluntary labels with public procurement guidelines can be a way to reinforce demand signals and scale up the uptake of clean materials and products across industrial value chains. While both instruments are well established within the EU policy framework, their practical relevance for alternative carbon varies by feedstock type (See also Section 3.2.1).

Voluntary labelling

Voluntary labels aim to enable differentiation based on specific attributes, such as environmental performance or climate impact. In the context of the chemical industry, this includes for example information on the share of bio-based or recycled content relative to virgin fossil-based alternatives.

At EU level, the most established voluntary label scheme is the EU Ecolabel, which has been in place since 1992 and is awarded to products and services meeting certain environmental standards. It is predominantly used for final consumer goods and covers a wide range of products, including paints and varnishes, paper products and cleaning supplies. It is also explicitly acknowledged under EU Green Public Procurement guidelines to promote uptake of certified products[104]. Beyond consumer goods and services, the Clean Industrial Deal, outlines plans to develop EU-wide voluntary labels for industrial products under the Industrial Accelerator Act. Initial attention is placed on low-carbon concrete, with the aim of certifying carbon intensity and potentially linking such labels to public procurement.

At present, there is no official EU label specifically covering alternative carbon across feedstocks comprehensively. However, European standards have been developed for some individual feedstocks, including biomass and recycled materials. For bio-based products, the official CEN Standard EN 16785-1 provides a harmonised methodology to certify the bio-based content of products[105]. For mechanically recycled content, EN 15343:2007 provides traceability and content calculation methods in plastic products[106]. For chemically recycled content, the European Commission is developing an EU-wide methodology under the Single-Use Plastics Directive, establishing mass balance rules and third-party verification requirements. This framework is expected to serve as a reference for future standards in packaging, textiles, and automotive sectors (See Section 3.2.2)[107]. For CCU, no EU-wide standards exist yet. Methodologies for carbon use in products are being developed under the Carbon Removal Certification Framework – although short-cycle chemical products are outside of the scope of for now (See Section 3.2.3).

Private sector certification schemes such as ISCC PLUS and RedCert² verify sustainability and traceability requirements along supply chains, supporting claims on product content. They use different chain-of-custody models, ranging from physical segregation over controlled blending to mass balance[108] (See also Section 4.1).

Overall, the landscape of voluntary labels and certification schemes is characterised by proliferation. According to the European Commission there are more than 230 sustainability labels in the EU and more than half of 'green claims' are considered to provide information that is 'vague, misleading or unfounded'[109]. To address this, the European Commission proposed the Green Claims Directive in March 2023, to require companies to substantiate and independently verify any environmental claims, including those made through voluntary labels.

The demand impact of voluntary labels depends strongly on consumers' and businesses' willingness to pay. Evidence from a recent Eurobarometer finds that almost 60 % of EU citizens are willing to pay more for sustainable products[110]. Yet, behavioural studies consistently show a gap between stated and actual behaviour, known as the 'intentionaction gap' where consumers overstate their green preferences in surveys but revert to price-driven choices in reality[111].

The contribution of voluntary labels to demand creation for alternative carbon is most likely limited. Labels can support product differentiation, but they do not address the gap between stated willingness to pay and actual purchasing behaviour. Their use also carries reputational risks where sustainability claims rely on unclear definitions or accounting approaches.

In addition, adding new voluntary schemes alongside mandatory reporting and product rules could increase administrative complexity, particularly in the absence of clear alignment on definitions, scope and verification methods. That said, voluntary labels could be implemented relatively quickly, and used alongside public procurement to enhance their impact on demand creation.

Public procurement

To strengthen demand for voluntary labels, they can be linked to public procurement frameworks, which can provide more predictable and sizeable demand beyond purely voluntary uptake. Public procurement refers to public authorities purchasing goods and services. Public authorities are major purchasers in sectors such as healthcare, transport infrastructure, construction and public services, where procurement accounts for a substantial share of demand[112]. Public procurement is a significant driver of demand driver in Europe, accounting for roughly 14 % of EU GDP (around EUR 2 trillion annually), according to estimates by the European Court of Auditors[113].

The principal framework consists of the Public Procurement Directives, such as Directive 2014/24/EU[114], which apply to public contracts above certain EU procurement value thresholds. These directives are transposed into national law by Member States and implemented by contracting authorities at national, regional and local level. Contracts below EU thresholds are subject to national rules and some general EU principles in certain cases[115]. The European Commission has announced a review of the EU public procurement framework, with a legislative proposal expected in 2026[116].

The integration of environmental considerations into procurement procedures is commonly referred to as Green Public Procurement (GPP). At EU level, GPP is supported through non-binding guidance and the development of common GPP criteria for selected product groups, intended to assist contracting authorities in integrating environmental considerations into tender procedures. While EU procurement law explicitly allows environmental and social criteria to be included in technical specifications, award criteria and contract performance clauses, their use remains voluntary[117]. The voluntary nature of GPP has contributed to uneven implementation across Member States and contracting authorities. In practice, many public contracts continue to be awarded primarily on the lowest price[118,119].

For the chemical sector, the impact is more indirect, as public procurement typically concerns chemical-intensive products and services, such as cleaning agents and construction materials, rather than basic chemical feedstocks as such[120,121]. This means that the potential of public procurement to act as a demand driver for alternative carbon in the chemical industry is concentrated in specific downstream market segments.

Public procurement is generally recognised as having greater potential to create more robust demand signals than voluntary labelling. However, procurement volumes relevant to chemical value chains are limited, and the capacity of public authorities to assess and apply environmental criteria varies.

Mandatory targets

Mandatory targets can create demand by requiring those that are obligated, for example wholesalers or retailers, to fulfil certain requirements for the products they place on the market. In the case of alternative carbon, this includes for example mandating a minimum share of alternative carbon in products, such as recycled or bio-based content.

The effects of mandatory targets on demand creation depend strongly on their design. Relevant design options include:

- Mandatory targets can be introduced as horizontal requirements applying across sectors or product-specific obligations within individual pieces of legislation.
- Targets may begin at relatively low levels and increase gradually, or they may have more stringent requirements from the start.
- Targets can be defined in a technology-specific manner, for example, focusing exclusively on recycled content, or they can be designed as technology-neutral instruments that allow different sources of alternative carbon to count toward compliance.
- Targets can be imposed at different points along the value chain, including at the level of feedstocks, intermediate materials such as polymers, or final products placed on the market.

In the EU, mandatory targets are already embedded in several product-specific frameworks and continue to evolve, most notably in packaging, batteries and vehicles. To date, these instruments have focused particularly on recycled content, such as for packaging and packaging waste. Similar targets exist for batteries and are proposed for vehicles (see Section 3.2.2). The extension of content requirements to bio-based chemicals is being considered, as illustrated in the updated Bioeconomy Strategy (see Section 3.2.1).

Generally, mandatory targets are widely regarded by stakeholders as a suitable demand-pull instrument to create a business case for alternative carbon feedstocks in the early stages of the transition. They can provide the necessary certainty for investments when target levels and trajectories are clearly defined and perceived as reliable. Even relatively modest initial targets can support investment if embedded in a stable long-term framework. However, their effectiveness depends strongly on design features.

Several design choices arise in this context. One concerns the technological scope of targets. Technology-specific targets were viewed as potentially useful in supporting the transition in its early stages, but less so over longer time horizons. Technology-neutral targets, by contrast, were seen as allowing greater flexibility and cost optimisation once multiple alternative carbon pathways are available at scale.

Another design choice relates to the level of application. Product-level mandatory targets are generally considered suitable for spreading the ‘green’ premium of alternative carbon across a broad range of products, thereby reducing the price impact on individual products and pulling demand through upstream value chains. Feedstock-level targets are administratively simpler but may raise challenges regarding cost pass-through along value chains and competition with imported products.

Compliance obligations, monitoring systems and enforcement are necessary to ensure that targets translate into real demand signals for alternative carbon. This requires a workable accounting framework (See also Section 4).

At the same time, stakeholders highlighted potential limitations. Some point out that quota-based approaches may involve efficiency trade-offs, as it is difficult to determine in advance where alternative carbon could be used most efficiently across applications. In addition, targets are typically implemented at the end of value chains, creating demand at the level of regulated products, which may not automatically translate into sufficient demand for alternative carbon feedstocks upstream. Lastly, the distribution of costs through the value chain was considered to require further analysis. The answer to where and at what level such targets should be set therefore needs to be firmly grounded in stakeholder consultations.

New tools and measures

In addition to existing policy instruments such as voluntary labels, public procurement and mandatory targets, new concepts building upon certificates are being discussed. Initial ideas have been proposed by different industry actors, including Shell and the Südzucker Group[xi].

They differ in scope, underlying accounting logic and their primary focus on alternative carbon versus broader industrial decarbonisation. The proposal put forward by Shell focuses on financing verified emission reductions across energy-intensive value chains. It would do so through mandatory purchase obligations for certificates linked to decarbonisation outcomes. While the approach does not target alternative carbon feedstocks directly, it could be extended to include circular or bio-based content requirements (Box 4).

The proposal of a 'Carbon Utilisation Trading System' by the Südzucker Group is more focused on alternative carbon in chemicals and materials. It is based on a certificate system using a book-and-claim accounting framework which separates physical material flows from sustainability claims. The system is designed to create scarcity over time, leading to a price signal that strengthens demand for non-fossil carbon certificates (Box 5).

Another model brought forward by industry stakeholders rests on an Extended Producer Responsibility concept[xii]. Under this approach, industries closest to the consumer would be required to pay a uniform climate fee on all products placed on the EU market, irrespective of carbon content. The revenues would be pooled into a central fund and allocated to upstream industrial decarbonisation or transition projects, potentially aligned with sector specific targets. The model establishes a uniform compliance obligation with designated revenue use and does not rely on certificate trading or product-level carbon accounting. Further design elements remain under discussion.

[xi] The proposals discussed in this section remain at an early or conceptual stage of development and have not been translated into concrete legislative initiatives. Accordingly, this section briefly outlines the core functioning of the proposals and summarises the stakeholder perceptions during interviews conducted in the course of this project.

[xii] This proposal was brought forward during stakeholder interviews carried out for this project. Given its ongoing development and the absence of a formal public proposal, it is mentioned here to reflect the range of views expressed but is not examined further.

Box 4. An emission reduction crediting mechanism for the clean industrial transition by Shell

In the proposal put forward by Shell[xiii], parties closest to the consumers (e.g. brand owners) would be required to buy sector-specific abatement credits that correspond to verified emission reductions in the respective value chains of energy-intensive industries such as chemicals, steel, and cement. These credits would be generated by industrial decarbonisation projects of upstream producers in Europe, and would be audited and certified against agreed upon baselines.

In practice, companies closest to the consumer would have to cover their share of the emission reductions required under sectoral targets through credits, calculated relative to their sales volume. In case of non-compliance, obligated parties would face a penalty, plus the cost of the required abatement credits.

Obligations could increase over time in line with sectoral climate targets. For example, regulators could set benchmarks of 20 % reduction after 5 years and 40 % after 10 years, with the required number of credits rising accordingly, thus creating a future trajectory for credit demand. To facilitate the transition to alternative carbon, the scope of targets and eligible projects could be extended to include requirements related to circular or bio-based content and projects aimed at scaling up these pathways.

Revenues from credit purchases would flow to upstream decarbonisation projects, creating a dedicated financing channel for industrial transformation in Europe. With regard to trade, importers would be subject to the same obligations as EU producers, while exports would remain outside the scope of the system.

[xiii] A description of the policy proposal can also be found here: Shell (n.d.), *Demand-side market strategies for energy-intensive industries in Europe*, Shell Chemicals. Available at: https://www.shell.com/business-customers/chemicals/resources/demand-market-strategies-for-energy-intensive-industries/_jcr_content/root/main/section/text/links/item0.stream/1751401053845/4f97deb5e9cfe0b422133c02b87da24bfae7bfc4/demand-market-strategies-for-energy-intensive-industries-in-europe.pdf

Box 5. A trading system for alternative carbon certificates by Südzucker Group

In the proposal by Südzucker Group[xiv], companies closest to the consumer, such as distributors of consumer goods, would be required to surrender certificates covering the embedded carbon in their products. This obligation would apply regardless of whether the carbon used is fossil or non-fossil.

Certificates could be obtained either from a regulatory authority or from producers placing non-fossil carbon products on the market, including products based on sustainable biomass, recycling or captured CO_2 from industrial processes[xv] or the atmosphere.

Upstream producers of non-fossil carbon feedstock would receive certificates free of charge equal to their production volume, which they could sell to downstream actors, helping to offset higher production costs. For compliance purposes, certificates from different sources would be interchangeable, while certificates linked to non-fossil carbon could additionally be used for sustainability claims.

To strengthen demand over time, the proposal introduces scarcity through a declining volume of certificates. This would create a price signal that increases over time, enhancing incentives for upstream producers to invest in non-fossil carbon production. For trade, importers would be required to surrender certificates for imported products, while exports would remain outside the scope of the system.

These concepts have been put forward in response to the disadvantage faced by alternative carbon under current regulatory and market conditions, for example due to only limited coverage and levels of carbon pricing or additional certification requirements and costs associated with more sustainable products compared to fossil-based counterparts. They aim to go beyond product-level measures to create demand at scale and channel financial resources across value chains into clean production investments upstream and improve the competitiveness of low- and alternative-carbon products.

[xiv] A description of the policy proposal can also be found here: Renewable Carbon Initiative (RCI) (2025), *RCI Policy Proposals for Facilitating the Transition to Renewable Carbon*, April 2025, 70 pp., with DOI: 10.52548/DZRU4577. Available at: https://renewable-carbon.eu/publications/product/rci-policy-proposals-for-facilitating-the-transition-to-renewable-carbon-pdf/. The Industrial Bioeconomy Dialogue Platform of the German Federal Ministry for Economic Affairs and Energy has also examined the concept. The final report can be found here: VDI Technologiezentrum, *Positionspapier der AG 1: Zertifikatehandel*, Dialogplattform Industrielle Bioökonomie, n.d. Available at: https://biooekonomie.vdi-tz.de/-lp/vXLXr29363/1y53p250

[xv] Only non-fossil recycled carbon and non-fossil captured CO_2 are considered in this context.

In this respect, the proposals relate to several challenges identified in Section 2, including the persistent cost gap between alternative and virgin fossil carbon, the limited market uptake of commercially available alternatives, and the difficulty of establishing a robust business case for upstream investment in new feedstock routes, production capacity and related infrastructure. Their design also reflects sector-specific characteristics, such as the high degree of integration of chemical value chains, the limited physical traceability of carbon once processed, and the fact that product-level measures may not always translate into financial incentives for upstream stages where transformation investments occur.

Industry is showing interest, although it depends on design choices. In this context, stakeholders highlighted a number of aspects for further discussion, including on safeguards, such as robust verification and monitoring.

Downstream and midstream companies have expressed reservations regarding the extent to which mandatory certificate or credit purchase obligations incentivise investment in new production capacities and technologies. There is concern that this could function primarily as a mechanism to pass on costs as opposed to translating into effective support for upstream investment in the transformation and scaling-up of production capacities.

Other stakeholders have pointed to the risk of double payment, where firms face higher prices for alternative carbon feedstocks while also being required to purchase certificates or credits.

Controversies arose over the risks that price uncertainty could create. There is a concern that volatile or unpredictable certificate or credit prices could undermine the business case for investment..

More broadly, there is a general acknowledgement that approaches decoupling certificates from physical products risk enabling misleading claims unless carefully designed. Reputational backlash and loss of public trust was considered as a risk to undermine not only individual schemes but broader transition efforts.

While some stakeholders acknowledged that, in principle, such mechanisms could mobilise financial flows at scale by monetising sustainability attributes or emission reductions, others doubted that they could be designed, legislated and implemented fast enough to influence near-term investment decisions in capital-intensive sectors such as chemicals.

Finally, administrative requirements remain a central issue. They require new registries, certification systems, verification procedures and dedicated governance structures.

There are concerns that additional reporting requirements risks duplicated reporting and certification obligations, layered on top of existing product, sustainability and reporting requirements. Downstream actors stressed that, without significant streamlining and alignment, system-level approaches risk increasing administrative costs without delivering proportional benefits.

5.3. INDIVIDUAL POLICY INSTRUMENT ROLES AND SCOPE FOR SYNERGIES

When assessed against the principles and enabling frameworks for lead markets, stakeholder perspectives suggest that existing and emerging policy instruments may fulfil different, potentially complementary, roles during the transition.

Voluntary labelling and certification schemes are considered to be relatively fast and flexible tools. They can be introduced comparatively quickly and support transparency and product differentiation. However, their ability to achieve scale and provide investment certainty is more limited. Because they rely on voluntary uptake and willingness to pay, their impact to create demand is inherently uncertain. As discussed in Section 2, the main constraint for alternative carbon pathways is not technology but cost competitiveness. Instruments that rely on voluntary price premiums are therefore unlikely to generate the stable and predictable demand needed for capital-intensive investments in biorefineries, advanced recycling or CCU infrastructure. Voluntary schemes can support the transition, but they are not sufficient to create investable business cases on their own.

Green public procurement could play a stronger role – and also be combined with voluntary labels, as considered for low-carbon industrial products by the European Commission. Public authorities can aggregate demand and send clearer signals than individual consumers. Where procurement criteria include recycled or bio-based content, early markets can be supported in specific applications such as construction materials, packaging or textiles. Nonetheless, public procurement can reach only limited scale given its niche role for the chemical industry. Its effectiveness depends on implementation at national and local level and on moving beyond lowest-price criteria. As shown in Section 2, the feedstock transition requires substantial investment in upstream production and processing capacities across the industry. Public procurement usually covers only downstream chemical products in certain market segments. Its impact on shifting feedstocks is therefore uneven across the value chains. Procurement can reinforce demand in specific segments, but will need to be complemented by other instruments to achieve a large-scale feedstock transition in the industry.

Mandatory content targets embedded in product legislation, as already implemented or planned for recycled or bio-based carbon, can create predictable demand. When accompanied by reliable long-term target trajectories, they can provide the investment certainty required for scaling up alternative carbon pathways. Given the cost gaps described in Section 2, sustained demand at sufficient volume is central for investment decisions. Well-designed mandatory targets can address this, particularly if applied beyond niche markets. To generate volumes large enough to influence upstream investment decisions, such targets would need to apply broadly across product groups and value chains, while taking into account what is technically and economically feasible. Technology-specific quotas may accelerate certain pathways in the early stages, but they can reduce flexibility and increase costs over time. Technology-neutral targets may allow cost optimisation once several pathways are mature. The choice between specificity and neutrality is therefore political and should reflect the stage of technological and market development. To effectively support the transition mandatory target, need to be implemented broadly to create sufficient demand for the feedstock transition upstream. As with other demand-side instruments they would likely require complementary supply side support (See section 4.1)

Certificate- or credit-based systems represent a broad approach to the industrial transition, going beyond demand-creation. By creating tradable certificates linked to carbon content or verified emission reductions, they aim to mobilise financial flows across value chains. In theory, such systems could enhance cost-efficiency and establish an industry-level mechanism for the transition, going beyond product-level demand creation. Such systems could help address structural limitations that lead markets alone may not resolve. With regard to speed and regulatory coherence, these proposals face challenges. They require new governance structures, registries and verification mechanisms, and would need to be carefully reviewed to determine the extent to which they can be integrated with existing frameworks, notably the EU ETS and product legislation, to avoid double regulation or conflicting incentives. Investment certainty is also a concern. Price volatility in certificate markets may weaken business cases unless stabilisation mechanisms are in place. At the same time, if designed with clear and reliable financial signals, such systems could reduce the structural disadvantage of non-fossil feedstocks under current market conditions. While these approaches could evolve into a large-scale solution in the medium to long term, their feasibility in the short term appears more limited compared with adapting and strengthening existing product legislation. As raised by stakeholders, several design considerations require further discussion (Section 5.2).

Table 2. Overview of lead market instruments in relation to core principles

Principle	Voluntary labelling	Public procurement	Mandatory content targets	Certificate / credit systems
Investment certainty	Dependent on voluntary uptake and willingness to pay; demand signals may fluctuate	Provides more predictable demand within specific public purchasing segments	Creates legally binding demand if targets and trajectories are clearly defined	Potential to structurally improve competitiveness of alternative carbon. Depends on design features such as scope, price formation and stabilisation mechanisms
Speed	Can be introduced comparatively quickly, especially where standards already exist to build on	Requires alignment of procurement rules and implementation capacity across authorities	Requires legislative process but can build on existing product legislation. Requires extension of monitoring and verification systems	Requires development of new/extension of existing governance structures, registries and monitoring and verification systems
Scale	Typically concentrated in niche or consumer-facing markets	Limited to product groups where public authorities are significant buyers but dependent on fiscal space and policy priorities	Can apply across broad product groups and value chains if embedded in horizontal or product legislation	Scalable across value chains and industries, depending on system design
Mandatory character	Voluntary by design	EU green public procurement guidelines remain voluntary	Binding compliance obligation for mandate-holders	Binding if structured as a compliance-based trading or certificate obligation
Regulatory coherence	Risk of fragmentation without harmonised EU definitions and verification rules	Embedded in EU procurement framework but implementation varies between Member States	Requires harmonised accounting methodologies to ensure legal certainty and comparability	Needs careful review of potential to align with EU ETS, product regulation and reporting frameworks to avoid overlap or inconsistencies

Source: Authors' own elaboration based on desk research and stakeholder interviews and workshop conducted for this study.

The analysed policy instruments should not be considered in isolation. A combination of tools may improve effectiveness and reduce trade-offs. Mandatory content targets can provide predictable demand and form the structural backbone of the early transition. Public procurement can support scaling markets in selected applications. Voluntary labels can enhance transparency and help establish accounting methodologies and sustainability criteria. Certificate-based mechanisms could over time, if carefully designed and integrated, link these elements and channel financial flows across value chains.

The integration of these options into the existing EU policy landscape is essential. The Bioeconomy Strategy already signals potential bio-based content requirements. The Circular Economy framework provides precedents for recycled content targets and is developing mass balance approaches as methodological foundation. The Industrial Carbon Management Strategy and the forthcoming ETS review offer entry points for strengthening the role of CCU. In addition, the proposed Industrial Accelerator Act empowers the European Commission to introduce EU-level demand-side measures for products derived from sustainable carbon through delegated acts. As the specific instruments remain undefined, this provision creates a broad enabling framework for the future development of demand-creation measures. In this context, industry proposals can be further examined and refined to address open design questions and assess how they could fit within the evolving EU policy framework.

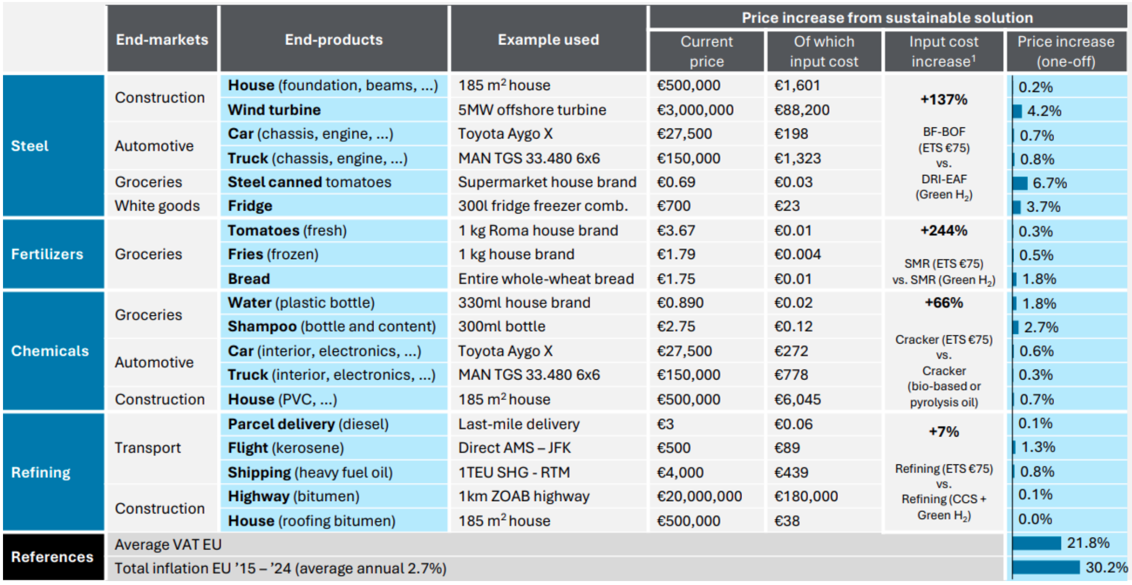
As noted in Section 4.1, common methodologies are a central enabler for any instrument to effectively create demand for alternative carbon. Without a functioning accounting system that underpins the flow of alternative carbon through chemical value chains, the proposed instruments may create legal uncertainty and administrative burden. To avoid delaying the transition, a pragmatic approach to mass balance will be needed at an early stage of the transition to support such policies – with a clear objective to increase robustness over time (See also Section 4.2).

5.4. POTENTIAL COSTS

Potential cost implications emerged as a cross-cutting concern among many stakeholders across policy options. Questions were raised not only about the level of additional costs associated with alternative carbon pathways, but also about how these costs might be distributed along value chains and affect competitiveness. At present, empirical evidence remains limited, with only a small number of studies attempting to quantify potential impacts. One such analysis, conducted by Deloitte in cooperation with industry, provides indicative estimates of possible price effects of shifting to more sustainable materials across different industries, including chemicals into final prices across a range of consumer and industrial goods[122].

This study finds that even substantial increases in input costs due to using more sustainable materials could result in relatively modest price effects at the level of final products across the industrial value chains analysed, suggesting some scope to absorb or distribute the associated 'green' premium (Figure 12).

Figure 12. Price scenarios for selected industrial products and consumer goods using sustainable materials.



	End-markets	End-products	Example used	Price increase from sustainable solution			
				Current price	Of which input cost	Input cost increase[1]	Price increase (one-off)
Steel	Construction	**House** (foundation, beams, ...)	185 m² house	€500,000	€1,601	**+137%** BF-BOF (ETS €75) vs. DRI-EAF (Green H_2)	0.2%
		Wind turbine	5MW offshore turbine	€3,000,000	€88,200		4.2%
	Automotive	**Car** (chassis, engine, ...)	Toyota Aygo X	€27,500	€198		0.7%
		Truck (chassis, engine, ...)	MAN TGS 33.480 6x6	€150,000	€1,323		0.8%
	Groceries	**Steel canned** tomatoes	Supermarket house brand	€0.69	€0.03		6.7%
	White goods	**Fridge**	300l fridge freezer comb.	€700	€23		3.7%
Fertilizers	Groceries	**Tomatoes** (fresh)	1 kg Roma house brand	€3.67	€0.01	**+244%** SMR (ETS €75) vs. SMR (Green H_2)	0.3%
		Fries (frozen)	1 kg house brand	€1.79	€0.004		0.5%
		Bread	Entire whole-wheat bread	€1.75	€0.01		1.8%
Chemicals	Groceries	**Water** (plastic bottle)	330ml house brand	€0.890	€0.02	**+66%** Cracker (ETS €75) vs. Cracker (bio-based or pyrolysis oil)	1.8%
		Shampoo (bottle and content)	300ml bottle	€2.75	€0.12		2.7%
	Automotive	**Car** (interior, electronics, ...)	Toyota Aygo X	€27,500	€272		0.6%
		Truck (interior, electronics, ...)	MAN TGS 33.480 6x6	€150,000	€778		0.3%
	Construction	**House** (PVC, ...)	185 m² house	€500,000	€6,045		0.7%
Refining	Transport	**Parcel delivery** (diesel)	Last-mile delivery	€3	€0.06	**+7%** Refining (ETS €75) vs. Refining (CCS + Green H_2)	0.1%
		Flight (kerosene)	Direct AMS – JFK	€500	€89		1.3%
		Shipping (heavy fuel oil)	1TEU SHG - RTM	€4,000	€439		0.8%
	Construction	**Highway** (bitumen)	1km ZOAB highway	€20,000,000	€180,000		0.1%
		House (roofing bitumen)	185 m² house	€500,000	€38		0.0%
References	Average VAT EU						21.8%
	Total inflation EU '15 – '24 (average annual 2.7%)						30.2%

Source: Deloitte (2025)[123].

Results however are highly dependent on assumptions regarding technology costs, energy prices, carbon pricing and cost pass-through along the value chain. Notably, more analysis is needed to account for real-world conditions such as long-term offtake agreements, competitive pressures from imports, or how costs are distributed across different segments of the value chain. Furthermore, it does not consider the potential aggregate effects of price increases accumulating along the value chain and on final consumers. Even so, the study provides a useful indication of potential orders of magnitude and should be complemented with further analysis to better understand cost impacts and distribution of demand creation instruments along the chemical value chain in more detail.

6. THE WAY FORWARD

Looking ahead, a phased approach may offer a structured pathway for transitioning feedstocks in the chemical industry.

In the short term, priority should be given to finalising a pragmatic approach to methodologies for differentiating the origin of carbon, such as through mass balance accounting. This approach should then be integrated into a roadmap aimed at improving robustness over time. In parallel, mandatory content requirements could be expanded or reinforced in selected product groups. As suggested in the Bioeconomy Strategy, this could include bio-based content requirements. Since such requirements are generally mandated for downstream products, their effectiveness will depend on whether they can create a credible and sufficiently strong demand signal for upstream producers to invest. They would therefore need to go beyond niche markets. Aligning public procurement criteria with such requirements could reinforce initial demand. The forthcoming review of the EU public procurement framework provides an opportunity to consider such approaches, with the European Commission already identifying procurement as a potential lever to support uptake of bio-based materials.

At EU level, the proposed Industrial Accelerator Act introduces a provision empowering the European Commission to adopt delegated acts establishing EU-level demand-side measures for products derived from sustainable carbon sources. As the specific instruments remain to be defined, this provides a policy window to examine how existing approaches, including content requirements or procurement criteria, might be further developed and scaled up across relevant product groups and value chains. In this context, the EU framework should aim to create enabling conditions for the emergence of new business models and clean technologies. At the same time, further analytical and design work could be undertaken to address open questions surrounding certification or credit-based mechanisms, including governance structures, safeguards and interaction with existing instruments and policy frameworks, Clarifying these elements would provide a basis for clarifying their potential role within the broader transition pathway.

Achieving sufficient scale in the short term will be essential to influence investment decisions towards alternative carbon pathways and support the transition of the chemical industry. Cost impacts should be closely monitored. Impact assessments can help to better understand cost implications across value chains. Gradual phase-in periods and, where necessary, complementary measures may also be required to safeguard competitiveness and avoid carbon leakage.

In the medium term, as alternative carbon pathways mature and volumes increase, content requirements could be broadened to move towards more technology-neutral designs, provided robust sustainability criteria are in place. Based on earlier analytical work, the feasibility and added value of integrating certificate- or credit-based mechanisms could then be reassessed. Their interaction with carbon pricing instruments, including the EU ETS, and with trade measures would require careful calibration to ensure policy coherence and avoid regulatory overlap.

In the longer term, as volumes of alternative carbon pathways increase and physical segregation becomes economically and technologically feasible, accounting approaches such as mass balance may gradually be phased out. Periodic review mechanisms should therefore be embedded from the outset to allow adaptation as technologies and markets evolve.

Different actors have distinct roles in this process. At EU level, the primary responsibility lies in ensuring regulatory coherence, methodological harmonisation and ambitious yet realistic long-term trajectories. Member States play a central role in implementing public procurement guidelines. Industry engagement to contribute to determining suitable product groups for lead markets, defining methodologies and accounting systems, and setting realistic targets will shape the pace and scale of the transition. Associations and civil society can facilitate continued stakeholder exchange to strengthen the robustness of lead market frameworks and further develop the toolkit of instruments to create demand and underlying accounting mechanisms.

Overall, the central challenge is the coherent design, sequencing and integration of policy instruments. Creating lead markets for alternative carbon requires instruments that are credible, scalable and aligned with the EU's broader vision for the chemical industry. A gradual strengthening of existing demand-creation measures, grounded in pragmatic accounting approaches that can be made more robust over time, appears to offer a practical pathway to initiate the transition and avoid any delays. In parallel, broadening their scope or complementing them with additional tools could be further explored to ensure that demand creation reaches the scale required for the transition.

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