Department for Energy Security & Net Zero

Unlocking Resource Efficiency

Phase 2 Chemicals Report

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Any enquiries regarding this publication should be sent to us at: Resource_efficiency@energysecurity.gov.uk

Contents

List of Tables

Introduction

The Department for Energy Security and Net Zero (DESNZ) and the Department for Environment, Food and Rural Affairs (DEFRA) commissioned Eunomia Research and Consulting to undertake a research project exploring the potential benefits from increasing resource efficiency in the UK. This report outlines the findings of this research for the chemicals sector.

For the purposes of this report, resource efficiency is defined as any action that achieves a lower level of resource use for a given level of final consumption. This can occur at any stage of the supply chain including production, consumption, and end-of-life. While material substitution may not always meet the definition of resource efficiency set out above, it is in scope of this research where it reduces whole life carbon.

This research was conducted in the second half of 2023, and reports were written in November 2023. As such, this report does not reflect sector developments beyond that point. Technical experts were consulted as part of research activities for this report. The following report reflects our understanding of the available evidence and is accurate to the best of our knowledge; however, if any factual errors are encountered, please contact us at Resource_efficiency@energysecurity.gov.uk.

Methodology

This aim of this research was to achieve four key objectives:

- Identify a comprehensive list of resource efficiency measures for each sector;
- Identify current and anticipated drivers and barriers which are affecting improvements in the identified resource efficiency measures in each sector, and their relative importance;
- Build consensus estimates for the current “level of efficiency” and maximum “level of efficiency” in 2035, for each of the identified resource efficiency measures in each sector; and
- Identify the extent to which industry is currently improving resource efficiency and build consensus estimates for the likely “levels of efficiency” in 2035 given current private sector incentives and the existing policy mix (a “business-as-usual” scenario), for each of the identified resource efficiency measures in each sector.

To achieve these research objectives, a mixed-methods methodology was developed. A literature review was conducted for each sector to synthesise evidence from the existing literature relevant to these objectives. In parallel, stakeholder interviews were conducted with industry and academic experts in each sector to test literature findings and fill any outstanding evidence gaps. A summary of findings was then presented and validated at sector-specific facilitated workshops with sector experts.

This project did not aim to identify policy recommendations but rather understand the potential for resource efficiency in the UK. It should be noted that some areas covered as part of the research fall under the responsibility of devolved nations of the UK; however, all reports cover the UK as a whole for completeness.

This project has attempted to identify three level of efficiency estimates for each resource efficiency measure:

- The **current level of efficiency** which is the best estimate for the current level of efficiency of the measure i.e., what is happening in the UK now (in 2023);
- The **maximum level of efficiency** which is the maximum level of efficiency that is technically possible by 2035 in the UK, without factoring in barriers that could be overcome by 2035 i.e., what is the maximum level that could be achieved; and
- The **business-as-usual (BAU) scenario** which is the level of efficiency that would be expected in the UK by 2035 with the current policy mix and private sector incentives i.e., what would happen if there were no substantial changes in the policy or private sector environment.

These levels of efficiencies have been identified to understand the potential for resource efficiency and do not represent government targets.

To estimate these levels of efficiency, indicators have been developed for each of the identified measures. These indicators have been chosen based on how well they capture the impact of the relevant measure, and how much data there is available on this basis (both in the literature review and from expert stakeholders).

For some measures, the current level of efficiency is baselined to 2023. This is not an indication of historic progress, but rather has been done in order to understand the potential for further progress to be made (in the maximum and BAU scenarios) where it was not otherwise possible to quantify a current level of efficiency.

Note, the purpose of the indicators in this research is so estimates on the current, maximum and BAU level of efficiency can be developed on a consistent basis. They are not intended be used as metrics to monitor the progress of these resource efficiency measures over time, or to be used as metrics for resource efficiency policies.

A high-level overview of the research stages is presented below. A more detailed version of this methodology is presented in the Phase 2 Technical Summary which accompanies this publication.

Literature Review

The literature sources were identified through an online search, and through known sources from DEFRA, DESNZ, the research team, and expert stakeholders.

Once literature sources had been identified they were reviewed by the research team and given an Indicative Applicability Score (IAS) ranging from 1 to 5 which indicated the applicability of the sources to the research objectives of this study. This score was based on five key criteria: geography, date of publication, sector applicability, methodolo-gies used and level of peer review.

After the five criteria of the IAS had been evaluated, the overall IAS score was calculated, ranging from 1 to 5, according to the number of criteria scoring 'high' and 'low.'

A detailed overview of the parameters used to assess high / medium / low scores for each of the five criteria feeding into the IAS calculation and methodology for calculating the score can be found in Appendix A.

The research team drafted a rapid evidence assessment and literature summaries as part of interim reports for each sector which synthesised the best available evidence from the literature for each of the four research objectives. When drafting these summaries, literature sources with a higher IAS score were weighted more than those with a lower IAS score.

Stakeholder interviews

The findings from the literature review were presented to, and tested with, expert stakeholders from each sector through a series of stakeholder interviews. The interviews aimed to capture a range of sector experts from both academia and industry (covering different aspects of the value chain) but it should be noted this is not an exhaustive or representative sample of the sector. The purpose of these interviews was to test the findings of the literature review against stakeholder expertise, and to fill any evidence gaps from the literature.

Facilitated workshops

Following the completion of stakeholder interviews, one half-day facilitated workshop was conducted for each sector. Stakeholders who participated in interviews were given the chance to contribute to supplement and validate findings.

Stakeholders contributed through sticky notes in a shared virtual Mural board, by participating in the verbal discussions and by voting on pre-defined ranges on the levels of efficiency and the top drivers and barriers. They were also given the chance to contribute further information through a post-workshop survey. The stakeholders were asked to signal the level of confidence they had in their votes and were advised to vote for a 'don't know' option if they felt the information fell outside their expertise. It is possible however that some votes were cast in areas where stakeholders may not have had expertise, so caution is advised when interpreting the findings.

Finally, the findings of the literature review and the stakeholder engagement were combined to reach final conclusions against each research objective. For the estimates on the level of efficiency for each measure (Objectives 3 and 4), a five-tier evidence RAG rating was assigned to indicate the level of evidence supporting the proposed figures. Only where the datapoints were supported by literature sources with high IAS and a high degree of consensus amongst experts in the interviews and workshop*,* were the datapoints considered to have a "green" evidence RAG rating. The definitions are as follows:

- **Red:** Limited evidence available from literature review or stakeholders
- **Red-Amber:** Some evidence available from literature review but it is not relevant/out of date, Limited evidence from stakeholders, stakeholders are not experts on this measure

- **Amber:** High quality evidence from either literature or stakeholders
- **Amber-Green:** High quality evidence from literature or stakeholders, evidence from stakeholders is supported by some information in the literature (or vice versa)
- **Green:** High quality evidence from literature supported by stakeholder expertise.

It should be noted that the business-as-usual (BAU) level of efficiency was only informed by the stakeholder engagement, so the maximum evidence RAG rating for the BAU is amber.

Limitations

This report was commissioned by the Government to improve the evidence base on the impact of resource efficiency measures. The methodology is designed to provide robust answers to the research objectives, based on the best available evidence at the time the work was undertaken.

While every effort was made to be comprehensive in the literature review, it is inevitable that some relevant literature may not have been captured. A full list of all the literature reviewed is provided in the annexes of each sector report.

The feedback captured during the interviews and workshops represent the views of a sample of stakeholders from industry, trade associations and academia. Effort was made to ensure that interviews and workshops included a cross-section of stakeholders from each stage of the sectors' supply chain, representing a range of backgrounds and perspectives. It is, however, noted that capacity and scheduling limitations meant that some stakeholders, whose view would have been valuable to the research, were not able to participate. As such, the views expressed by research participants in this report are not representative of the sector as a whole.

A key research objective of this project is to estimate the level of efficiency of resource efficiency measures in 2035. Any future projections are inherently uncertain as they depend on a range of different factors such as technological innovation, consumer behaviour change and the macro-economic environment. The estimates from this research are the best estimates that could be produced, based on the current literature and stakeholder expertise. Evidence RAG ratings have been provided to indicate the level of supporting evidence for each of these estimates.

The report does not seek to make recommendations on the appropriate direction of Government policy or independent industry action. DESNZ and DEFRA will seek to conduct further engagement with stakeholders to inform the next steps for resource efficiency policy within Government, ensuring that any omissions or developments in the evidence reviewed in this report are taken into account.

Sector Introduction

General introduction

Chemicals play a crucial role in society and are present in almost all products we purchase, consume and use. The UK chemicals industry produces fundamental components for other manufacturing processes and substances used within final consumer mixtures and products, with chemicals used in over 90% of manufactured goods.[1] The primary chemical feedstocks are utilised in subsequent manufacturing to produce a diverse array of secondary downstream products, including polymers (that are essential for plastics), paints, detergents, personal care items, agrochemicals, adhesives, fragrances, lubricants, fuel additives, construction materials and catalysts, to name but a few examples.[2] The UK is also a global leader in pharmaceuticals.[3]

Chemical manufacturing is complex, with thousands of different substances and products, traded between hundreds of manufacturing sites across the UK and internationally. The types and application of chemical production processes are diverse but can generally be defined as being continuous or batch. Continuous chemical operations involve a continuous flow of materials through a production system, while batch operations process materials in discrete quantities, typically in separate, sequential steps.

To further aid the analysis in this report, the scoped chemical supply chain has been categorised into three broad manufacturing tiers:

- Companies engaged in **Tier 1** activities (such as SABIC, INEOS, Lanxess)[4] process basic feedstock into bulk commodity chemicals, often using energy-intensive continuous processes. These chemicals are foundational for all later stages and other production processes.
- Companies engaged in **Tier 2** activities (such as Huntsman, INEOS, Syngenta, Pfizer) take bulk commodity chemicals and undergo further chemical reactions or blending to create part/finished mixtures (refined primary chemicals) - an intermediate step in the process. There could be many intermediate steps within this tier with chemicals often being moved or traded between sites and/or regions. Batch processing is more prevalent in this tier than in Tier 1 which primarily comprises continuous processes, however continuous processes are still widely applied in Tier 2.
- Companies engaged in **Tier 3** activities (Such as CRODA, Dulux, Reckitt, Unilever), produce final formulations for end markets, incorporating them into articles (e.g., textiles), consumer products (e.g., shampoos, conditioners, hair dyes,) and industrial

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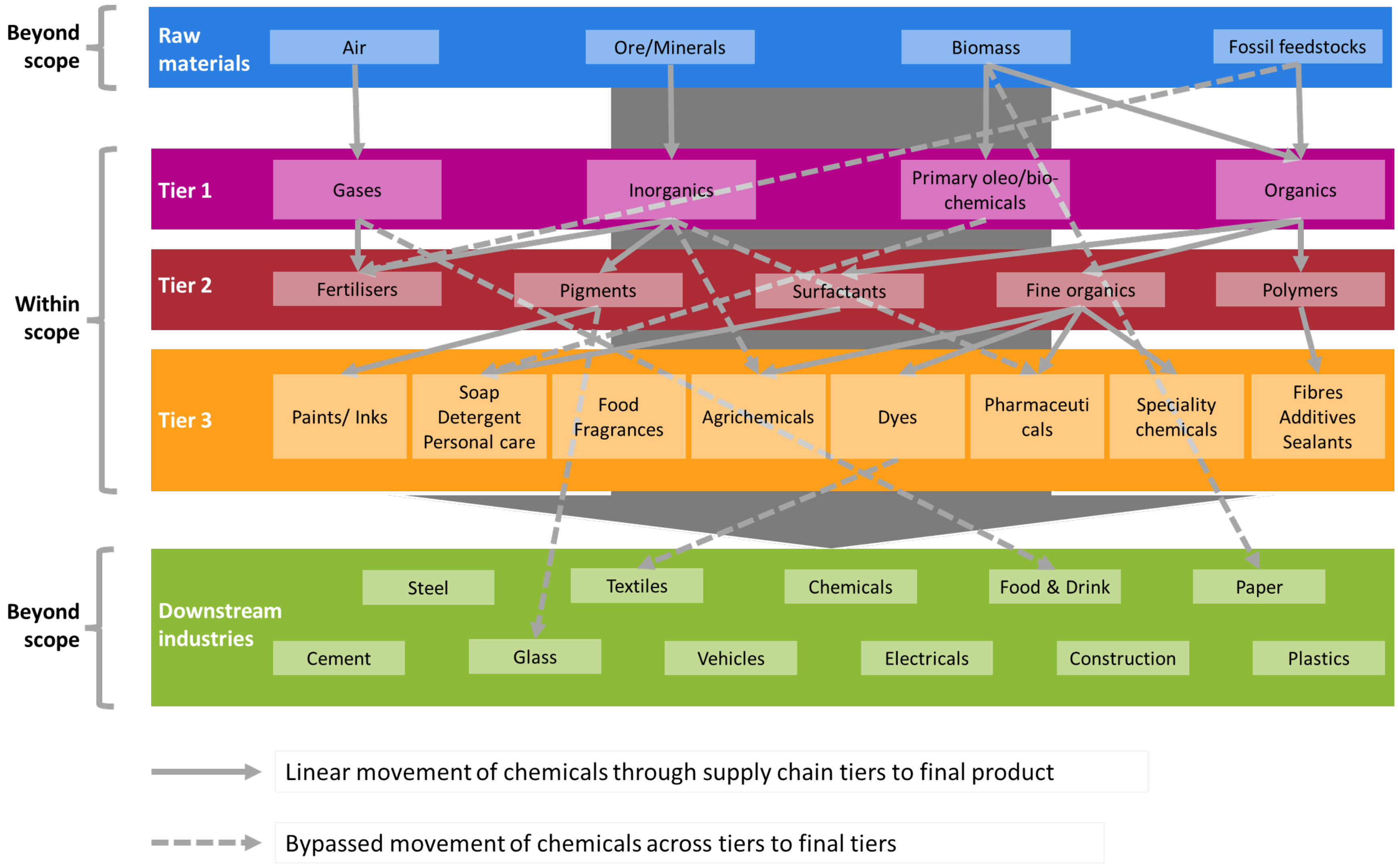
[1] Green alliance (2023) A new formula: Cutting the UK chemical industry's climate impact. Available at: link
[2] Cefic (n.d.) CHEMICAL INDUSTRY SNAPSHOT. Available at: link
[3] Cefic (n.d.) CHEMICAL INDUSTRY SNAPSHOT. Available at: link
[4] Note that we have defined the three tiers to provide a general steer on characterisation of production processes, types of company (size, style of manufacture, role in the market etc) and flow of substances down the supply chain. In practice it is entirely possible for a given company (e.g., INEOS, 3M, Dupont etc) to fulfil more than one tier of the chain. i.e., the manufacturing of refined feedstocks under tier 1 is used by the same company (not necessarily at the same location) to produce secondary substances or even final consumer mixtures etc.

products (e.g., metal working fluids). Tier 3 stands apart from Tier 2 as it delivers the final, ready-to-use products. Batch processing is most prevalent in this tier. The sector's complexity arises from these layers, each with distinct processes, contributing to the overall chemical manufacturing landscape.

The chemicals sector is therefore heavily interlinked with other consumer industries that have been investigated separately within the wider research project, as demonstrated in the figure below. Note that the interactions presented in this diagram are not exhaustive but demonstrate some of the complexities regarding the interactions between different tiers in the chemicals sector as well as upstream and downstream sectors. The downstream industries presented in this diagram are also not exhaustive. This figure demonstrates how other sectors investigated in the wider research project are interlinked with this sector study. Solid arrows demonstrate how tiers interlink linearly with one another to create value-added products along the supply chain. However, the process is not always linear and movement of product within, and across tiers is possible. The dotted arrows show how tiers can be bypassed with minimal processing to a higher value product within the supply chain. For example, industrial gases created in Tier 1 could be used directly within the food and drink industry.

Figure 1: Demonstration of how the chemicals sector supply chain links with itself and other UK industries[5]



[5] Figure adapted from image presented during stakeholder interview.

UK chemicals sector overview

According to Cefic, the leading European trade association for the chemical industry, the UK chemical manufacturing sector is the second largest manufacturing industry in the UK behind transport and machinery.[6] In 2021, the chemical industry turned over £75.2 billion, this contributed £30.7 billion of added GDP to UK economy. The industry also exported £54 billion worth of stock. In the UK, there are at least 4,535 companies (directly/indirectly involved in chemical production) employing over 141,000 workers.

The production of high-volume basic commodity chemicals (e.g., ammonia, ethylene, propylene, BTX (benzene, toluene, xylene) is concentrated in clusters in the North West of England (Runcorn/ Widnes) the North East (Teesside and Humberside) and Scotland (Grangemouth) (Tier 1). Speciality chemicals manufacture (often but not always) using these basic chemicals are manufactured throughout the UK (Tier 2), while the South and South-East are prominent for high-value (Tier 3) pharmaceuticals and agrichemicals.[7] Manufacturing locations often hinge on historic resource availability such as North Sea hydrocarbons, salt, limestone and energy sources (historically coal). Major processing clusters are located alongside industrial customers in these regions. The chemicals sector is primarily fed by the importation of ethane from the United States which is then used to produce key primary chemicals, in particular ethylene, which is distributed between clusters via pipeline. Other primary chemicals produced in the UK include other olefins (propylene and butene) as well as ammonia and some aromatics. Methanol is not currently made in the UK.[8] Production locations for specialty chemicals and pharmaceuticals are more widely distributed, with increased pharmaceutical research and development (R&D) around prominent universities like Oxford and Cambridge in the South-East and Eastern England.[9]

Current major challenges faced by the UK chemicals sector include high energy prices, especially for natural gas that serves as both feedstock and fuel. A shortage of skilled chemists and engineers is also a significant concern.[10] Competition from China and the US, particularly with China's lower energy costs poses a challenge. Moreover, uncertainties over geopolitical impacts on supply chain connections with Europe and further afield, contribute to the industry's challenges.[11]

The role for resource efficiency in the UK chemicals sector

The UK chemicals sector is one of the UK’s largest industrial carbon emitters; contributing 14% of UK industrial greenhouse gas (GHG) emissions and 2.3% of all UK GHG emissions in 2021.[12] Nevertheless, UK-made chemicals have lower GHG emissions per unit chemical produced than the global average which should be advantageous in supplying markets that

[6] Cefic (n.d.) CHEMICAL INDUSTRY SNAPSHOT. Available at: Link
[7] Cefic (n.d.) CHEMICAL INDUSTRY SNAPSHOT. Available at: Link
[8] Green alliance (2023) A new formula: Cutting the UK chemical industry's climate impact. Available at: Link
[9] Cefic (n.d.) CHEMICAL INDUSTRY SNAPSHOT. Available at: Link
[10] Cefic (n.d.) CHEMICAL INDUSTRY SNAPSHOT. Available at: Link
[11] Cefic (n.d.) CHEMICAL INDUSTRY SNAPSHOT. Available at: Link.
[12] DESNZ, 29th June 2023 - UK greenhouse gas emissions by Standard Industrial Classification. Available at: link

demand greener products, primarily due to the choice of feedstocks used by the UK. [13] [14] However, the UK is a net importer of certain chemical products, so therefore imports high embedded emissions.[15] It's important to note that whilst the chemical industry emits GHGs, when looking at a full carbon life-cycle approach, it can also contribute to products that have a net saving in GHG emissions (e.g. production of renewable energy technology). In 2011, the International Council of Chemical Associations (ICCA) found that some products in the chemicals sector enabled GHG savings 2-3 times greater than their own emissions.[16] The ICCA work identified opportunities where the chemicals sector could contribute to wider GHG savings through the development of new green products in downstream sectors. These include insulating foams in buildings, agrichemicals, lighting, plastic packaging, automotive plastics, low-temperature detergents, engine efficiency, synthetic textiles, and marine antifouling coatings.[17]

A vibrant and sustainable chemicals sector is critical to enabling a rapid transition to a net zero and a circular future. The chemical manufacturing industry underpins many critical technologies in the transition to a more sustainable economy, including batteries, heat pumps, insulation and wind turbines. However, the sector faces a significant challenge in transitioning to Net Zero as chemicals manufacture is inherently carbon and energy intensive.[18] The UK has the eighth largest chemicals industry by sales value globally. Despite growth in 2020 and 2021, chemical output has been shrinking throughout 2022 and is expected to contract over at least the short-term.[19] This is a result of considerable headwinds throughout 2022 such as the high price of energy, in part due to ongoing conflict in Ukraine, and a wider challenging economic environment for many consumers, which has been exacerbated by labour and raw material shortages.[20]

According to a report by the Green Alliance, the chemical industry could move towards net zero by prioritising resource efficiency, alongside electrification and replacing fossil feedstocks. [21] Resource efficiency is being considered by the chemicals sector as a priority measure for achieving Net Zero commitments; in 2019, 73% of the Chemical Industries Association (CIA)[22] member sites set at least one target related to resource efficiency in accordance with the Sustainable Development Goals targets. The average number of targets per site increased from 4.5 in 2018 to 4.8 in 2019 of which nearly three quarters are being met or exceeded.[23] These resource efficiency targets cover energy, emissions, water, waste, raw materials and

[13] Green alliance (2023) A new formula: Cutting the UK chemical industry's climate impact. Available at: Link
[14] CCC, The sixth carbon budget. Available at Link
[15] Green alliance (2023) A new formula: Cutting the UK chemical industry's climate impact. Available at: Link
[16] HMG / Sustainability Exchange (2011) Enabling the Transition to a Green Economy: Government and business working . Available at: Link
[17] HMG / Sustainability Exchange (2011) Enabling the Transition to a Green Economy: Government and business working . Available at: Link
[18] Cefic (n.d.) CHEMICAL INDUSTRY SNAPSHOT. Available at: Link
[19] Cefic (n.d.) CHEMICAL INDUSTRY SNAPSHOT. Available at: Link
[20] Cefic (n.d.) CHEMICAL INDUSTRY SNAPSHOT. Available at: Link
[21] Green alliance (2023) A new formula: Cutting the UK chemical industry's climate impact. Available at: Link
[22] The leading national trade association representing and advising chemical and pharmaceutical companies across the UK.
[23] Chemical Industries Association (n.d.) Sustainability. Available at: Link

yields. However, the ambitiousness of these targets is not reported, and it should be noted that these targets are not always appropriate for all types of chemical manufacturing processes.[24]

Sector characterisation

Some of the proposed measures discussed in this report may be more applicable to some tiers than others; for example, companies engaged in Tier 1 activities produce a high volume of chemicals at low financial margins so increasing costs by small amounts impacts their business models a lot more than Tier 3 companies that produce for end-user markets with higher margins.

The business model for Tier 1 companies usually involve a high degree of front-end design and Capital Expenditure (Capex) to put in place infrastructure for a continuous steady state of production. These facilities can also have much more energy intensive processing. Therefore, optimised efficiency involves achieving a steady, continuous rate of controlled reactions. This can mean that there may be limitations in what measures can be achieved due to relative inflexibility in the operational phase. Conversely, Tier 2 and 3 businesses tend to be based more on batch processing and may have more flexibility in their operational design which could incorporate some of the other measures more easily, but they may lack the business case for significant infrastructure changes and redesign. As a result, differing levels of efficiency are likely to be gained between tiers and care should be taken to consider this in the report findings. The application of specific measures may therefore need to be tailored depending on the specific tier of the chemical industry. Similarly, different parts of the chemicals industry, within each tier, are likely to achieve highly differing levels of efficiency. Nevertheless, this report aims to (as far as possible) integrate and discuss measures for the industry as a whole, noting that any efficiency improvement in the lower tiers and downstream industries, will have knock-on effects upstream.

Sector scope

The key focus of this report is on actions that improve material resource efficiency. Therefore, energy efficiency measures or fuel-switching measures (e.g., actions that reduce energy use/carbon emissions but do not impact resource use or efficiency) are outside the scope of this study. However, carbon capture for feedstock and hydrogen as a feedstock (excluding heating) will be considered as they are material inputs within the definition of resource efficiency used in this report. Measures which reduce water use are in scope whilst measures which change land use only (and not other resource use) are out of scope.

It is important to note that the chemicals industry and the energy sector are heavily interconnected as chemicals essentially function as energy storage.

Where chemicals differ to other sectors, investigated as part of the wider research project, is that energy is fundamental in converting one chemical to another. This energy is held within the chemical and passed down through the value chain (essentially as an energy storage vehicle). Stakeholders stressed that you cannot decouple the energy input from the feedstock

[24] Chemical Industries Association (n.d.) Sustainability. Available at: Link

as you could with, say the vehicles sector where energy input can be addressed completely separately to the manufacturing process.

Because of this, particularly in Tier 1 and Tier 2 companies, stakeholders noted that energy should not be decoupled from the resource efficiency measures as they have been defined for this study. The production of basic chemicals (Tier 1) are very high emitters of carbon therefore it is vital to acknowledge that energy input should not be considered in isolation to material inputs which are investigated in this report. Stakeholders stressed that the decarbonisation of energy is therefore critical to achieving a sustainable chemical industry. Nevertheless, as discussed previously, fuel switching measures are out of scope.

Furthermore, this report doesn’t specifically analyse sustainability and safety concerns beyond the scope of resource efficiency. Factors like chemical safety and other environmental aspects are vital for the industry’s long-term sustainability therefore resource efficiency should be considered alongside other design factors such as these when considering implementing the measures discussed in this report.

In terms of the value chain, the study focus extends from the production and use of primary building block chemicals (Tier 1) up to the formulation of chemical products, encompassing products used in various industry applications that do not require further chemical processing (Tier 3). Final products used in downstream industries and upstream raw materials extraction/refining are therefore excluded from scope as outlined in Figure 1.

The exception to the above is the use of plastics (covered separately in the Unlocking resource efficiency: Phase 2 plastic report). Whilst other end uses of chemicals are out of scope, plastics play a major role in the chemical industry. Therefore, for plastics, this report covers aspects of the value chain from basic feedstock production to the point of virgin pelletisation. Mechanical recycling of plastics is out of scope as the feedstock will come from plastics waste streams and feed directly into downstream consumer industries (this is covered in the Unlocking resource efficiency: Phase 2 plastic report). However, chemical recycling of plastics and reuse of the monomer as a secondary carbon feedstock is a key aspect for consideration within the chemicals sector as they can be reintroduced into the chemicals industry within the scoped boundaries (Tier 1 to Tier 3). Similarly, regeneration/recycling of other end of life chemicals is in scope (e.g., regeneration of used lubricants, metal working fluids, oils, solvent recovery, catalysts etc.).

While the scope covers domestic manufacturing, transportation of chemicals and transboundary movements won't be included due to difficulty in implementing and influencing these measures abroad.

A summary of the aspects scoped for this study are listed in the following table:

Table 1: Sector scope

Aspect	In scope	Out of scope
Focus of report	Material resource efficiency – However, energy is an important feedstock for this sector rather than a decoupled input.	Energy efficiency measures, fuel-switching measures, actions that reduce energy use/carbon emissions but do not impact resource use/resource efficiency.
Resources	Carbon capture for feedstock, hydrogen as feedstock (excluding heating), measures reducing water use.	Land use changes.
Sustainability and safety	Not in scope	Not specifically analysed beyond the scope of resource efficiency. However, these aspects should be considered alongside resource efficiency.
Value chain focus	From Tier 1 (production of basic chemicals) to Tier 3 (chemical formulation products used in various industry applications). Plastics are covered from basic feedstock production to virgin pelletisation. Monomer feedstocks from recycled plastics are considered in scope. For other chemicals, regeneration/ recycling of other end-of-life chemicals is considered in scope.	Downstream final products, upstream raw materials extraction/refining. Mechanical recycling and chemical recycling of plastics (covered in the plastics sector report).
Domestic production	Covers domestic manufacturing.	Transportation of chemicals and transboundary movements.

The chemicals sector has been defined within the following product and industry sub-categories (segments), defined by the ONS, to ensure that the research and targeted stakeholders cover these aspects.

Table 2: Chemical sector segments based on ONS categorisation.

Product	Industry
P26 Coke and refined petroleum products	I26 Manufacture of coke and refined petroleum products
P27 Paints, varnishes and similar coatings, printing ink and mastics	I27 Manufacture of paints, varnishes and similar coatings, printing ink and mastics
P28 Soap and detergents, cleaning and polishing preparations, perfumes and toilet preparations	I28 Manufacture of soap and detergents, cleaning and polishing, perfumes and toilet preparations
P29 Other chemical products	I29 Manufacture of other chemical products
P30 Industrial gases, inorganics and fertilisers (all inorganic chemicals) - 20.11/13/15	I30 Manufacture of industrial gases, inorganics and fertilisers (inorganic chemicals) - 20.11/13/15
P31 Petrochemicals - 20.14/16/17/60	I31 Manufacture of petrochemicals - 20.14/16/17/60
P32 Dyestuffs, agrichemicals - 20.12/20	I32 Manufacture of dyestuffs, agrichemicals - 20.12/20
P33 Basic pharmaceutical products and pharmaceutical preparations	I33 Manufacture of basic pharmaceutical products and pharmaceutical preparations
P34 Rubber and plastic products	I34 Manufacture of rubber and plastic products

Literature review approach

The literature review identified 155 sources that discussed resource efficiency in the chemicals sector. Note that not all of these references are included in this final report under each measure, as they were used to inform our understanding of the subject matter and define the measures discussed in this report. These were identified using a range of search strings relating to resource efficiency, the circular economy and the chemicals sector. The search strings are listed in Appendix B. Further sources were identified from sector experts via the interviews and a call for evidence sent directly to stakeholders. The full list of sources used are listed in Appendix C.

These 155 sources comprised:

- 15 academic papers;
- 13 academic reports;
- 29 industry reports;
- 22 policy documents;
- 15 technical studies;
- 58 website articles; and
- 3 webinars.

The sources were considered of generally high applicability and credibility when assessed against the data assessment framework, which recognises the relevance of the sources and the strength of their methodology. The sources had an average Indicative Applicability Score (IAS) of 3.9 (out of 5), with 92 sources exhibiting a score of 4 or above. 64 sources were specific to the UK market and 46 were specific to Europe. Stakeholder consultation indicated that the initial literature review identified a comprehensive list of measures, although they also suggested some additional sources which were then incorporated. Nevertheless, certain measures were covered more in literature than others. For example, a high volume of literature was available for Measure 2 (substitution of fossil-based organic material) whereas less was found for Measure 3 (Secondary material content) likely because, as corroborated by stakeholders, there is recognition of the need for the chemicals industry to transition to alternative feedstocks whereas secondary feedstocks are more product specific and considered to be less directly relevant to the chemicals sector.

More detail on the purpose and approach for these literature reviews can be found in the accompanying methodological annex.

Interview approach

A total of 10 stakeholders were interviewed broadly representing the chemical sector value chain; 4 researchers, 2 manufacturers, 4 trade bodies. Whilst there was a slight under representation from manufacturers, this was remedied by the 4 trade body organisations representing industry.

Table 3: List of organisations interviewed for the chemicals sector

Organisation	Type
Axalta	Manufacturer
British Coatings Federation (BCF)	Trade association

Centre for Process Innovation (CPI)	Trade association
Chemical Industries Association (CIA)	Trade association
Green Alliance	Academia / Research
INEOS	Manufacturer
Innovate UK KTN	Academia / Research
Society of Chemical Industry	Trade association
UK Research and Innovation (UKRI)	Academia / Research
University of Cambridge	Academia / Research

Workshop approach

There were eight participants in attendance at the workshop. The participants broadly represented the chemicals sector value chain: one manufacturer, five academics and researchers, and two trade association members with expertise in manufacture technology, innovation and policy. Whilst there was an under representation from manufacturers, this was boosted by two trade body organisations representing industry. It should be noted that two of the ‘academic/research’ representatives include R&D thinktanks that bring together academia, businesses, government and investors to develop research into the marketplace and have close connections within and a good understanding of industry.

Table 4: List of organisations attending the chemicals sector workshop

Organisation	Type
INEOS INOVYN	Manufacturer
Centre for Process Innovation	Academia / Research
Innovate UK KTN	Academia / Research
Loughborough University	Academia / Research
University of Cambridge	Academia / Research
Green Alliance	Academia / Research
Chemical Industries Association	Trade association
Society of Chemical Industry	Trade association

Drivers and barriers

Drivers and barriers were categorised using two separate systems:

- The PESTLE framework which is focused on the types of changes: political, economic, social, technological, legal and environmental;
- The COM-B framework which is focused on behaviour change:
    - **Capability**: can this behaviour be accomplished in practice?
        - Physical Capability – e.g., measure may not be compatible for certain processes
        - Psychological Capability – e.g., lack of knowledge
    - **Opportunity**: is there sufficient opportunity for the behaviour to occur?
        - Physical Opportunity: e.g., bad timing, lack of capital
        - Social Opportunity: e.g., not the norm amongst the competition
    - **Motivation**: is there sufficient motivation for the behaviour to occur?
        - Reflective motivation: e.g., inability to understand the costs and benefits,
        - Automatic motivation: e.g., lack of interest from customers, greater priorities

List of resource efficiency measures

The list of resource efficiency measures in the chemicals sector identified via the literature review and interviews can be found in Table 5. This list of measures was produced following a deselection and merging process of a longlist of preliminary measures considered at the commencement of this project. The longlist was put together following a preliminary literature review and discussion with the sector team and industry subject matter experts. The deselection process was informed through discussions with interviewed stakeholders and expert judgement by the sector team. A detailed description of each measure and analysis is included within the following sections of this report.

Appendix D contains a list of resource efficiency measures that were discarded from the scope of this study, with a justification for doing so.

Table 5: List of resource efficiency measures for the chemicals sector

#	Lifecycle stage	Strategy	measure name	Measure indicator
1	Design	Lightweighting	Reducing net resource input in formulation	% reduction in weight of chemical required to maintain

				functionality compared to 2023 levels
2	Design	Material substitution	Substitution of virgin fossil-based organic feedstocks	% of virgin fossil-based organic feedstock chemicals that have been substituted with alternative carbon feedstocks
3	Design / End of life	Recycled content	Secondary material content	% in weight of recycled/secondary post-use material content in chemicals production
4	Design / Manufacturing and assembly	Production efficiencies	Process efficiencies (yield) (closed process)	% improvement in process yield compared to 2023 levels
5	Design / Manufacturing and assembly	Production efficiencies	Process efficiencies (water consumption)	% weight reduction in water consumption compared to 2023 levels
6	Sale and Use	Collaborative consumption	Collaborative consumption of raw material / resources / by-products	% increase in weight of production waste avoided by the chemicals sector through sharing of resources compared to 2023 levels

1.0 Measure 1 – Reducing net resource input in formulation

1.1 Chemicals resource efficiency measure

1.1.1 Description

Reduction in net resource use to deliver same/improved final use functionality using changes in design at formulation stage (Tier 3).

This measure aims to reduce the resources required in products whilst maintaining the same/improved functionality during final use through change in design at formulation stage (Tier 3). For the chemicals sector, reducing the demand for chemicals can be achieved by:

- Reducing overengineering in product formulation (i.e., only use what is required for final product to work).
- Use of higher quality formulation that requires less of it in the first place (e.g., fewer layers of higher quality coating).
- Use of higher quality formulation that extends the life of the final product (e.g., longer cycles between coatings). This is also known as life extension.
- Use of higher concentration formulations to reduce the quantity of formulation required in final product.
- The use of outcome-based business models that encourage reduction in consumption of chemicals for a given function/service by offering service as a product (e.g., chemical leasing).

Note that this list is not exhaustive. This measure, as it is defined for the chemicals sector, has limited examples within the chemicals industry, particularly in Tier 1 and Tier 2 industries as it is usually applied at product/service level (Tier 3 and downstream). Despite this, all tiers are ultimately impacted as material reductions trickle upstream. For this measure it was not possible to break the data down by the ONS segments listed in Table 2.

1.1.2 Measure indicator

The '**% reduction in weight of chemical required to maintain functionality compared to 2023 levels'** was selected as the indicator for this measure as it demonstrates how much resource could be saved compared to baseline levels by 2035.

1.1.3 Examples in practice

Stakeholders were able to provide some examples during the formulation stage (Tier 3). For example, plastics are often filled out with calcium carbonate ($CaCO_3$) to reduce virgin plastic consumption. This cuts down plastic production costs and may alter production conditions and several physical and chemical properties of finished plastic products.[25]

Another example in the coating industry involves aeration, where air bubbles are added to the coating to reduce the weight of the material making it cheaper to produce by reducing the quantity of formulation required for the same volume of product. It also provides engineering benefits through weight reduction, particularly when used on large structures or in weight-critical applications such as vehicles.

According to stakeholders, consumer products (e.g., detergents) have been lightweighting chemicals for decades by reducing the volume of material and packaging which saves on transportation costs and resulting emissions savings. At the formulation stage (Tier 3), this can be achieved through increased product concentrations.

The chemicals industry can contribute to life extension by improving the quality of the chemicals being used downstream. For example, DSM[26] has developed advanced plastics that enable furniture manufacturers to design more durable products with longer lifespans.[27]

There are also numerous examples of implementing alternative outcome-based business models[28] that enable this measure. Product-as-a-service[29] or chemical leasing[30] can minimise the quantity of product required for a given application by retaining ownership of the chemical and charging based on the outcome or the functionality as opposed to the volume. This incentivises the producers/operators to minimise the quantity of material required.

It is particularly applicable for companies with chemical processes that are not part of their core activities, such as agrichemicals, catalyst and wastewater treatment companies. In case studies, chemical usage was reduced by 10-80% after the introducing of chemical leasing and the Centre for Research into Energy Demand Solutions (CREDS) estimates that it could lead to a 50% reduction in chemical use in ‘speciality chemical’ sectors (e.g., industrial cleaning, wastewater treatment, inks and dyes and agricultural fertilisers).[31]

For example, in chemical management for water treatment, the basis for payment is cubic meters of purified water rather than per unit of cleaning chemicals used (chemical leasing).[32] Another notable example of an outcome-based business model provided by stakeholders involves the pricing of agrichemicals such as fertilisers and pesticides. In this case, they are

[25] Bedeko (n.d.) CaCO3 Filler Masterbatches. Available at: Link
[26] https://www.dsm.com/corporate/home.html
[27] PwC (2019) Circular economy: A new source of competitive advantage in the chemicals industry. Available at: Link
[28] An "outcome-based model" is an umbrella term for a business model where payment is contingent on the achievement of specific results or outcomes rather than the volume of product sold.
[29] Product-as-a-service is a business model where consumers pay for access or use of a product rather than owning it outright. It can be applied in any sector.
[30] An outcome-based model used within the chemicals industry. It is a collaborative business model where the chemical supplier is compensated based on the performance, rather than the volume of chemicals sold.
[31] CREDS (2021) Resource efficiency scenarios for the UK: A technical report. Available at: Link
[32] PwC (2019) Circular economy: A new source of competitive advantage in the chemicals industry. Available at: Link

priced based on the quantity of the harvested crop they are used on, rather than the weight of chemicals.

Some stakeholders highlighted the catalyst market as a good example of retained ownership by manufacturers (or leasing of the product as a service) within the chemicals sector whereby the manufacture continues to own, maintain and recover the catalyst. Johnson Matthey have demonstrated a 98% lower carbon footprint by designing their catalysts for recovery compared to primary (mined) metal production.[33] However, it is worth noting that, other than the examples given, these business models are not very common and are mostly limited to specific applications within the chemicals sector. Overall, most stakeholders were generally unaware of other key segments that use similar business models, though recognised that this could be applied further within the chemicals sector.

1.2 Available sources

1.2.1 Literature review

The literature review identified 16 sources, used in this report, that discussed 'Reducing net resource input in formulation', although there was little quantitative evidence on the future levels of resource efficiency that could be achieved through this measure. This comprised:

- four industry reports;[34] [35] [36] [37]
- one academic paper;[38]
- one technical study;[39]
- four policy documents;[40] [41] [42] [43] and

[33] Johnson Matthey (n.d.) PGMs and circularity. Available at: Link
[34] Green alliance (2023) A new formula: Cutting the UK chemical industry's climate impact. Available at: Link;
[35] PwC (2019) Circular economy: A new source of competitive advantage in the chemicals industry. Available at: Link
[36] OECD (2017) Economic Features of Chemical Leasing. Available at: Link
[37] IBM (2020) Meet the 2020 consumers driving change Why brands must deliver on omnipresence, agility, and sustainability. Available at: Link
[38] Ncube, A., Mtetwa, S., Bukhari,M., Fiorentino, G and Passaro, R (2023) Circular Economy and Green Chemistry: The Need for Radical Innovative Approaches in the Design for New Products. Available at: Link
[39] EEA (2021) Designing safe and sustainable products requires a new approach for chemicals. Available at: Link
[40] JRC (2022) Safe and sustainable by Design chemicals and materials - Framework for the definition of criteria and evaluation procedure for chemicals and materials. Available at: Link
[41] House of Commons (2018) Chemicals Sector Report. Available at: Link
[42] Ciatti et al. (German Environment Agency & RPA) (2021) Development of REACH – Review of evidence on the benefits & costs of REACH. Available at: Link
[43] Defra (2023) UK REACH alternative transitional registration model (ATRm). Available at: Link

- six website articles.[44] [45] [46] [47] [48] [49] [50]

A full list of the sources used in this measure are listed in Appendix C.

The relevant sources were considered of high applicability and credibility when assessed against the data assessment framework, which recognises the relevance of the sources and the strength of the methodology within each. The sources exhibited an average IAS of 4 (out of 5), with 10 sources exhibiting a score of 4 or above. Seven literature sources were UK-specific and all the sources were published recently (within the last 5 years). The interviews were used to test the literature review findings and fill knowledge gaps.

1.2.2 Interviews

Initially, this measure was presented as "lightweighting" during stakeholder interviews. However, stakeholders pointed out that "lightweighting" is less relevant in a chemical context, as it typically refers to the final product, not the chemical itself, which is reduced in quantity rather than made lighter.

This caused confusion in interviews, as it differed from the understanding in other industries where it involves techniques to reduce product weight such as substituting heavy materials with lighter ones. Consequently, stakeholders hesitated to discuss this measure, deeming it less applicable to the chemicals sector. Therefore, the measure was renamed 'reducing net resource input in formulation' to better convey the reduction of material quantity while maintaining functionality.

Some stakeholders conflated this measure with Measure 4 (process efficiencies) by suggesting that the chemicals industry, especially in Tier 1 and Tier 2 sectors, may have already maximised efficiency in minimising material usage due to strong economic incentives. Nevertheless, others argued that resource reduction strategies can still be applied in the formulation stage, particularly in Tier 3 sectors like paints and coatings, where chemical products serve functional purposes and room for improvement remains.

Stakeholders generally agreed that while outcome-based business models are intriguing and can prove effective in certain cases to minimise the quantity of chemicals in the final application, their widespread adoption in the chemicals sector is lacking and they typically do not align with the predominant business models in the industry (particularly at the Tier 1 and Tier 2 level) which rely on high throughput/low margin business models. One academic stakeholder noted that a main challenge to improving resource efficiency in the sector is to decouple volume from margin by modifying business models to maintain value whilst reducing material throughput although no detail on how to achieve this was given. Stakeholders

[44] HM Government (2018) Our Waste, Our Resources: A Strategy for England. Available at: Link
[45] HM Government (2023) Environmental Improvement Plan. Available at: Link
[46] BCG (2022) Winning the Consumer with Sustainability. Available at: Link
[47] Cefic (n.d.) CHEMICAL INDUSTRY SNAPSHOT. Available at: Link
[48] HSE (2023) UK registration, evaluation, authorisation and restriction of chemicals. Available at: Link
[49] ECHA (2023) How to substitute? Available at: Link;
[50] UK Government (2023) New vision to create competitive carbon capture market follows unprecedented £20 billion investment. Available at: Link

emphasised the need to avoid placing excessive emphasis on outcome-based business models due to their limited practical implementation.

1.2.3 Workshop

During the chemicals sector workshop, stakeholders broadly agreed with the concept of this measure, acknowledging that resource reduction in product formulations is technically feasible within the chemicals sector but that levels of improvement are relatively limited due to numerous barriers. The discussion particularly focussed on consumer acceptance, health and safety, technical limitations and regulation. Initially, queries arose regarding the definition of a chemical in the context of the measure, as numerous formulation chemicals exist including fillers, active ingredients and water. Because of the multivariable definition, it was suggested that the focus of the indicator on overall weight reduction of the chemical may not be useful as it does not recognise the wider environmental impacts of individual chemicals and their application.

The level of engagement in the workshop was as follows:

- Eight stakeholders across industry and academia were active on the mural board and six stakeholders actively contributed to verbal discussion.

1.3 Drivers & Barriers

The drivers and barriers influencing this measure were identified through a combination of the literature review and stakeholder interviews.

1.3.1 Drivers

Table 6 below shows the main drivers for reducing net resource input in formulation of chemicals. The most significant drivers are shown in bold as voted for by stakeholders in the workshop.

Table 6: Drivers for chemicals measure 1

Description	PESTLE	COM-B
Policy and regulatory drivers	**Political / Legal**	**Capability – psychological**
Mandatory and voluntary carbon reporting may stimulate the market	**Economic / Environmental**	**Opportunity – social**
Carbon Tax	**Economic**	**Motivation – automatic**

Cost savings from reduced resource consumption	**Economic**	**Motivation – automatic**
Consumers demand more sustainable products	**Social**	**Opportunity – social**
Better quality products have competitive advantages	Technological	Opportunity – physical
UK chemicals industry can build upon its competitive advantage	Environmental	Opportunity – physical
Support for innovative SMEs drives innovation	Economic	Capability – physical
Outcome-based business models can reduce chemicals required for a given output	Economic	Opportunity – physical
Company sustainability commitments	Environmental	Motivation – automatic

Policy and regulatory drivers

Resource efficiency is a key environmental policy target across economic sectors, as set out by the resources and waste strategy for England.[51] This aims to eliminate avoidable waste by 2050. For the chemicals sector specifically, there are broad ambitions to transition towards more sustainable use of chemicals[52] (of which one aspect is resource efficiency). The UK chemicals strategy is currently under development.

Beyond England, resource efficiency in chemicals production and consumption is encouraged by policy instruments. For example, the safe and sustainable by design (SSbD) framework in the European Union (EU) is a voluntary initiative to identify chemicals which can be produced and used sustainably.[53] To classify as SSbD, the production, use and end-of-life of a chemical must meet a number of principles, for example, principle 1 – material efficiency (e.g. optimising the solvent amount for the purpose, minimising the number of chemicals used in the production process and minimising the use of critical raw materials). The initiative is a driver for increasing resource efficiency as consumers are increasingly seeking sustainable products.[54] Notably, the SSbD framework is currently being tested in a number of case studies by industry

[51] HM Government (2018) Our Waste, Our Resources: A Strategy for England. Available at: Link
[52] HM Government (2023) Environmental Improvement Plan. Available at: Link
[53] JRC (2022) Safe and sustainable by Design chemicals and materials - Framework for the definition of criteria and evaluation procedure for chemicals and materials. Available at: Link
[54] BCG (2022) Winning the Consumer with Sustainability. Available at: Link

representatives across the EU.[55] The framework may be further developed / refined based on the outcome of these case studies. Its finalisation is expected in 2025.[56]

In the UK, policy drivers to increase resource efficiency in the chemicals sector are limited, but could be increased in the future e.g., depending on the UK Chemicals Strategy and whether the UK adopts an SSbD-type approach.

The importance of this driver was highlighted by the workshop participants, who indicated that this driver could either have a positive or a negative impact depending on its execution and that any trade-offs with other policies (such as health and safety, energy consumption etc.) must be balanced. One stakeholder mentioned that policy should outline how to measure resource efficiency, as an agreed approach on how to measure resource efficiency would provide more transparency to the end-user. Another stakeholder emphasised that policies and regulatory drivers should aim to move the whole supply chain, as the producers themselves only have limited control.

Mandatory and voluntary carbon reporting may stimulate the market

The lower volume of chemicals needed for a given function makes them less carbon intensive as fewer materials (and processing) are required. More concentrated, or lighter products, can result in lower embedded emissions from production and fewer transport emissions. As a result, this measure can reduce the overall carbon footprint and aid in achieving emission reduction targets.

Improvements in the reporting of carbon emissions could stimulate industry to adopt resource efficiency measures. Since the majority of emissions derived from the chemicals industry is associated with upstream and downstream operations,[57] reporting these emissions would urge chemical companies to identify ways to support reductions in resource use for a given output.

Many chemical companies have established their own sustainability commitments. These companies are more likely to invest in and develop systems towards resource and carbon efficiency such as reducing net resource input. In the workshop, one stakeholder mentioned that for these commitments to be effective, companies need to be held accountable, for example by consumers or enforcement of regulation.

In the workshop, one stakeholder mentioned that mandatory carbon reporting and the resulting visibility of emissions would lead to increased pressure from consumers, shareholders and suppliers/downstream users. Other stakeholders brought up the point that this driver does not fit in a vacuum and should be related to other regulations.

Carbon tax

[55] For example, the first three case studies were published in June this year: JRC (2023) Safe and Sustainable by Design chemicals and materials – Application of the SSbD framework to case studies. Available at: Link
[56] European Commission (2023) Safe and sustainable by design – Timeline. Available at: Link
[57] Green alliance (2023) A new formula: Cutting the UK chemical industry's climate impact. Available at: Link

Stakeholders also went further by suggesting the introduction of a carbon tax. One stakeholder mentioned that while this would be a painful measure for the industry, it will likely be effective in generating change as reducing carbon emissions would directly reduce cost. However, there were concerns over this with one stakeholder suggesting that the effectiveness of this driver depends on the willingness of consumers to pay more, as costs would likely be passed onto consumers for operators to remain profitable. This may not be acceptable to consumers in the current economic climate and may exacerbate inflationary pressures.

Cost savings from reduced resource consumption

The interviews indicated that a key driver for this measure is the potential cost reduction for operators that results from reduced resource consumption for a given function. These cost reductions stem from lower production and transportation costs. This is already driving companies to maximise this measure where technically feasible. Nevertheless, stakeholders added that costs may be incurred to develop technologies/methods to reduce the formulation required for a given function.

In the workshop, this driver was not prioritised highly by the stakeholders, however one stakeholder did mention that this driver is already a necessity to maintain operations, especially for bulk/commodity chemicals.

Consumers demand more sustainable products

Consumer demand for greener products with lower resource use and carbon intensity is one of the key drivers identified in literature. One source, referencing an Institute for Business Value (IBM) survey[58], noted that consumer product companies who can provide more sustainable offerings have benefitted greatly from increased consumer awareness and demand for such products.[59] However, stakeholders noted that this driver is stronger in certain segments than others. For example, consumer facing industries (Tier 3 and downstream) are more driven by this aspect as consumers demand more sustainable products. Tier 1 and Tier 2 chemicals companies are involved in the manufacture of primary or intermediate chemicals that are not visible to the consumer and therefore they may be less influenced by this driver. As Tier 3 companies demand more green chemicals to generate more sustainable products, it is likely that this driver will have ripple effects to Tier 1 and Tier 2 companies. Stakeholders also noted that while consumers express interest in greener products, they may not be willing to pay a premium for it, as discussed in the barriers section for this measure.

Better quality products have competitive advantages

Enhanced product design, achieved through higher-quality formulations, can lead to reduced material requirements for final use and longer product lifetimes. This, in turn, results in decreased material consumption. Such improvements can offer a competitive edge to manufacturers by providing better quality products than competitors and potentially increasing

[58] IBM, (2020) Meet the 2020 consumers driving change Why brands must deliver on omnipresence, agility, and sustainability. Available at: Link

[59] Ncube, A., Mtetwa, S., Bukhari,M., Fiorentino, G and Passaro, R (2023) Circular Economy and Green Chemistry: The Need for Radical Innovative Approaches in the Design for New Products. Available at: Link

revenue per unit of chemical volume.[60] Furthermore, products that are better designed to be reused at end-of-life will reduce the need for virgin materials[61], driving both reduced waste generation and lower resource consumption in chemical manufacturing. The UK already has developed a strong market for high-quality, low-volume chemicals which can be built upon as discussed in the following driver.[62]

UK chemicals industry can build upon its competitive advantage

The UK chemicals sector invests heavily in R&D[63] and has already developed a strong market for high-value low-volume chemicals, such as pharmaceuticals, which presents an opportunity to build upon its competitive advantage, as a leader in R&D, to further establish itself as a low-carbon competitor in the global chemicals market. [64,65]

However, in the workshop, one stakeholder did mention they are unsure if the UK has a competitive advantage currently, but they could see this develop as the market changes.

Support for innovative SMEs drives innovation

Available finance for short- and long-term investments, such as earmarked funds to support small and medium-sized enterprises (SMEs) can support the implementation of safe and sustainable by design approaches, including technologies that reduce net resource input in production by focusing on the function that a product delivers.[66, 67]

Outcome-based business models can reduce chemicals required for a given output

Outcome-based business models enable reduction in resource use for manufacturers, as it makes it in the best interest of the manufacturer to achieve the outcome with as little resource as possible.[68] [69] The ‘product as a service’ approach is a closed-loop business model that offers alternative systems of chemical management, such as chemical leasing, take back schemes and more collaborative use of the chemicals. Through these processes, chemicals can be used without being purchased, which shifts the focus of manufacturers and suppliers from value creation per unit chemical to the functionality and application of each chemical.[70] This incentivises producers to consider a larger portion of the product lifecycle and thus reconsider the quantities of resource required during production for a given outcome. This was corroborated by one of the stakeholders in the workshop who agreed that outcome-based business models can be effective at reducing net input in a formulation. However other stakeholders were keen to point out that they are only applicable to certain applications within

[60] Green alliance (2023) A new formula: Cutting the UK chemical industry's climate impact. Available at: Link
[61] Green alliance (2023) A new formula: Cutting the UK chemical industry's climate impact. Available at: Link
[62] Green alliance (2023) A new formula: Cutting the UK chemical industry's climate impact. Available at: Link
[63] Cefic (n.d.) CHEMICAL INDUSTRY SNAPSHOT. Available at: Link
[64] House of Commons (2018) Chemicals Sector Report. Available at: Link
[65] Green alliance (2023) A new formula: Cutting the UK chemical industry's climate impact. Available at: Link
[66] EEA (2021) Designing safe and sustainable products requires a new approach for chemicals. Available at: Link
[67] PwC (2019) Circular economy: A new source of competitive advantage in the chemicals industry. Available at: Link
[68] Green alliance (2023) A new formula: Cutting the UK chemical industry's climate impact. Available at: Link
[69] OECD (2017) Economic Features of Chemical Leasing. Available at: Link
[70] Green alliance (2023) A new formula: Cutting the UK chemical industry's climate impact. Available at: Link

the chemicals sector (as previously discussed) and are not practical in other segments, particularly in Tier 1 industries where the current business model does not support this. Stakeholders noted that whilst the concept has been around for many years, it is not a widespread business model and they are only aware of limited examples.

Company sustainability commitments

With many chemical companies having established their own net zero commitments, it is likely that company commitments further down the value chain are likely to have a ripple effect upstream to Tier 1 companies who produce the feedstocks.

1.3.2 Barriers

Table 7 below shows the main barriers for reducing net resource input in formulation. The most significant barriers are shown in bold as voted for by stakeholders in the workshop.

Table 7: Barriers for chemicals measure 1

Description	PESTLE	COM-B
Consumer perception and acceptance (e.g., unit sizes)	**Social**	**Motivation – reflective**
Regulatory barriers	**Legal / Political**	**Capability – psychological**
High costs in improving production processes	**Economic**	**Capability – physical**
Limited knowledge in incorporating safety and sustainability in design	**Social**	**Capability – physical**
Impacts on wider market from supply/demand imbalances	Economic / Technological	Capability – physical
Health and safety concerns	Social	Motivation – reflective

Consumer perception and acceptance

During the workshop, stakeholders argued that consumer perception and acceptance might be the biggest barrier to reducing net resource input in formulation. One stakeholder argued that this measure will only work if it is coupled with clear consumer education, allowing them to use less material and see the benefit of reduced use. One example, given by a stakeholder, included cleaning detergents which have become much more compact than they were two or three decades ago. As a result, the suggested doses are lower, but a significant issue is consumer acceptance. It was noted that consumers who are familiar with older dosages are often sceptical about the notion that less of the same product will generate the same cleaning effect. In contrast, there is a tendency to use more product than required or specified. Thus, even though the chemicals sector may be able to achieve a 5% level of efficiency through this measure – e.g., via highly compacted detergents, specialised enzyme systems or bleach activators – consumption at the consumer phase is a challenge.

Regulatory barriers

Stakeholders indicated that some regulatory requirements prevent the use of certain chemicals which might improve the quality of the formulation, which result in less of it being used. For example, one stakeholder noted that stricter regulations on per-fluoroalkyl substances (PFAS) under Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) regulations[71], due to their persistent nature and potentially harmful effects on humans and the environment, might mean that more of another (less effective) chemical is needed, resulting in increased resource use. PFAS can increase the durability of chemical products such as industrial paints, where the absence of PFAS would mean that more often repainting and therefore greater quantities of paints, are required to fulfil the function over time, despite being safer to use. Consideration of the wider aspects of safety and sustainability must therefore also be considered when promoting resource efficiency.

Similarly, one stakeholder gave an example for plastic bottles where efforts to reduce the amount of material used meant that the thickness of the plastic used in the bottle was reduced (i.e., less material stretched more thinly). Where the contents of plastic bottles can contain pressurised liquids (e.g., carbonated drinks) there was concern over product safety following cases of bottle explosions. As a result, products can be over-specified in order to meet safety requirements which usually outweigh resource efficiency concerns. Whilst this is considered in the design phase for specific products in downstream sectors (see plastic and glass reports), this consideration is made within the chemicals value chain. In relation to this point, a policy expert highlighted that there are regulatory drivers on what is the acceptable level of safety but equally barriers on what is not acceptable today in regulation which changes dynamically.

Stakeholders noted that regulatory barriers are dynamic therefore companies must navigate changes in regulation – e.g., changes in acceptable level of safety in product regulations. One stakeholder in the workshop added that transnational companies face a variety of regulatory challenges in global markets, which adds to the complexity in developing products for certain markets as national regulations are not always aligned.

This barrier is addressed to some extent by mechanisms within REACH, as socioeconomic analyses and alternatives assessment aim to ensure the overall impact (taking into account human health, the environment and the economy) of restrictions is positive. Therefore, any reduction in resource efficiency should only be accepted if the benefits (e.g. protection of human health and the environment) are more significant (representing an overall positive effect on sustainability). Furthermore, analysis of alternatives should consider the overall

[71] HSE (2023) UK registration, evaluation, authorisation and restriction of chemicals. Available at: Link

sustainability of the alternatives, including resource use.[72] Policy initiatives such as SSbD can also be developed to help address this barrier (see section 1.3.1).

Furthermore, stakeholders noted that the registration requirements expected under UK REACH may be a barrier to using more resource efficient chemicals, as companies, especially smaller ones, may not have the expertise or resources (time and finances) to register new substances, or even existing substances that were registered under EU REACH.[73] The UK Government are exploring options for alternative transitional registrations to reduce the burden of registration for substances that have already been registered in the EU. There is some evidence that REACH benefits innovation (e.g. through improved supply chain communication and through authorisation) and if these benefits are realised in UK REACH (as per the objectives of the legislation to enhance competitiveness and innovation), they could support innovation in more resource efficient chemicals.[74]

High costs in improving production processes

In many cases, investment might be needed to reduce the quantity of chemicals required for a given function (for example to improve the specification of a given product). One stakeholder remarked that the high Capex associated with a significant overhaul of existing production processes is one of the main barriers to further improvement of this measure. This was corroborated by other stakeholders who indicated that the sector primarily wants to maximise the use of its existing assets and resources, rather than invest in more radical change. Stakeholders widely agreed that the “low hanging fruit” will already have been gathered by industry and further improvements would require significant additional investment. Additionally, during the workshop one stakeholder pointed out that within some companies, there are at most two more financial cycles for major infrastructure expenditure before 2050. Whilst another acknowledged that different companies would not have the same financial cycle, both were keen to point out that decisions on investment need to be made quickly in order not to miss out on having the appropriate infrastructure in place, to impact net zero targets by 2050.

During the workshop, one stakeholder noted that in certain cases there are technical ways to reduce resource consumption, however, they may require more expensive materials than the ones that are being replaced. Due to this, the increased costs outweigh any savings from reduced material use. One stakeholder in the workshop added that this measure could reduce the competitiveness of products beyond the UK due to increased costs.

Limited knowledge in incorporating safety and sustainability in design

The SSbD framework, announced by the EU in December 2022, offers guidance on improving safety and sustainability during production. The European Environment Agency identified that the education sector is a source of potential inertia when it comes to product design. They argue that engineering, product design students and chemical synthesis students typically

[72] ECHA (2023) How to substitute? Available at: Link
[73] Defra (2023) UK REACH alternative transitional registration model (ATRm). Available at: Link
[74] Ciatti et al. (German Environment Agency & RPA) (2021) Development of REACH – Review of evidence on the benefits & costs of REACH. Available at: Link

have limited training in incorporating wider safety and sustainability aspects in design.[75] However, stakeholders argued that wider sustainability aspects are already key considerations during the front-end engineering design (FEED) stage of a processes. Given the recent developments in this field, operators should continue to adopt evolving best practice and guidance when developing processes/ products.

Impacts on wider market from supply/demand imbalances

A key point raised by stakeholders was the sector’s high dependency on market demand, which fluctuates significantly with GDP or the demand of specific products in certain industries. Stakeholders noted that small changes to the demand of a particular chemical product can have wider effects on the chemicals market. For example, one stakeholder stated that if a continuous process is producing two chemicals as the product of a reaction, a separate market needs to be established for both. Any fluctuation, be it a decrease or increase in demand for one of these chemicals, can disrupt the established balance resulting in price fluctuations which may impact the economic viability of processes.

Continuous operations are designed to maintain a consistent output, making it challenging, if not practically impossible (from a stoichiometric and technical perspective), to alter the volumes and proportions of materials being produced without shutting down the process (at high expense). Were downstream demand for certain chemicals to increase, it would require ramping up of production. On the contrary, if demand is too low, it may be uneconomical to keep the plant in operation. However, this is a costly option for operators.

If demand exceeds the design tolerances for the process for sustained periods, additional extraction and production capacity may be feasible. This is a lot slower and expensive to mobilise due to feasibility studies, planning requirements etc. and can have significant long-term impacts on the upstream, downstream and interconnected markets. Manufacturing systems are extensively interconnected, with many product value chains operating at the global level. Implementing change in one part of the system therefore has knock-on effects.

There is a continuous issue of under- or over- supply, depending on demand, which the sector can minimise through improved demand forecasting and adjusting throughput/ stockpiling as necessary to cope with this.

Furthermore, in cases where slower reaction rates are required to reduce output, stakeholders noted that side reactions can become more prominent, resulting in higher quantities of undesired byproducts and therefore, additional waste streams which incur costs and loss of material value. Another stakeholder added that there may be more opportunities for resource efficiency in the upper supply chain tiers where more chemical reactions take place.

[75] EEA (2021) Designing safe and sustainable products requires a new approach for chemicals. Available at: Link

1.4 Levels of efficiency

Table 8: Levels of efficiency for chemicals measure 1

Indicator: % reduction in weight of chemical required to maintain functionality compared to 2023 levels			
Level of efficiency	Current	Maximum in 2035	Business-as-usual in 2035
Value	0%	3 – 10%	3 – 10%
Evidence RAG	Not applicable	Red	Red-Amber

1.4.1 Current level of efficiency

No existing literature data were found regarding current or historical resource efficiency levels for this measure, relative to this baseline. Stakeholders noted that companies will already be doing this with one stakeholder stating that companies may have already exhausted possible action on this measure. Stakeholders were unable to provide quantitative efficiency level for the chemical industry as a whole due to their specificity to various markets.

As the indicator for this measure is an index, relative to current levels, the estimated level of efficiency is set at 0%, serving as a baseline for subsequent scenarios. The evidence RAG rating for this efficiency level is therefore not applicable.

1.4.2 Maximum level of efficiency in 2035

No literature data were available to estimate a maximum efficiency level for this measure. Stakeholders generally agreed that this measure is likely to be optimised as far as possible within the chemicals sector, with only limited potential for improvements in specific segments. For instance, one stakeholder mentioned that the coating industry might achieve a 10 to 15% increase in efficiency for certain products under strong demand and incentives, although even for this niche application this is considered to be ambitious. Overall, stakeholders agreed that, whilst it is always possible to improve efficiencies, opportunities for reducing net resource input in formulation across the sector are limited, resulting in a low percentage reduction in the weight of chemicals required for functionality. In the interviews two stakeholders agreed that the value was in the range of 0-5% with one stating that it was closer to lower range. One stakeholder disagreed however stating that 5% seemed low. During the workshop, there was limited agreement, one stakeholder argued a 3-5% reduction as many of the steps along the supply chain have already been optimised for scale and price over decades, with little room for improvement. However, until recently the drivers have mainly been cost and market price. The addition of atom efficiency or environmental impact in design considerations will add to the pressure to improve this measure. Another argued for greater improvement of 6-10% arguing that there is still opportunity to reduce and provide more efficient products, mainly in Tier 3 companies with ripple effects through the entire supply chain. Another argued a stretch target of >10% within certain sectors but that this would require significant changes in consumer behaviour and regulations. Despite limited consensus on a specific value, stakeholders concurred that any improvements in efficiency are likely to be small, thus indicating a limited, but notable, degree of confidence in this estimate.

On reflection of stakeholder input and in the absence of more comprehensive data, the maximum efficiency level for the sector is estimated to be 3-10%, which stakeholders supported as a reasonable estimate during workshop voting. The evidence RAG rating for this efficiency level is red, reflecting the lack of supporting literature evidence, lack of consensus and limited engagement from stakeholder in discussion of this level of efficiency.

1.4.3 Business-as-usual in 2035

As per above, there was no available literature data to estimate a business-as-usual (BAU) level of efficiency for this measure and stakeholders were only able to provide an indicative value during interviews. However, it was noted that there might be limited improvements possible in certain segments.

In the workshop however, stakeholders were more optimistic about the business-as-usual scenario. Five stakeholders believed that values between 6-10% were likely, with two stakeholders having a high level of confidence in this figure. Two stakeholders noted that this figure may only apply to certain chemicals such as polymers where there is still opportunity for progress. Four stakeholders argued, with medium certainty, that 3-5% was more realistic as most optimisations will have already occurred. One stakeholder believed that 0-2% was more accurate for similar reasons. While half of the votes were for 6-10% and stakeholders had the highest level of confidence in this range, there was no unanimity with several stakeholders believing a lower value would be more appropriate. On reflection of stakeholder input, a range of 3-10% has been estimated for the business-as-usual scenario. It is important to note that this range is not supported by literature and as a result, the evidence RAG rating for this efficiency level is categorised as amber-red.

2.0 Measure 2 – Substitution of virgin fossil-based organic feedstocks

2.1 Chemicals resource efficiency measure

2.1.1 Description

Substitution of virgin fossil-based organic feedstocks with alternative organic feedstocks.

This measure aims to increase resource efficiency by substituting virgin fossil-based organic feedstocks with alternative (hydro)carbon feedstocks for the production of building block chemicals. Three alternative feedstocks include:

- Biobased feedstocks
- Captured carbon dioxide (CO_2) (from Carbon Capture Utilisation and Storage (CCUS) reacted with (green) hydrogen feedstocks
- Secondary carbon feedstocks from waste products (e.g., chemical recycling of plastics or captured methane)

The chemicals sector has evolved over many years in close connection with the widespread use of fossil fuels in energy and transportation. However, as the use of fossil fuels for these purposes declines in line with Net Zero targets, embodied carbon emissions (in chemicals) will form an increasing proportion of carbon emissions.[76] A net zero chemicals sector is impossible to achieve without switching a significant proportion of the industry's feedstocks away from virgin fossil fuels.[77] Therefore the chemical industry must explore alternative sources of organic feedstock.[78] Currently, 98% of chemicals globally are produced using fossil fuel feedstocks[79] which generate GHG emissions during production and release embedded carbon as they degrade at end of life. About 10% of global fossil fuels are used as a petrochemical feedstock. The remaining 90% is used for energy production.[80]

Industry leaders recognise this shift; a survey run by PwC in 2019, 54% of chemical company CEOs expected resource and materials substitution to transform their business, with 46% anticipating a significant impact from the economy's decarbonisation.[81] Various organisations including the UKRI, IBLF and the Chemistry Council Innovation Committee are forming working groups to identify opportunities and develop roadmaps for transitioning the sector away from virgin fossil carbon. In Europe, the European Chemical Industry Council has created a similar

[76] International Energy Agency (2021) Net Zero by 2050: A Roadmap for the Global Energy Sector. Available at: Link
[77] SystemIQ (2022) Planet Positive Chemicals. Available at: Link.
[78] Green alliance (2023) A new formula: Cutting the UK chemical industry's climate impact. Available at: Link
[79] Green alliance (2023) A new formula: Cutting the UK chemical industry's climate impact. Available at: Link
[80] S&P global (2022) Petrochemical Feedstocks. Available at: Link
[81] PwC (2019) Circular economy: A new source of competitive advantage in the chemicals industry. Available at: Link

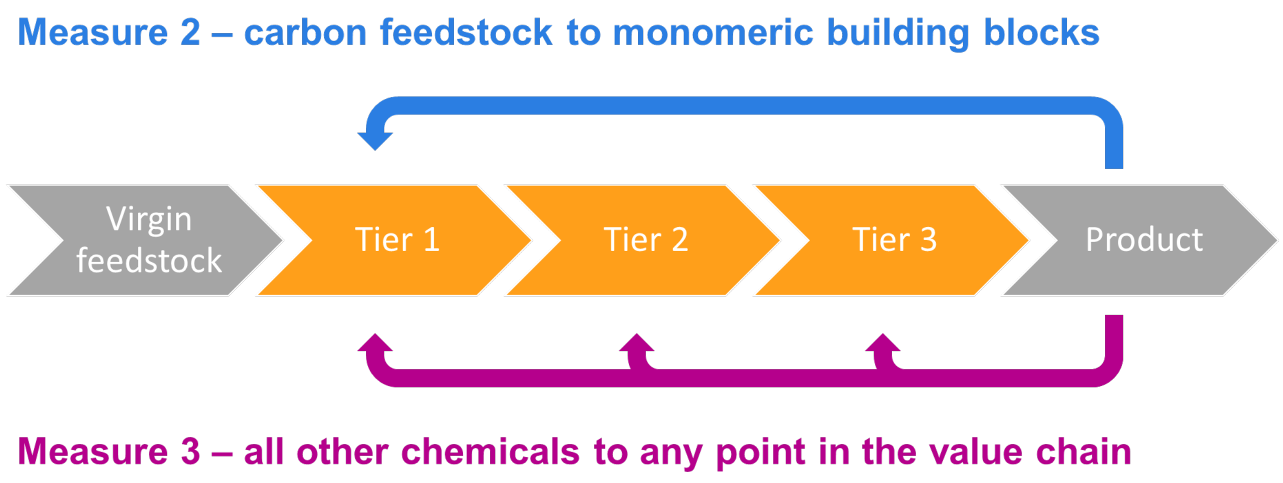
roadmap[82] and many multinational chemical manufacturers and users are publicly committing to this transition.[83, 84] Among the stakeholders interviewed and in reviewed literature, this measure is considered critical for enhancing resource efficiency and ensuring the long-term sustainability of the UK chemicals sector.[85]

The most promising alternative carbon feedstocks are biomass-based methanol (bio-methanol) and electricity-based methanol (e-methanol from CCUS and hydrogen), both of which can be used as a feedstock for building block chemicals production. Chemical recycling of plastics into monomers will also reduce the amount of primary carbon feedstock that will be required for chemical production.[86] Mechanical recycling of plastics recycling is elaborated on in the accompanying plastics sector study.

Definition of secondary carbon feedstocks

It is important to note that for this measure, secondary carbon feedstocks are considered to be a key substitute for virgin carbon. It is limited to recycling chemicals as a carbon (monomeric) feedstock at the beginning of the value chain, whereas Measure 3 (secondary material content) includes the recovery of all other chemicals as a secondary feedstock at any other point in the value chain as shown in Figure 2.

Figure 2: Difference between measure 2 and measure 3



This measure (Measure 2) is most applicable at the basic chemicals production level (Tier 1); however, substitution can be achieved at the front end of other subsectors such as basic feedstocks for pharmaceuticals which may otherwise be considered under Tier 3.

It is also important to note that Measure 3 covers all other chemicals (including organic) that can be reintroduced at any point within the chemicals sector. However, organic chemicals

82 Cefic (n.d.) The EU Chemical Industry Transition Pathway. Available at: Link
83 Unilever (2022) Unilever and Geno launch $120m venture to scale alternative ingredients. Available at: Link
84 Croda (2022) Sustainability targets. Available at: Link
85 Green alliance (2023) A new formula: Cutting the UK chemical industry's climate impact. Available at: Link
86 Lopez, G., Keinar, D., Fasihi, M., Koiranen, T., Breyer, C., (2023) From fossil to green chemicals: sustainable pathways and new carbon feedstocks for the global chemical industry. Available at: Link

entering Tier 2 and Tier 3 under Measure 3 must be in a more complete form that more closely resembles the final product. For example, waste organic paints may be reintroduced to Tier 3, under Measure 3, as they will be regenerated into paints again without needing to be broken down into monomeric basic building block feedstocks which is a requirement for Measure 2. Organic feedstocks cannot be reintroduced at Tier 1; under Measure 3 however, inorganic feedstocks can.

2.1.2 Measure indicator

Through discussion with stakeholders, the indicator '**% of fossil-based organic feedstock chemicals that have been substituted with alternative carbon feedstocks'** was selected for this measure.

As this is a substitution measure (rather than a reduction measure), a replacement factor is needed to understand the relative emissions from using alternative feedstocks against fossil-based feedstocks.

2.1.3 Examples in practice

Biomass

There are numerous examples of the use of alternative feedstocks within industry which are being increasingly explored by the chemicals sector. Biobased feedstocks are the most established alternative carbon feedstocks. The energy and chemicals industries in Brazil, for example, rely heavily on sugar cane stems as a significant source of organic feedstock for bio ethylene.[87] However, most chemical industry segments in the UK still heavily rely on fossil fuels.[88] Nonetheless, some companies are setting ambitious targets to reduce or eliminate fossil-based feedstock usage. For instance, Croda aims for over 75% of its organic raw materials to be biobased by 2030,[89] and Unilever pledged to source 100% of carbon for its cleaning and laundry products from renewable or recycled sources by 2030, partnering with Genomatica in 2022 to scale up alternative ingredients.[90]

Stakeholders noted that cross-sector collaboration (discussed further in Measure 6 (collaborative consumption)) has successfully promoted the use of secondary bio feedstocks for the chemicals industry in some sectors, such as the whisky industry selling leftover barley to bio-manufacturers.

Whilst focussing on biomass for energy rather than chemicals, analysis by the Climate Change Committee (CCC) in their 6th Carbon Budget report suggests the potential to triple current levels of imported biomass by 2050, depending on demand.[91] Modelling indicates that future domestic supply of sustainable biomass could fulfil about 10% of the UK's energy demand by 2050, with the majority sourced from biogenic waste and residue resources. The chemicals sector currently consumes 10% of fossil feedstocks and would therefore be in competition with

[87] Green Alliance (2023) A new formula: Cutting the UK chemical industry's climate impact. Available at: Link
[88] Green Alliance (2023) Can the UK's chemical industry wean itself off fossil fuels? Available at: Link
[89] Croda (2022) Sustainability targets. Available at: Link
[90] Unilever (2022) Unilever and Geno launch $120m venture to scale alternative ingredients. Available at: Link
[91] BEIS (2021) Biomass Policy Statement. Available at: Link

the energy sector (alongside other critical industries such as food) for these resources.[92] The latest UK Biomass Strategy[93] recognises significant competition for biomass within industrial sectors.

Carbon Capture and Utilisation (CCUS)

Combining CCUS with hydrogen to produce hydrocarbon feedstocks is a nascent but promising development. While CO_2 capture and utilisation have been practiced for many years, such as Covestro's factory in Germany that utilises CO_2 from a nearby coal-burning power plant to blow mattress and upholstery foam[94], the use of captured carbon as an alternative feedstock to replace fossil fuels is relatively limited to date.

However, there are noteworthy initiatives, like the £5.4 million FLUE-2-CHEM project, which is funded by UKRI. This project is assessing both the scientific and commercial viability of transforming waste flue gases (primarily CO_2) into surfactants for the consumer products market. It serves as an excellent example of collaboration, involving 13 partners across the entire supply chain, working to develop a process that transforms raw materials into a final marketable product. [95]

Chemical recycling

Chemical recycling of waste carbon feedstocks is another promising alternative. While various technologies exist globally, few large-scale examples effectively transform low-quality waste plastics into high-quality feedstock. Examples include the Quality Circular Polymers (joint venture between LyondellBasell Industries and Suez) in the Netherlands[96] and in the UK, the ReNew ELP site in Teesside, set to become the world's first HydroPRS™ site in 2023[97] and Quantafuel's plans to establish processing plants for converting low-value plastic waste into high-value products.[98]

One manufacturer stated in the workshop that PVC recycling has seen significant success, especially in the EU, noting the VinylPlus[99] programme which has enhanced the recycled PVC market significantly. However, much of this is likely to be via mechanical recycling which is beyond the scope of this measure. Furthermore, the VinylLoop chemical recycling process in Italy closed in 2018 as it was unable to remove additives sufficiently in line with recent EU REACH restriction of lead in PVC.[100]

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[92] S&P global (2022) Petrochemical Feedstocks. Available at: Link
[93] Department for Energy Security & Net Zero (2023) Biomass Strategy. Available at: Link
[94] PwC (2019) Circular economy: A new source of competitive advantage in the chemicals industry. Available at: Link
[95] Society of Chemical Industry (2023) Flue2Chem: SCI, Unilever and 13 partners launch £5.4m net zero collaboration project. Available at: Link
[96] https://www.qcpolymers.com/en/about-the-company/
[97] https://muratechnology.com/renewelp/
[98] https://www.quantafuel.com/sunderland
[99] VinylPlus® is the European PVC industry's commitment to sustainable development, working to improve the sustainability performance of PVC by aiming to enhance its recycling.
[100] PlastEurope.com (2018) VINYLOOP: Closure of operation in Italy / Phthalates issue under REACH brings down European PVC recycling project. Available at: Link

2.2 Available sources

2.2.1 Literature review

The literature review identified 23 sources, used in this report, that discussed the substitution of virgin fossil-based organic feedstocks, although there was little quantitative evidence on the future levels of resource efficiency that could be achieved through this measure. This comprised:

- eight industry reports;[101] [102] [103] [104] [105] [106] [107] [108]
- two academic papers;[109] [110]
- four policy documents;[111] [112] [113] [114] and
- nine website articles.[115] [116] [117] [118] [119] [120] [121] [122] [123]

A full list of the sources used in this measure are listed in Appendix C.

The relevant sources were considered of high applicability and credibility when assessed against the data assessment framework, which recognises the relevance of the sources and the strength of the methodology within each. The sources exhibited an average IAS of 4.2 (out

[101] Society of Chemical Industry (2023) Flue2Chem: SCI, Unilever and 13 partners launch £5.4m net zero collaboration project. Available at: Link
[102] Croda (2022) Sustainability targets. Available at: Link
[103] PwC (2019) Circular economy: A new source of competitive advantage in the chemicals industry. Available at: Link
[104] SystemIQ (2022) Planet Positive Chemicals. Available at: Link.
[105] Green alliance (2023) A new formula: Cutting the UK chemical industry's climate impact. Available at: Link
[106] Innovate UK KTN (2022) Report Launch: Unlocking the UK's biomass resources as a feedstock for Chemical Manufacturing. Available at: Link
[107] The Climate Change Commitee (2020) 6th Carbon Budget. Available at: Link
[108] Royal Society of Chemistry (2023) The PLFs Revolution. Available at: Link
[109] Lopez, G., Keinar, D., Fasihi, M., Koiranen, T., Breyer, C., (2023) From fossil to green chemicals: sustainable pathways and new carbon feedstocks for the global chemical industry. Available at: Link
[110] Ncube, A., Mtetwa, S., Bukhari,M., Fiorentino, G and Passaro, R (2023) Circular Economy and Green Chemistry: The Need for Radical Innovative Approaches in the Design for New Products. Available at: Link
[111] BEIS (2021) Biomass Policy Statement. Available at: Link
[112] BEIS (2021) Industrial decarbonisation strategy. Available at: Link
[113] Department for Energy Security & Net Zero (2023) Biomass Strategy. Available at: Link
[114] UK Government (2023) Carbon capture, usage and storage net zero investment roadmap. Available at: Link
[115] Unilever (2022) Unilever and Geno launch $120m venture to scale alternative ingredients. Available at: Link
[116] International Energy Agency (2021) Net Zero by 2050: A Roadmap for the Global Energy Sector. Available at: Link
[117] S&P global (2022) Petrochemical Feedstocks. Available at: Link
[118] Cefic (n.d.) The EU Chemical Industry Transition Pathway. Available at: Link
[119] UK Government (2023). Plastic packaging tax – chemical recycling and adoption of a mass balance approach [Closed Consultation]. Available at: Link
[120] World Bank, (2022) Sufficiency, sustainability and circularity of critical materials for clean hydrogen. Available at: Link
[121] Renewable Carbon Initiative (2023) RCI Carbon Flows Report: Compilation of supply and demand of fossil and renewable carbon on a global and European level. P.76. Available at: Link
[122] PlastEurope.com (2018) VINYLOOP: Closure of operation in Italy / Phthalates issue under REACH brings down European PVC recycling project. Available at: Link. Available at: Link
[123] Gov.UK (2023) New vision to create competitive carbon capture market follows unprecedented £20 billion investment. Available at: Link

of 5), with 15 sources exhibiting a score of 4 or above. 11 literature sources were UK-specific and all the sources were published recently (within the last 5 years). The interviews were used to test the literature review findings and fill knowledge gaps.

2.2.2 Interviews

Stakeholders unanimously agreed that this measure is vital for enhancing resource efficiency and ensuring the long-term sustainability of the chemicals sector. They stressed the importance of incorporating diverse feedstocks to transition away from fossil fuels, as no single feedstock can offer a complete solution. One stakeholder noted that even a complete switch to alternative feedstocks might not be sufficient to meet net-zero targets without reducing the size of the chemicals sector altogether. Another argued that transitioning from hydrocarbon fuels (from the energy and transportation sectors) toward renewable/ electricity/ hydrogen fuels could potentially release sufficient biobased feedstock (that are currently used as fuels) to support a significant portion of the chemicals industry in the long term. However, questions were raised about its feasibility given competition with other sectors in the shorter to medium term such as sustainable aviation fuels.

Stakeholders acknowledged that both industry and government recognise the importance of this measure but stressed the need for action in its implementation. While there is momentum within the industry, more concerted efforts are required to establish a coherent strategy and provide clear signals that encourage industry investment in these transformative changes. It was also suggested that support should be directed towards early adopters who embrace new technologies as soon as they become available, as their actions can lead the way for others to follow suit.

Stakeholders also noted that whilst biobased feedstock is a good potential alternative to fossil feedstocks, they emphasised that there remain significant ethical and practical issues with its use such as competition with food and habitat destruction to produce fuel crops. Nevertheless, stakeholders agreed that priority should be given to using bio feedstocks as a valuable chemical feedstock rather than as an energy feedstock which would result in immediate re-release of carbon in the atmosphere. Using biobased feedstocks in longer-life items such as chemicals (within products), sequesters atmospheric carbon for longer and places higher value on it.

Another stakeholder believed that even when all alternatives are considered, none of them alone are sufficiently well developed to fully replace fossil-based carbon entirely by 2035 and that a transition to net zero would require downsizing the industry as a whole. This view was shared by the majority of stakeholders. However, stakeholders widely agreed that, while currently nascent, CCUS and chemical recycling could see significant growth in the coming decades which would support the transition away from fossil-based feedstocks.[124,125] The UK

[124] Gov.UK (2023) New vision to create competitive carbon capture market follows unprecedented £20 billion investment. Available at: Link
[125] The Climate Change Commitee (2020) 6th Carbon Budget. Available at: Link

government has set out plans for a new competitive UK carbon capture, usage and storage market by 2035 through a recent £20 billion investment.

2.2.3 Workshop

Workshop participants supported the inclusion of this measure as an action towards resource efficiency in the chemicals sector. Stakeholders noted that the main theme of the measure is the circularisation of the carbon economy and that it is important for the government to consider all three substitution options together as none of them alone would be sufficient to meet targets. It was suggested that all solutions aim to achieve the same goal and should thus be seen as a combined policy.

A main point of clarification that was discussed was whether this measure aims to substitute all fossil-based (including secondary carbon) or solely virgin fossil-based resources. As a result, this measure was renamed to specify the substitution of virgin fossil-feedstocks.

A point of discussion was the difference between CCS and CCU and the role of CCS in resource efficiency. It was clarified that CCS theoretically offers long-term storage of carbon that can be used in the future and was included in this measure for that reason. However, stakeholders were sceptical as to whether stored carbon would be feasibly accessible as a feedstock in future. One stakeholder noted that the latest UK Biomass Strategy[126] largely expanded upon the storage of carbon, rather than the utilisation component.

The level of engagement in the workshop was as follows:

- Eight stakeholders across industry and academia were active on the mural board and five stakeholders actively contributed to verbal discussion.

2.3 Drivers & Barriers

2.3.1 Drivers

Table 9 below shows the main drivers for Measure 2. The most significant drivers are shown in bold as voted for by stakeholders in the workshop.

Table 9: Drivers for chemicals measure 2

Description	PESTLE	COM-B
Government strategy promotes development of alternative feedstocks	**Political**	**Capability – psychological**
Net Zero Commitments	**Social / Political / Legal**	**Motivation – automatic**

[126] DESNZ (2023) Biomass Strategy. Available at: Link

Consumers demand more sustainable products	Social	Opportunity – social
UK chemicals industry can build upon its competitive advantage	Environmental	Opportunity – physical
Improved transparency of feedstock availability	Technological	Capability – physical
Mandatory carbon reporting may stimulate market	Economic	Motivation – automatic

Government strategy promotes development of alternative feedstocks

Stakeholders agreed in the workshop that clear and consistent government guidance on the development of alternative feedstocks could be a key driver for this measure. Stakeholders were keen to note that consideration of all three options should be considered as part of cohesive policy making. This could include the support and promotion of CCUS, chemical recycling and the bioeconomy which are currently largely treated as separate policy ambitions with responsibility sitting within different areas of government.

There is currently support for CCUS, within government strategy.[127,128] Government recognises the need to capture carbon and combine with hydrogen as outlined in the Industrial Decarbonisation Strategy[129] and demonstrated by the planned industrial carbon capture and storage (CCS) clusters around the UK as set out in the CCUS Net Zero Investment Roadmap[130, 131] It is also expected to play a key role within the UK's Biomass Strategy[132] where use of CCUS will increase the availability of carbon to bind with hydrogen which can be used as an alternative feedstock. The strategy for the development of CCUS provides the signals to industry to invest in the development of this technology and subsequently reduce costs.

Similarly to CCUS, the UK has acknowledged the resource efficiency benefits of chemical recycling for plastic waste materials. Chemical recycling is (briefly) mentioned in the 'Resource and Waste Strategy for England'[133] as having the potential to be complementary where mechanical recycling is infeasible. The Government recently undertook a consultation to gather views on the potential adoption of a mass balance approach for chemically recycled plastic as

127 Green alliance (2023) A new formula: Cutting the UK chemical industry's climate impact. Available at: Link
128 Gov.UK (2023) New vision to create competitive carbon capture market follows unprecedented £20 billion investment. Available at: Link
129 BEIS (2021) Industrial decarbonisation strategy. Available at: Link
130 UK Government (2023) Carbon capture, usage and storage net zero investment roadmap. Available at: Link
131 Green alliance (2023) A new formula: Cutting the UK chemical industry's climate impact. Available at: Link
132 Department for Energy Security & Net Zero (2023) Biomass Strategy. Available at: Link
133 HM Government, OUR WASTE, OUR RESOURCES: A STRATEGY FOR ENGLAND. Available at: Link

part of the Plastic Packaging Tax (PPT).[134] This is because several stakeholders across the plastics value chain have raised concerns that it is sometimes not possible for businesses to distinguish between plastic from virgin sources and chemically recycled plastic. This lack of distinction means that producers which use chemically recycled plastic in packaging, could still be exposed to the PPT, as they cannot prove that its packaging contains sufficient recycled content to avoid paying the tax. Thus, the UK government intends to further progress the development of the PPT in order to both boost chemical recycling.

The UK government actively promotes the bioeconomy and aims to create a larger supply of bio feedstocks, this is accentuated by its recent publication of the Biomass Strategy.[135] This strategy outlines a comprehensive plan to harness the potential of biological resources sustainably. It underscores the government's commitment to advancing bio-based industries, fostering innovation and ensuring the responsible management of biomass resources. The strategy's key objectives include expanding the availability of bio feedstocks (domestically and from imports), supporting research and development in bioenergy and bioproducts and encouraging the adoption of sustainable practices throughout the biomass value chain. By doing so, the UK aims to not only enhance its economic resilience but also contribute significantly to environmental sustainability and carbon reduction efforts.[136] Furthermore, consideration should be given to directing biomass to higher value, higher employment markets, such as fine and speciality chemicals, materials (etc.) to ensure maximum value extraction from the finite biomass feedstocks.[137] The strategy for the development of the UK bioeconomy provides the signals to industry to invest in the development of carbon-based feedstocks to drive higher levels of biofeedstock availability and increase demand.

Net zero commitments

With consumer demand for green products increasing, companies are encouraged to implement sustainability commitments.[138] This driver is particularly relevant for organisations with net-zero commitments or organisations that supply consumer products. To realise such commitments, companies will opt for alternative solutions that reduce reliance on fossil feedstocks. Thus, this driver may encourage manufacturers to focus on substituting the main fossil-based feedstocks with greener chemicals, driving higher market demand and potentially expanding their application in the sector. Furthermore, companies will be investigating their supply chains due to consumer and investor pressure which has ripple effects further up the value chain. This was further confirmed in the workshop with stakeholders mentioning that this measure plays a crucial role in meeting net zero commitments.

Consumers demand more sustainable products

[134] UK Government (2023). Plastic packaging tax – chemical recycling and adoption of a mass balance approach [Closed Consultation]. Available at: Link
[135] Department for Energy Security & Net Zero (2023) Biomass Strategy. Available at: Link
[136] Department for Energy Security & Net Zero (2023) Biomass Strategy. Available at: Link
[137] BEIS (2021) Biomass Policy Statement. Available at: Link
[138] Ncube, A., Mtetwa, S., Bukhari,M., Fiorentino, G and Passaro, R (2023) Circular Economy and Green Chemistry: The Need for Radical Innovative Approaches in the Design for New Products. Available at: Link

Consumer demand for greener products with lower resource use and carbon intensity, is one of the key drivers identified in literature. With one source noting that consumer product companies who can provide more sustainable offerings have benefitted greatly from increased consumer awareness and demand for such products.[139] However, stakeholders noted that this driver is stronger in certain segments than others. For example, consumer facing industries (Tier 3) are more driven by this aspect as they are responsible for the manufacture of consumer products. The Tier 1 and Tier 2 chemicals companies are involved in the manufacture of primary or intermediate chemicals may be less directly influenced by this driver. As Tier 3 companies demand more green chemicals to generate more sustainable products, it is likely that this driver will have ripple effects to Tier 1 and Tier 2 companies.

UK chemicals industry can build upon its competitive advantage

The UK chemical industry's advantage of generating lower emissions per tonne of chemical than the global average can be a significant driver towards further resource efficiency.[140] There has already been significant UK investment in solutions revolving around biobased, CCUS and chemically recycled materials. The UK chemical industry already generates lower emissions per tonne of chemical than the global average, due to the choice of feedstock, which could be seen as a competitive advantage when developing lower carbon products. Thus, as an established leader in innovation and R&D, the UK chemicals sector has an opportunity to build upon its competitive advantage, to become a low-carbon competitor in the global chemicals market by promoting and increasing the use of substitute feedstocks.[141, 142] Stakeholders noted that adoption of this measure could be an opportunity to boost the UK chemistry-based industries.

Improved transparency of feedstock availability

In a 2022 report, Innovate UK noted that an up-to-date database of biomass availability across the UK would provide clarity on volumes and availabilities of different feedstocks and allow for more fluid trade between the producers and users of biomass, to maximise efficiency.[143] Such a database would also provide information on geographic spread and seasonal variation. Similar databases for alternative feedstocks other than biomass may also provide visibility of the supply and thus increase accessibility to such feedstocks. Although stakeholders noted that attempts at similar databases have been unsuccessful as businesses have been reluctant to share commercially sensitive information such as product volumes due to the limited number of market players.

Mandatory carbon reporting may stimulate market

[139] Ncube, A., Mtetwa, S., Bukhari,M., Fiorentino, G and Passaro, R (2023) Circular Economy and Green Chemistry: The Need for Radical Innovative Approaches in the Design for New Products. Available at: Link
[140] Green alliance (2023) A new formula: Cutting the UK chemical industry's climate impact. Available at: Link
[141] House of Commons (2018) Chemicals Sector Report. Available at: Link
[142] Green alliance (2023) A new formula: Cutting the UK chemical industry's climate impact. Available at: Link
[143] Innovate UK KTN (2022) Report Launch: Unlocking the UK's biomass resources as a feedstock for Chemical Manufacturing. Available at: Link

Scope 3 reporting currently occurs on a voluntary basis. Improvements in the reporting of carbon emissions may stimulate industry to adopt low-carbon feedstocks with fewer imbedded emissions. Through mandatory reporting of scope 3 emissions, companies would have to be transparent about their operating models and thus be encouraged to shift their upstream and downstream operations to demonstrate emission savings. In this instance, the substitution of fossil-based feedstocks with green alternatives would be a significant change in the upstream phase of chemicals production and is therefore seen as a favourable solution. It is likely that such a transition will subsequently stimulate the green chemicals market with higher demand for supply. One of the stakeholders emphasised the importance of this driver, as the visibility of the carbon footprint will lead to increased pressure on the industry.

2.3.2 Barriers

Table 10 below shows the main barriers for Measure 2. The most significant barriers are shown in bold as voted for by stakeholders in the workshops.

Table 10: Barriers for chemicals measure 2

Description	PESTLE	COM-B
Availability of cheap, low carbon energy	**Technological**	**Opportunity – physical**
Pricing of alternative feedstocks is uncompetitive	**Economic**	**Opportunity – physical**
Wider environmental issues with alternative feedstocks	**Environmental**	**Opportunity – physical**
Competition with other sectors	**Economic**	**Opportunity – physical**
Lack of consideration of risks and trade-offs in policy support guidance	**Political**	**Capability – psychological**
High investment in equipment	Economic	Capability – physical
Variability of alternative feedstocks	Technological	Opportunity – physical
Lack of technology proof of concept	Technological	Capability – physical
Scale up risks of green hydrogen and CCU	Economic	Capability – physical

Slow development of value chains	Economic / Technological	Opportunity – physical
Lack of clear policy focus and direction	Political	Opportunity – social
Limited consumer demand	Social	Opportunity – social
Net Zero as a major challenge for the industry	Environmental / Political / Legal	Capability – physical
Knock-on effects of changing manufacturing systems in product value chains	Technological	Capability – physical
Considerations of other sectors during development of regulation	Legal	Opportunity – physical
Lack of technology diversity across sub-sectors	Technological	Capability – physical

Availability of cheap, low carbon energy

During the chemicals sector workshop, stakeholders emphasised that an important barrier is the availability of cheap, low carbon energy required to implement this measure. Another participant agreed, adding that it is critical to have renewable electrical energy available on demand with supply continuity. Stakeholders were keen to point out that this measure, along with wider decarbonisation of the sector will not be feasible without access to consistent, low-cost, renewable energy.

Pricing of alternative feedstocks is uncompetitive

Stakeholders pointed out that a significant challenge to implementing this measure is the need to attain a competitive cost for alternative feedstocks and products, which are currently more expensive than their fossil-based counterparts. They emphasised that scaling up production of alternative feedstocks to generate markets and ultimately reduce the cost of collection and processing of these feedstocks is essential to encourage the adoption of this measure. It is crucial for both market demand (push) and product availability (pull) to align and complement each other effectively. Stakeholders indicated that biobased feedstocks are closest to price parity with virgin feedstock and that CCUS is furthest. Chemical recycling requires significant work/investment to make it competitive.

Wider environmental issues with alternative feedstocks

Increased biomass production can result in emissions stemming from displacement effects known as indirect land use change (ILUC). Rainforests and grasslands comprise an example source of such additional emissions. In natural ecosystems, carbon released from the growth of flora is normally stored in the soil and biomass. However, when these areas are converted into new agricultural developments, there is a net increase in greenhouse gas emissions. Thus, by replacing natural ecosystems with artificial landscapes, emissions increase, contributing to climate change.

The environmental effects of ILUC can outweigh direct emissions benefits from using biomass.[144] Stakeholders noted that whilst a partial transition to biobased feedstocks is likely to be beneficial, a large-scale, or complete, transition to biobased feedstock could introduce wider environmental and societal issues. One stakeholder in the workshop therefore argued that full Lifecycle analysis is required for any alternative feedstocks.

Competition with other sectors

There is likely to be high levels of competing demand for alternative feedstocks, particularly biomass, from other sectors, including the energy and aviation sectors, meaning that a consistent, low cost, supply could be difficult to attain.[145] Stakeholders noted that care needs to be taken to promote the use of alternative feedstocks in higher value applications, such as chemicals, since these products are retained within the economy for more extended periods compared to fuels. As a result, longer-lasting carbon-based products act as sequesters of carbon for longer periods of time and are typically more useful and thus have greater value over their lifetime than fuels. For instance, the use of biobased feedstocks for fuels like Sustainable Aviation Fuel (SAF), release carbon into the atmosphere more readily than other durable chemicals. Nevertheless, current regulatory frameworks promote the use in fuels over other uses which was highlighted as a concern among stakeholders.[146]

Lack of consideration of risks and trade-offs in policy guidance

Alternative feedstocks have the potential to replace most fossil-derived virgin feedstocks, but the trade-offs between the alternatives and the significant risk of new and increasing impacts on nature are not yet properly examined and managed in UK policy. For example, the Biomass Strategy does not include a robust hierarchy that outlines the risks and trade-offs of the applications of different types of biomass, green hydrogen or captured carbon.[147] In the workshop, one stakeholder mentioned that due to this lack of policy it is currently too risky to drive major investments in this area.

High investment in equipment

Stakeholders highlighted that making substantial changes to the process and equipment may be necessary when switching to different feedstocks. If a transition involves using alternative bio-based versions of the feedstocks already in use (such as bio-ethylene instead of ethylene),

[144] Department for Energy Security & Net Zero (2023) Biomass Strategy. Available at: Link
[145] Department for Energy Security & Net Zero (2023) Biomass Strategy. Available at: Link
[146] Green alliance (2023) A new formula: Cutting the UK chemical industry's climate impact. Available at: Link
[147] Department for Energy Security & Net Zero (2023) Biomass Strategy. Available at: Link

the adjustments required would be relatively minor. However, if an entirely different feedstock is introduced (for example, bio-methanol), this could require significant investments in modifying both the processes and the equipment. Variations of biobased, chemical recycling and CCUS feedstocks may be more readily available as a drop-in replacement however investment in technology at the front end of the process would still be required to convert the material into useful feedstocks that are compatible with existing infrastructure.

Variability of alternative feedstocks

Stakeholders noted that alternative feedstocks, especially those derived from biobased and chemical recycling sources, exhibit more variability in terms of both their availability and composition compared to fossil-based feedstocks. Stakeholders stressed that, while this is not an insurmountable challenge, operators will need to develop a better understanding of variations and introduce greater flexibility to accommodate them in the process. For example, when it comes to chemical recycling into monomers, the plastic feedstock can exhibit variations in composition, quality and quantity on a daily or regional basis. This means there isn't the same level of consistency as with virgin hydrocarbon feedstock. While operators and waste management firms can make efforts to minimise these variations in supply by stockpiling, some degree of inconsistency should be anticipated therefore the process should be specified to accept these variations. Similarly, biobased feedstocks may also show inconsistencies in their composition, quality and quantity depending on the supplier, time of year and location. In contrast, these issues are less prominent with CCUS.

Lack of technology proof of concept

One source identified that while industry has committed to reducing the sector's GHG emissions by 90% by 2050, many plans are dependent on government support.[148] This is corroborated by one of the stakeholders who noted that industry is waiting for the development of infrastructure, such as CCUS clusters, before investing themselves. Enhanced support from research and development will be required to facilitate upscaling of CCUS such as through investment for early plant deployment.

Stakeholders also noted that there has been relatively limited ambition and application of pilot plants for biobased feedstocks within industry which has hindered the proof of concept at scale. Proof of successful scale up of chemical recycling is also yet to be demonstrated. This was further supported by one stakeholder in the workshop, who emphasised the need for larger demonstration facilities.

Scale up risks of green hydrogen and CCU

While CCU and green hydrogen are key parts of the UK government's Industrial Decarbonisation Strategy,[149] there are inherent risks associated with scaling them up. Despite significant investment in hydrogen as an alternative feedstock, there remain significant

[148] Green alliance (2023) A new formula: Cutting the UK chemical industry's climate impact. Available at: Link
[149] UK Government (2021) Industrial Decarbonisation Strategy. Available at: Link

compatibility, capacity and efficiency limitations.[150] This was corroborated by stakeholders who agreed that hydrogen is currently too expensive (energy intensive and dangerous) to store and transport which has prevented proof of scale. Furthermore, green hydrogen requires the significant use of critical minerals such as aluminium, zinc, copper and nickel which have environmental, social and supply chain issues.[151]

Slow development of value chains

This transition to a chemical sector that manufactures chemicals from non-fossil feedstocks will require creation of new value chains, cross-sector partnerships and business models that allow the sector to create value from alternative feedstocks. This may be because not all manufacturers have easy access to such feedstocks, or are unaware of the available supply.

A report by Innovate UK about the use of biomass as a feedstock for the chemical manufacturing industry found that a lack of communication between the providers of biomass, such as growers and end-users was a key barrier.[152] Similarly, chemical recycling of plastics is heavily interlinked with the waste industry and consistent supply of waste plastics at scale is required which needs collaboration among producers, consumers, local authorities etc. which takes significant time and effort from stakeholders to achieve.

Lack of clear policy focus and direction

In a survey undertaken by Innovate UK, 89% of participants answered that despite the publication of high-level government strategies, there was insufficient clarity, focus and direction within them to signal investment by the chemical manufacturing industry.[153] This was corroborated by the stakeholders, who mentioned there was not enough focus on sustainability as a sector. The stakeholders emphasised the need for a carefully mapped out sustainable transition strategy, which addresses concerns around stranded assets and a wholesale change in the way the industry operates. While the government has allocated R&D support for CCUS, one report from the Green Alliance argued that current government industrial policy leans heavily on CCS and hydrogen for industrial emissions reductions, with comparatively less support for electrification and resource efficiency which might steer companies towards less optimal solutions creates a barrier towards improved resource efficiency.[154]

Current government industrial policy leans heavily on CCS and hydrogen for industrial emissions reductions, with comparatively less support for electrification and resource efficiency. In the workshop, one stakeholder argued that there are limitations to focusing too much on one solution/strategy independently from other technologies. They highlighted that it is important than multiple options are considered and attention isn’t solely focussed on one

[150] Green alliance (2023) A new formula: Cutting the UK chemical industry's climate impact. Available at: Link
[151] World Bank, (2022) Sufficiency, sustainability and circularity of critical materials for clean hydrogen. Available at: Link
[152] Innovate UK KTN (2022) Report Launch: Unlocking the UK's biomass resources as a feedstock for Chemical Manufacturing. Available at: Link
[153] Innovate UK KTN (2022) Report Launch: Unlocking the UK's biomass resources as a feedstock for Chemical Manufacturing. Available at: Link
[154] Green alliance (2023) A new formula: Cutting the UK chemical industry's climate impact. Available at: Link

winning option. One stakeholder mentioned that due to this lack of policy it is currently too risky to drive major investments in this area.

These concerns were echoed on the use of hydrogen in other sectors, such as energy and transportation. Similar concerns also apply to chemical recycling feedstocks where there is a need to develop them to be competitive with virgin feedstocks but not so much so as to favour its use over other more sustainable alternatives such as mechanical recycling of plastics – in line with the waste hierarchy.

Limited consumer demand

Whilst consumers are increasing their appetite for sustainable products in certain segments, the interviews revealed that there is relatively limited consumer/end user demand for biobased chemicals in others, particularly within industries like coatings. Stakeholders pointed out that even though many consumers express support for biobased products, there isn't a strong enough incentive for them to pay a premium for these alternatives. One stakeholder also highlighted a disconnect between what consumers claim to prefer and what they are genuinely interested in or willing to invest in. Stakeholders also indicated that this measure is not as strong for segments such as pharmaceuticals and agriculture, who are under less consumer pressure for green products.

Net Zero as a major challenge for the industry

The transition to a net zero economy will be a major challenge for the chemicals industry, which lacks a robust route for lowering its carbon emissions and has generally relied on incremental, conservative investment in solutions. The sector is highly dependent on government actions towards CCS infrastructure development and has avoided implementing more impactful changes in its operations. Additionally, stakeholders indicated that net zero commitments are not as strong for segments such as pharmaceuticals and agriculture who are under less consumer pressure for green products.

Knock-on effects of changing manufacturing systems in product value chains

Changes in one process can jeopardise the production of feedstock for another. Manufacturing systems are extensively interconnected, with many product value chains operating at the global level. Implementing change in one part of the system therefore has knock-on effects and implementing safe and sustainable by design approaches requires effective collaboration throughout the product value chain, from production through to waste management, reuse and recycling. In the workshop, one stakeholder mentioned that these knock-on effects could significantly affect the availability of resources, thus changing the production landscape.

Considerations of other sectors during development of regulation

Stakeholders noted the importance of developing regulation so that it meets overarching resource efficiency objectives rather than being limited to one particular sector or technology. For example, there are clear drivers for the use of chemical recycling for poor quality plastics, but this should not become the default treatment method for plastics, in line with the waste hierarchy. Support for alternative feedstock industries is necessary whilst ensuring it doesn't out-compete preferable treatment methods or sectors that would be preferable from overall resource efficiency perspective such as chemical recycling of plastics over mechanical recycling. Stakeholders also pointed out that the current regulations for sustainable aviation fuel favour the use of biobased feedstocks for aviation fuel, as opposed to other industries like the chemicals sector. This preference has led to a significant portion of the biobased feedstock being combusted as a fuel for aviation purposes, rather than being preserved and utilised for other, longer-life, applications.

Lack of technology diversity across sub-sectors

Diversity in the adoption of various technologies throughout the sector, instead of relying heavily on particular ones, is important to ensure different facets of the sector are addressed. This approach ensures that multiple points within the sector benefit from alternative feedstocks, rather than placing all bets on just a few technologies. For example, polymers in liquid formulations (PLFs) make up a significant proportion of polymers on the consumer market but receive relatively little focus compared to plastics in the development of alternative feedstocks. PLFs are a broad group of polymers that are used as thickeners, emulsifiers and binders in products including household detergents, cosmetics and agrochemicals with around 36 million tonnes produced annually worldwide from fossil feedstocks. However, while progress has been made on biobased plastics, comparatively little attention has been paid to the sustainable production of PLFs, which is a large opportunity to improving polymer resource efficiency.[155] Improving resource efficiency requires investment/ investigation of alternative feedstocks all areas of the chemicals sector in order to achieve wider resource efficiency aims rather than focussing on single, high priority segments.

2.4 Levels of efficiency

Table 11: Levels of efficiency for chemicals measure 2

Indicator: % of fossil-based organic feedstock chemicals that have been substituted with alternative carbon feedstocks			
Level of efficiency	Current	Maximum in 2035	Business-as-usual in 2035
Value	3–10%	21-40%	6-15%
Evidence RAG	Amber-Green	Red-Amber	Amber

[155] Royal Society of Chemistry (2023) The PLFs Revolution. Available at: Link

2.4.1 Current level of efficiency

It is estimated that globally, 98% of chemicals are produced using fossil feedstocks[156]. Although specific data for the UK could not be found, estimates for the EU-27 suggested that 93% of embedded carbon in certain chemicals segments is fossil-based.[157] Due to the absence of data at the interview stage, stakeholders worked off the basis that approximately 10% (provided by one stakeholder) of carbon feedstocks are currently from alternative feedstocks which informed their estimates for the BAU and maximum levels of efficiency. This estimate received support from multiple stakeholders for indicative purposes and corresponds with the subsequently found EU-27 data.

Stakeholders emphasised that biobased feedstocks are the most developed among the alternatives, likely constituting most alternative feedstocks. However, one stakeholder suggested that only an "extremely low" proportion of feedstocks in the chemicals industry are biobased. Regardless, stakeholders noted that biobased feedstocks are used across most segments, with significant variations by segment. For instance, high-value products, especially in pharmaceuticals, rely more on biobased feedstocks compared to segments prioritising low-cost bulk chemicals, like agrichemicals; however, detailed data by segment could not be obtained.

Of the current, non-virgin carbon feedstocks, bio-based feedstocks make up approximately 55% of non-fossil feedstocks and recycled chemicals make up 45% of non-fossil feedstocks.[158] CCUS and chemical recycling of plastics are less developed alternatives therefore making up a negligible portion of non-fossil feedstocks. [159] In the workshop there was a lack of consensus over current levels of implementation of CCU as a feedstock within industry. Two stakeholders argued that there is some activity, but mostly at the "experimental" level and that the growth of non-virgin carbon feedstock use is dwarfed by the continued growth in overall market demand for carbon therefore a low range of 3-5% is likely. Others argued with medium certainty that there are already sectors that use significant use of bio-based feedstocks, which is the main current source of alternative carbon. They also highlighted that in some sectors, bio-based can exceed 10% (e.g., personal care products) and much lower in others (e.g., bulk chemicals). When considering the wide range of chemicals/materials within the sector, there are significant gaps in what is being done. A lot may not be being accounted at this stage.

The estimated range for the percentage of alternative feedstocks replacing fossil-based feedstock chemicals is between 3% and 10% depending on the chemical process or product. This was further supported in the workshop, where the stakeholders were split in their votes, with the majority of the votes being for either 3-5% or 6-10%, but one vote with high confidence for 0-2%. The lower end represents the global value, while the upper end represents an ambitious estimate for the UK provided by stakeholders. The evidence RAG rating for this

[156] Green alliance (2023) A new formula: Cutting the UK chemical industry's climate impact. Available at: Link
[157] Renewable Carbon Initiative (2023) RCI Carbon Flows Report: Compilation of supply and demand of fossil and renewable carbon on a global and European level. P.76. Available at: Link
[158] Renewable Carbon Initiative (2023) RCI Carbon Flows Report: Compilation of supply and demand of fossil and renewable carbon on a global and European level. P.76. Available at: Link
[159] Renewable Carbon Initiative (2023) RCI Carbon Flows Report: Compilation of supply and demand of fossil and renewable carbon on a global and European level. P.76. Available at: Link

efficiency range is amber-green, indicating a reasonably high degree of certainty despite lacking UK-based literature evidence, as there was some agreement among stakeholders that this estimate is reasonable.

2.4.2 Maximum level of efficiency in 2035

One stakeholder noted that it may be feasible for the entire chemical industry to be supplied with bio-based feedstocks that are currently used for energy and transportation. Once hydrocarbon fuels are phased out for these sectors, this material could be available for the chemicals sector. However, stakeholders collectively agreed that a future scenario would likely involve a combination of all three alternative feedstocks, but none could provide specific proportions for this mix for 2035. One global scenario estimates that, were the chemicals sector to transition to 100% alternative feedstocks by 2050, 20% would be biobased, 25% CO_2-based and 55% from recycling.[160] Note that these values are not specific to the UK and this could not be corroborated by stakeholders in the workshop.

One stakeholder suggested that an ambitious target of 30% non-fossil feedstocks by 2035 would give the correct signals to industry. However, they noted that this is unlikely to be achievable in practice, and they acknowledged its practical challenges. Another stakeholder suggested an absolute maximum estimate of 50% by 2035, which would be highly challenging to attain and would require substantial support. Stakeholders generally agreed in interviews that 50% was highly ambitious and that a value closer to 30% was a more reasonable maximum level of efficiency estimate. However, in the workshop, stakeholders were split in their votes between 21-30% and >30%, with only one vote for 11-20% suggesting that there is substantial scope to improve this measure significantly by 2035.

From discussion with stakeholders and in the workshop, it was inferred that a best-case maximum level of efficiency could exceed 30% although no specific maximum was provided by stakeholders. The 50% value from one stakeholder was excluded as it was considered ‘too ambitious’ by other stakeholders in interviews. A range of 21-40% was decided based on the workshop voting. The evidence RAG rating for this level of efficiency is red-amber because it is not supported by evidence in literature and a lack of consensus among stakeholders. However, stakeholders were unanimously ambitious, suggesting that significant improvements can be made to this measure.

2.4.3 Business-as-usual in 2035

As with the maximum level of efficiency, stakeholders suggested that a BAU scenario would probably involve a blend of the three alternative feedstocks. Bio-based feedstocks are expected to be the first to see widespread adoption due to their cost-effectiveness in reducing carbon emissions whereas the adoption of CCUS and chemical recycling may lag behind unless substantial investments and support are provided.

[160] Renewable Carbon Initiative (2023) RCI Carbon Flows Report: Compilation of supply and demand of fossil and renewable carbon on a global and European level. P.54. Available at: Link

Stakeholders were less confident in providing a specific BAU efficiency level in the interviews. One stakeholder tentatively estimated a range of 20-30% by 2035, while another stakeholder considered 15% of all carbon feedstocks coming from alternative sources to be an ambitious BAU estimate given the current trajectory. However, in the workshop a majority of stakeholders provided estimates of 6-15% with a high degree of confidence. The evidence RAG rating for this level of efficiency is amber because it is not supported by evidence in literature but there was agreement among stakeholders, with a good level of confidence, that it is a reasonable estimate. However, stakeholders noted that there are significant challenges to overcome in order to meet these levels such as improving feedstock reliability and decisive investment in technologies. One stakeholder noted that this level of efficiency is mainly driven by commercialisation of chemical recycling technologies for polymers.

3.0 Measure 3 – Secondary material content

3.1 Chemicals resource efficiency measure

3.1.1 Description

Increasing the use of secondary, post-use, material content in chemicals production.

This measure is concerned with the utilisation of secondary materials as an input to the chemicals industry. More precisely, it pertains to the use of secondary materials that have already served their initial primary purpose, as opposed to by-products from chemical reactions or unused reagents from chemical processes, which are covered under Measure 6 (collaborative consumption).

This measure encompasses materials that would otherwise become waste and includes recycling, as well as the reuse, regeneration or remanufacture of waste chemicals/products into secondary products. It is important to note that the final secondary product may differ from the primary product.

However, it is worth mentioning that this measure excludes materials intended for use as raw carbon feedstock for the petrochemicals industry, such as plastic chemical recycling or methane recovery, as these are addressed in Measure 2 (substitution of fossil-based feedstocks) as demonstrated in Figure 2. Instead, this measure concentrates on other materials within the chemicals industry, such as the reuse or regeneration of substances like paints, lubricants, solvents and catalysts, among others.

This measure can be implemented across all tiers of the chemicals sector. Nevertheless, post-use secondary materials are usually tailored to their particular segment, making them more suitable for use further down the supply chain, typically from Tier 2 to Tier 3. Stakeholders noted that uptake of this measure will vary by segment and for some it may add little-to-no benefit. For example, stakeholders noted that agrichemicals are not suitable for recovery due to their dispersive nature and there are limited benefits to end-users. Whereas some consumer-facing industries/products such as domestic paints are more suitable as there is consumer appetite. However, it was not possible to break the data down by the ONS segments listed in Table 2 for this measure. Within each segment, there may be nuanced opportunities for use of secondary materials. As this is a substitution measure (rather than a reduction measure), a replacement factor is needed to understand the relative emissions from using secondary material.

3.1.2 Measure indicator

The '**% in weight of recycled/secondary post-use material content in chemicals production'** was selected as an indicator for this measure. It demonstrates the percentage of virgin material that has been displaced, and the recycled/secondary post-use material that would otherwise be classified and treated as waste. This incorporates end of life consumer waste (e.g., unused/waste paints) and process wastes (e.g., cleaning wastes etc.) that are not considered to be a by-product etc.

3.1.3 Examples in practice

Stakeholders noted that secondary chemicals are gaining prominence within the chemicals industry as companies increasingly prioritise sustainability. Due to the diversity of this measure, it should be noted that the examples highlighted below are illustrative and not comprehensive.

Stakeholders highlighted solvents as a notable example of materials that commonly undergo regeneration.[161] The way solvents are employed can vary significantly depending on the application. In larger-scale, closed processes, solvents are often regenerated on-site through closed-loop recovery systems, which require only occasional replenishment to account for evaporation losses. Conversely, in smaller-scale and often batch processes, solvents are typically used in a single pass, which can result in substantial waste volumes. According to stakeholders, pharmaceutical manufacturing consumes significant quantities of solvents to achieve high-purity products. Waste management companies like Trade-be frequently collect spent solvents and these solvents are then regenerated to either match the original user's specifications (through a toll service) or transformed into a marketable product.[162]

Stakeholders highlighted the substantial room for improvement in handling post-use waste. For instance, paints represent an area where increased recycling efforts could make a significant difference. In the production of paints and coatings, waste generation is relatively low. However, when these products are used, a notable amount of waste occurs, particularly in the form of unused residual paint left in containers and paints that are often washed down the sink or collected as waste. BCF have introduced a PaintCare program[163], aiming to significantly improve recycling rate for surplus paint. The target is to increase the recycling rate from 2% in 2021 to 75% by 2030.[164] This initiative encompasses a range of approaches, including encouraging both consumers and painters to return any remaining paint to designated collection points. It also involves the segregation of paints into solvent-based and water-based categories, followed by processes such as remanufacturing them into new paints, reclaiming pigments and repurposing them into other product categories, like concrete.

Other examples include recycling tyres into primary input materials via pyrolysis oil, as well as reprocessing of inorganic chemicals for renewable energy and lithium-based batteries.

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[161] Regeneration is the process of returning a product (e.g. a solvent) to its original form for reuse.
[162] https://www.tradebe.co.uk/solvent-recycling
[163] https://www.paintcare.org.uk/
[164] BCF (n.d.) PaintCare. Available at: Link

Johnson Matthey is another example of a company actively exploring ways to minimise the consumption of critical materials through design for recovery, which can result in up to a 98% lower carbon footprint compared to primary (mined) metal production.[165] Johnson Matthey aims to have at least 75% of the platinum-group metals (PGMs) they use in manufacturing come from recycled sources by 2030.[166]

3.2 Available sources

3.2.1 Literature review

The literature review identified 14 sources, used in this report, that discussed Secondary material content, although there was little quantitative evidence on the future levels of resource efficiency that could be achieved through this measure. This comprised:

- three industry reports;[167] [168] [169]
- three technical reports;[170] [171] [172]
- two academic papers;[173] [174]
- two policy documents;[175] [176] and
- four website articles.[177] [178] [179] [180]

The relevant sources were considered of high applicability and credibility when assessed against the data assessment framework, which recognises the relevance of the sources and the strength of the methodology within each. The sources exhibited an average IAS of 4.2 (out of 5), with ten sources exhibiting a score of 4 or above. Six literature sources were UK-specific and all sources were published within the last 5 years. The interviews were used to test the literature review findings and fill knowledge gaps.

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165 Johnson Matthey (n.d.) PGMs and circularity. Available at: Link
166 Johnson Matthey (2022) Sustainability. Available at: Link
167 Cefic (2021) Cefic position statement on circular economy 2.0 – Towards a carbon-smart circular future. Available at: Link
168 Green alliance (2023) A new formula: Cutting the UK chemical industry's climate impact. Available at: Link
169 Johnson Matthey (2022) Sustainability. Available at: Link
170 UNDP (2022) Transitioning To A Circular Economy Through Chemical and Waste Management. Available at: Link
171 HBM4EU / EEA (2022) Chemicals in a circular economy - Using human biomonitoring to understand potential new exposures. Available at: Link
172 RIVM (2020) Coping with Substances in a Circular Economy. Available at: Link
173 Ncube, A., Mtetwa, S., Bukhari,M., Fiorentino, G and Passaro, R (2023) Circular Economy and Green Chemistry: The Need for Radical Innovative Approaches in the Design for New Products. Available at: Link;
174 Levi, P., Cullen, J (2018) Mapping Global Flows of Chemicals: From Fossil Fuel Feedstocks to Chemical Products. Available at: Link
175 Defra (2021) What we want to achieve: packaging waste recycling targets. Available at: Link
176 ECHA (2010) Guidance on waste and recovered substances. Available at: Link
177 BCF (n.d.) PaintCare. Available at: Link;
178 Johnson Matthey (n.d.) PGMs and circularity. Available at: Link
179 PlastEurope.com (2018) VINYLOOP: Closure of operation in Italy / Phthalates issue under REACH brings down European PVC recycling project. Available at: Link. Available at: Link
180 INEOS, n.d Circular Economy. Available at: Link

3.2.2 Interviews

Following discussions with stakeholders, a decision was made to merge this measure with the previously distinct 'Remanufacture/Reuse' measure which is presented in the list of discarded measures in Appendix D. This choice was motivated by the difficulties encountered in distinguishing between the two measures. In the chemicals sector, terms like recycling, regeneration, remanufacture and recovery are frequently used interchangeably, regardless of whether they lead to the creation of the same secondary product or not. Stakeholders generally agreed that there is significant room for improvement of this measure, particularly by incorporating post-use wastes as feedstocks.

Stakeholders also emphasised the strong connections between this measure and Measure 2 (substitution of fossil-based feedstocks), Measure 5 (water consumption) and Measure 6 (collaborative consumption) as process wastes are frequently repurposed within internal processes to reduce waste or used/sold as feedstock for alternative processes, making it challenging to distinguish between them in practice. However, this measure has been considered independently to account for post-use waste and other diverse waste streams, such as cleaning wastes, which cannot easily be used as feedstock for alternative chemical processes.

Stakeholders pointed out that much of the recycling focus in the chemical industry has primarily centred on plastics as an alternative carbon feedstock - see Measure 2 (substitution of fossil-based feedstocks). Given the wide array of chemicals used in the industry (including inorganic chemicals), reclaiming these substances for secondary markets presents numerous obstacles and challenges. Therefore, this measure has been kept separate from Measure 2 (substitution of fossil-based feedstocks). The reader should be reminded that mechanical recycling of plastics and other products is considered beyond the scope of this sector study as it is discussed in detail in Measure 4 (recycled content in plastic products) of the accompanying Unlocking resource efficiency: Phase 2 plastic report.

While it is preferable to maximise the recovery of such materials, stakeholders acknowledged that achieving 100% capture of post-use waste is unlikely to be achievable in practice. Therefore, they suggested considering alternative, more sustainable approaches. For example, instead of focusing solely on reusing these materials, exploring self-degrading polymers in paints could be a more sustainable option by allowing paints to be washed away. Similar approaches are considered in the agrichemicals sector where recovery of the chemicals is not possible. Stakeholders stressed that approaches such as these should be recognised as an important circular solution and not dismissed solely on the grounds of resource efficiency. Whilst an important consideration, this is beyond the scope of this measure and is not elaborated further in this report.

3.2.3 Workshop

Measure 3 caused confusion during the workshop, with most stakeholders raising questions regarding its scope. One participant questioned why paint recycling has been included, but not plastic packaging. It was suggested that approximately 70% of organic chemicals are used in polymer manufacture and it seemed odd to not include chemicals from mechanical recycling.

Due to the complexities in scoping this sector and measure, to avoid double counting impacts from other sector reports and measures discussed separately in this study, stakeholders found it difficult to determine what should be considered in this measure. As a result, stakeholders were not comfortable with voting confidently for this measure. However, most stakeholders acknowledged that a lot more could be done to utilise secondary material from downstream sectors and within the chemicals industry.

A manufacturing stakeholder used the example of transformer oils, for which certain companies have been able to develop easier separating methods. This is so that such high-performing oils are recovered and then potentially reused. Many other processes also result in sludge generation, which often contains useful materials that can be reclaimed with reprocessing.

Due to the confusion, it was recommended during the workshop that the indicator should re-evaluated to simplify the defined scope to determine the magnitude of the levels of efficiency that could be achieved. The indicator was therefore redefined more simply as the "% recycled content" for voting. The simplification means that it is harder to distinguish the outcomes of voting from other measures. There may therefore be some overlap with this measure, Measure 2 and potentially Measure 6.

The level of engagement in the workshop was as follows:

- Six stakeholders across industry and academia were active on the mural board and five stakeholders actively contributed to verbal discussion.

3.3 Drivers & Barriers

3.3.1 Drivers

Table 12 below shows the main drivers for Measure 3. The most significant drivers are shown in bold as voted for by stakeholders in the workshop.

Table 12: Drivers for chemicals measure 3

Description	PESTLE	COM-B
Producer responsibility schemes	**Political**	**Capability – psychological**
Recycling targets stimulate markets	**Political, Economic**	**Motivation – automatic**

Design for recovery enables efficiency improvements	**Technological**	**Capability – physical**
Customers demand more sustainable products	Social	Opportunity – social

Producer responsibility schemes

During the workshop, several stakeholders mentioned that they believe producer responsibility schemes are a key driver for Measure 3 as they pressure companies to identify lower cost/profitable ways to manage the material, particularly for critical materials or minerals that suffer from supply scarcity. One academic noted that this is already applied on certain levels for catalysts, but not so much for materials like lubricants. One stakeholder said that supply chain carbon tax might have a similar effect.

Recycling targets stimulate markets

Recycling targets aim to maximise the availability of secondary content as a feedstock for new products and are a key driver in increasing the supply. These can be industry targets such as the UK coatings industry commitment to 75% leftover paint recycling target by 2030[181], or government targets such as DEFRA's proposed recycling target of 41% in 2024 and 56% in 2030 for plastic packaging.[182] Whilst the latter is relevant to Measure 2 (substitution of fossil-based feedstocks), similar ambitious targets for other materials might stimulate a market for them. Some chemical companies such as Johnson Matthey and INEOS have established their own recycling targets which may stimulate the development of recycling systems.[183, 184]

Design for recovery enables efficiency improvements

One of the key enablers to achieving high recycling rates is the design of products in a way that makes them easy to recycle.[185] Formulators should consider recovery when developing formulations for products. Additionally, a fit-for-purpose information system that contains information on which products contain which chemicals would allow recyclers and other users of secondary material to do so safely and in line with regulations.[186] During the workshop, one stakeholder added that design for recovery will help in overcoming technical limitations around the use of secondary content.

Customers demand more sustainable products

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181 https://www.paintcare.org.uk/2021/11/04/uk-coatings-industry-commits-to-net-zero/
182 "Defra (2021) What we want to achieve: packaging waste recycling targets. Available at: Link
183 Johnson Matthey (2022) Sustainability. Available at: Link
184 INEOS, n.d Circular Economy. Available at: Link
185 Green alliance (2023) A new formula: Cutting the UK chemical industry's climate impact. Available at: Link
186 Cefic (2021) Cefic position statement on circular economy 2.0 – Towards a carbon-smart circular future. Available at: Link

In certain segments, consumers are increasingly demanding more sustainable products such as increases in the percentage of secondary content.[187] Since many chemical customers are not directly consumer-facing, this may not be relevant to all segments of the industry. However, there could be indirect impacts on manufacturers due to consumer-facing businesses facing increased pressure from consumers and investors to be more transparent about their supply chains. The development of product standards/labelling for secondary materials could enable this measure by increasing customers' confidence in secondary materials and therefore increase demand for them.[188] Nevertheless, this is limited to certain segments (e.g., consumer-facing industries) rather than industrial users. Additionally, one stakeholder mentioned in the workshop that while surveyed customers want more sustainable products, in some segments they are often unwilling to pay extra for them or to accept lower performance (e.g. detergents).

3.3.2 Barriers

Table 13 below shows the main barriers for Measure 3. The most significant barriers are shown in bold as voted for by stakeholders in the workshop.

Table 13: Barriers for chemicals measure 3

Description	PESTLE	COM-B
Lack of recycling capacity	**Technological**	**Capability – physical**
Technical limits to mechanical / chemical recycling	**Technological**	**Capability – physical**
Waste regulations prevent handling of secondary material	**Technological, Legal, Political**	**Capability – physical**
Lack of control over downstream users	**Technological**	**Opportunity – physical**
Uncertainty over winning technologies	Environmental, Political, Legal	Capability – psychological
High costs in improving production processes	Economic	Opportunity – physical

Lack of recycling capacity

[187] Ncube, A., Mtetwa, S., Bukhari,M., Fiorentino, G and Passaro, R (2023) Circular Economy and Green Chemistry: The Need for Radical Innovative Approaches in the Design for New Products. Available at: Link
[188] Cefic (2021) Cefic position statement on circular economy 2.0 – Towards a carbon-smart circular future. Available at: Link

One stakeholder indicated that there is a lack of recycling capacity in the UK and that not many facilities can recover key materials, particularly chemicals needed for the energy transition (e.g., 'black mass'[189] from battery reprocessing is currently exported to the Netherlands). This is partially attributed to a high barrier to entry caused by permitting legislation and associated costs. Additionally, a large portion of the recycling supply chain and associated investments are currently located offshore. This makes it less commercially viable to implement recycling technology in the UK, as proximity to the recycling plants is one of the key factors for investment. If more of the recycling supply chain were located in the UK, this would create a much better commercial environment for investment. This is because there would be higher assurance of recycled material supply, lower transportation costs and less product exports. As a result of this barrier, key secondary materials may be low in availability, as they are not widely recycled domestically.

In the workshop, one stakeholder added that they believe this will reduce in significance when the market for secondary materials becomes more financially attractive.

Technical limits to mechanical / chemical recycling

Mechanical recycling of chemicals is often a challenge due to collection and sorting limits that stem from toxicity or contamination of material. This can restrict the availability of secondary materials. For example, PFAS is under increased scrutiny due to public health concerns and is facing restrictions. This causes a large concern when it comes to mechanical polymer recycling, as these restrictions may hinder the viability of recycling facilities. If the latest EU PFAS restriction comes into effect and mandates that every facility has to demonstrate an absence of PFAS at 0.1% in a product, then this will be a major barrier to mechanical recycling that will ultimately position chemical recycling processes as the best option. Chemical recycling may offer an opportunity to treat lower quality, or contaminated plastics, that would otherwise be incinerated or landfilled into monomer feedstock for the chemicals sector. However, it is uncertain as to whether chemical recycling technology can deal with some of the hazardous or problematic contaminants that currently restrict mechanical recycling. For example, under the VinylPlus[190] programme, a promising VinylLoop chemical recycling process in Italy closed in 2018 as it was unable to remove additives sufficiently in line with recent EU REACH restriction of lead in PVC.[191]

Waste regulations prevent handling of secondary material

Whilst receiving slightly fewer votes that the previous two barriers, a notable barrier raised by stakeholders, in the workshop and in interviews, concerns the handling of post-use and industrial materials, which are typically categorised as waste. Handling such materials necessitates obtaining a waste handling license and site permits, which was described as a bureaucratic, often sluggish and costly process which can deter improved management of

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189 Mixed substances obtained from lithium-ion battery recycling, which includes valuable materials like lithium, cobalt and nickel.
190 VinylPlus® is the European PVC industry's commitment to sustainable development, working to improve the sustainability performance of PVC by aiming to enhance its recycling.
191 PlastEurope.com (2018) VINYLOOP: Closure of operation in Italy / Phthalates issue under REACH brings down European PVC recycling project. Available at: [Link]

resources. Additionally, when dealing with hazardous materials, there are even more stringent regulations and expenses involved, which discourage operators from handling such materials appropriately and hinder their reuse as feedstocks in chemical processes.[192] Stakeholders noted that the barriers from waste regulations can lead to one of the following two scenarios: 1) avoidance of handling secondary materials and therefore materials are not retained within the circular economy by disposing of waste; and 2) offshoring of waste due to a lack of UK infrastructure to treat accordingly.

Furthermore, stakeholders pointed out regional disparities in the application of these regulations. For instance, a specific type of paint container may be considered hazardous waste in one region of the country but permitted for recycling in another. Inconsistent policies between local authorities further hinder widespread adoption. This issue is compounded by the devolution of power, where varying legislative and classification frameworks prevent a consistent approach. In the workshop, one stakeholder pointed out that this is also an international issue and that waste regulations add large amounts of difficulty to cross-border trade.

Stakeholders noted that this problem is worsening as stricter regulations on materials, such as persistent organic pollutants, lead to the reclassification of existing waste streams, necessitating more costly handling procedures. They provided an example where a reclassification rendered a product unsuitable as a feedstock and finding a waste handler willing to accept it became challenging. This concern highlights a key consideration for the transition to a safe circular economy. While resource efficiency should strive towards circularity, it is important that circularity does not lead to human or environmental exposure to harmful chemicals (e.g. due to legacy pollutants in materials that were produced before regulations and are now becoming waste). As such, regulations should classify waste in a way that encourages reuse and recycling where it is safe to do so. Waste which may contain harmful chemicals must be handled carefully (e.g. tested, treated, and potentially subject to high-temperature incineration if contaminants cannot be removed).

Stakeholders suggested that a simplified or more streamlined approach, could provide a more nuanced solution by increasing the amount of material that can be effectively recovered. However, no further details were provided by stakeholders. Any approach should consider the abovementioned point about human health and environmental protection, emphasised by the growing body of evidence looking at chemicals exposure in a circular economy.[193, 194]

Under REACH registration, manufacturers and suppliers of chemicals must recommend safe handling methods for waste, to ensure downstream users can implement safe waste management practices.[195] Exercising these measures should enable more reuse and recycling of materials to improve resource efficiency.

[192] UNDP (2022) Transitioning To A Circular Economy Through Chemical and Waste Management. Available at: Link
[193] RIVM (2020). Coping with Substances in a Circular Economy. Available at: Link
[194] HBM4EU / EEA (2022). Chemicals in a circular economy - Using human biomonitoring to understand potential new exposures. Available at: Link
[195] ECHA (2010) Guidance on waste and recovered substances. Available at: Link

Lack of control over downstream users

One stakeholder stated that waste created during production already has a high recycling rate and that the majority of unrecycled waste is out of their control. This is because post-use waste is not generated by the chemicals sector, but by consumers and therefore the sector has limited control over both its generation and how it is treated.

Uncertainty over winning technologies

Stakeholders noted that the chemicals sector is relatively risk averse when investing in wholly new technologies and has generally relied on incremental, conservative investment in solutions. Stakeholders noted that this is because there is uncertainty as to which technological solutions offer the best direction for transition to net zero and returns on investment. According to stakeholders, the chemicals sector is reliant on government steer towards encouraging investment in certain sectors and are reluctant to invest in technologies that do not support government strategy.

High costs in improving production processes

One stakeholder remarked that the high Capex associated with a significant overhaul of the production process, is one of the main barriers to further improvement of this measure. This was corroborated by other stakeholders who indicated that the sector primarily wants to maximise the use of its existing assets and resources, rather than investing in more radical change. Stakeholders widely agreed that the “low hanging fruit” will already have been actioned by industry and further improvements would require significant additional investment.

Additionally, as manufacturing systems are extensively interconnected, changes in one process can affect the production of feedstock for another. With many product value chains operating at the global level, applying a change in one part of the system, such as implementing safe and sustainable by design approaches, may result in high costs across the whole value chain.

3.4 Levels of efficiency

Table 14: Levels of efficiency for chemicals measure 3

Indicator: % in weight of recycled / secondary post-use material content in chemicals production			
Level of efficiency	Current	Maximum in 2035	Business-as-usual in 2035
Value	0 – 5%	10 – 20%	0 – 5%
Evidence RAG	Red	Red	Amber

3.4.1 Current level of efficiency

Stakeholders noted that uptake of this measure will vary by segment and for some it may add little-to-no benefit. For example, stakeholders noted that agrichemicals are not suitable for recovery due to their dispersive nature and there are limited benefits to end-users of products that use secondary material whereas some fast-moving consumer goods, such as cleaning products, are more suitable as there is consumer appetite.

None of the interviewed stakeholders were able to provide a specific estimate for the impact of this measure. Moreover, most of the opportunities for improving the use of secondary materials in literature were found in plastics, which are addressed under Measure 2 (substitution of fossil-based feedstocks).

Stakeholders acknowledged that while some recycling, remanufacturing, or reuse of materials occurs, the vast majority of chemical feedstocks are currently virgin. Exceptions to this trend are more noticeable in segments like catalysis, solvents and lubricants. In contrast, for most other segments, the use of secondary feedstocks is minimal. This observation aligns with literature, which indicates that globally, secondary production routes (those based on recyclate) and alternative feedstocks make up a fraction of total inputs to the sector. [196]

Considering the information from stakeholder interviews and literature, it is unlikely that current levels of efficiency for incorporating secondary materials in the listed segments (Table 2) would exceed the range of 0 – 5%. Stakeholders did not vote on this level of efficiency due to confusion of the measure scope therefore the evidence RAG rating for this level of efficiency is red due to the limited evidence and stakeholder agreement. Despite this lack of agreement it is noted that there is some confidence that the use of secondary materials is generally within this range because use is relatively low across these segments.

3.4.2 Maximum level of efficiency in 2035

Stakeholders generally agreed that there is significant potential to improve upon this measure in most segments. However, the drive and likelihood of uptake is likely to vary significantly by segment. For example, products with higher margins (typically Tier 3) might be able to afford the development and use of alternative chemical ingredients, whereas others relying on high-throughput/low-margin business models (Tier 1) have less incentive and/or ability to do so. Nevertheless, stakeholders noted that there may be limitations on the quantity and quality of chemicals available from post-use and production waste streams. Furthermore, it is difficult to distinguish efficiency level improvements for this measure from some of the other measures given that they are heavily interlinked.

Again, stakeholders were unable to provide quantitative estimates for this measure, therefore it is challenging to place a maximum level of efficiency on this measure. A range of 10-20% was

[196] Levi, P., Cullen, J (2018) Mapping Global Flows of Chemicals: From Fossil Fuel Feedstocks to Chemical Products. Available at: Link

put to stakeholders in the interviews which was deemed to be a reasonable estimate by them. In the workshop one stakeholder estimated 16-20% with low confidence and added that it was unlikely to increase beyond this without significant intervention whereas another stakeholder voted for 5-10% also with low confidence. Therefore, the proposed level of efficiency is estimated to be 10-20%. The evidence RAG rating for this level of efficiency is red because no evidence could be identified in literature and stakeholders were unable to provide a quantitative indication of its implementation or vote confidently on the level of efficiency. Nevertheless, stakeholders generally considered this to be an important measure where there is notable room for improvement.

3.4.3 Business-as-usual in 2035

Improvement upon this measure is underway in certain segments. For example, segments with higher margins, such as consumer products, are developing methods to increase the use of secondary products where there is consumer demand. Similarly, the coatings sector is promoting the use of post-use wastes in their ingredients. However, other high-throughput/low-margin producers (i.e., in Tier 1 and Tier 2) have limited incentive and/or ability to do so therefore improvements under a BAU scenario are likely to be very limited. Some stakeholders noted that beyond the plastics sector, major increases are not anticipated.

In the workshop, a small three stakeholders voted for the BAU being 0-2% with two votes for 3-5%. Most of the votes cast by stakeholder were with low confidence. On reflection of these votes a range of 0-5% has been estimated. The evidence RAG rating for this level of efficiency is amber because no evidence could be identified in literature but stakeholders voted consistently between this range during stakeholder workshops.

4.0 Measure 4 – Process efficiencies

4.1 Chemicals resource efficiency measure

4.1.1 Description

Maximising material efficiencies within production processes.

This measure focuses on enhancing process efficiencies, specifically maximising the yield of production within a process. Its primary goal is to identify opportunities for improving process efficiencies within a specific operation. In the context of this report, process efficiency is defined as the quantity of useful product divided by the total quantity of inputs, otherwise known as yield.

It is important to note that resources, such as by-products, are often traded or shared between sites, particularly in industrial clusters - this aspect is addressed in Measure 6 (collaborate consumption). However this does not constitute improved efficiencies within the defined process as covered under this measure. Improved efficiency yields can be achieved through various means, including:

- Using recovered reagents or reaction by-products from other internal processes.
- Streamlining processes by reducing the number of process steps.
- Transitioning from batch processes to continuous processes.[197]
- Employing more efficient alternative processes.
- Enhancing process optimisation.
- Digitalisation of processes.
- Reducing process waste.

These measures collectively aim to make production processes more efficient, ultimately contributing to resource conservation and improved sustainability. This measure is relevant at all tiers in the chemicals sector as process efficiencies can be made at all levels. However, there are greater opportunities for improvements further down the value chain, particularly at Tier 3. This is because Tier 1 involves the production of bulk commodity chemicals using continuous processes that are already highly efficient, whereas Tier 3 processes, which mainly encompass specialty chemical manufacturing, are predominantly carried out using discrete batch processes.

[197] Batch processes involve intermittent, variable production with high flexibility, while continuous processes entail uninterrupted, steady production with less flexibility but higher throughput.

It was not possible to break the data down by the ONS segments listed in Table 2 for this measure. However, Tier 1 and Tier 2 chemical industries represent approximately 50% of UK GVA[198], assuming that they comprise primarily petrochemicals, polymers and basic inorganics.

4.1.2 Measure indicator

The '**% improvement in process yield compared to 2023 levels'** was selected as an indicator for this measure following discussion with stakeholders.

It demonstrates how efficiently material is used at facility level and demonstrates the reduction of material that would otherwise be classified and treated as waste within a production facility per unit of production. Alternative indicators that were considered for this measure but excluded are shown in Appendix D.

4.1.3 Examples in practice

Process design

Maximising the yield, or process efficiency is a key part of the design process for any chemical manufacturing plant. Process efficiencies are decided upon during the design stage but often involve trade-offs with other aspects, such as cost, specification requirements and energy consumption particularly in larger scale, continuous processes. Process designers incorporate design methodologies to ensure many aspects, such as process safety, materials safety, energy efficiency and feedstock consumption, are included within the design. For example, the Dow Chemical Company developed an eco-efficiency compass which managers must consider during decision-making. This compass considers whether offerings are being dematerialised into services, or energy efficiency has been increased[199]

Digitalisation

Globally, a digital transition is taking place because of the ability of digital technologies to facilitate economic growth, create jobs and improve efficiency, transparency, reliability, access to finance and information security across economic sectors.[200, 201] The chemicals sector is moving more slowly towards digitalisation compared to other sectors.[202] However, the potential for increasing efficiency in chemicals production has been identified and is driving a digital agenda for the sector.[203, 204] For example, process efficiency may be increased using big data,

[198] Assuming Tier 1 and Tier 2 comprise primarily of petrochemicals, polymers and basic inorganics. https://www.parliament.uk/globalassets/documents/commons-committees/Exiting-the-European-Union/17-19/Sectoral-Analyses/7-Sectoral-Analyses-Chemicals-Report.pdf
[199] PwC (2019) Circular economy: A new source of competitive advantage in the chemicals industry. Available at: Link
[200] Strategy& (2019) Digitization for economic growth and job creation, Regional and industry perspectives, Available at: Link
[201] The World Bank (2023) Digital Development. Available at: Link
[202] KPMG (2020) Reaction: the new reality for the global chemical industry. Available at: Link
[203] KPMG (2020) Reaction: the new reality for the global chemical industry. Available at: Link
[204] Deloitte, (n.d.) The future of digitalization in the chemical industry. Available at: Link

information management and machine learning models.[205, 206] Artificial intelligence (AI) technologies have already been developed to support the chemical industry, for example, Uptime AI monitors equipment in chemical plants to facilitate early diagnosis and solving of problems (preventing/reducing any impacts of technical problems on yield) and monitors operating conditions to identify the optimal parameters to maximise yield and efficiency.[207] In Europe, nearly 60% of chemical companies responding to a survey said that they expect digitalisation to lead to better and faster implementation of their sustainability goals.[208]

The digital transition is likely to increase process efficiencies in the chemicals sector. Unplanned equipment downtime can cause an estimated loss of 5 – 20% of productive capacity in industrial facilities,[209] therefore, the development and use of digital tools such as AI to anticipate and prevent or quickly solve problems with operating equipment/ conditions could significantly increase process efficiency and yields. Notably, in the EU, the Chemicals Strategy for Sustainability sets out policy ambition to digitalise the EU chemicals sector, for a number of reasons, including to support the greening of manufacturing processes.[210] In 2017, the Made Smarter review concluded that the UK has potential to apply digital technologies in industrial settings to improve resource efficiency, making it more resilient.[211] In response to a Chemical Industries Association survey, companies indicated that digitalisation is not yet widely adopted in the chemicals sector, but they generally recognised that AI has potential to help with efficiency-related aspects such as yield management.[212]

Limiting batch processing could improve efficiency

One stakeholder shared that most high tonnage chemical manufacture is continuous production which improves efficiency. Alternatively, batch processing is more wasteful but is necessary for high value speciality chemicals where a large and consistent market is not developed. Efficiencies could be made by moving to more continuous processes. However, stakeholders noted that whilst there is potential to increase efficiencies in this way, often this does not align with the business models of the smaller, more niche producers as greater flexibility is required.

Improving continuous process efficiency

Most operators run continuous improvement programs to maximise the efficiency and output of a process. Stakeholders noted that even in large-scale, highly-optimised processes, there is always scope for improvement although this is likely to be limited. This often highly depends on how a plant has been run in the past and on the level of investment. For instance, stakeholders

[205] WSP (2023) Key Performance Indicators for the Chemicals Strategy for Sustainability. Available at: Link
[206] Arthur D Little (2023) DIGITAL TECHNOLOGIES FOR SUSTAINABILITY IN THE EUROPEAN CHEMICAL INDUSTRY. Available at: Link
[207] https://www.uptimeai.com/chemicals.html
[208] EY (2022) Why the chemical industry is prioritising digitalisation. Available at: Link
[209] https://blog.isa.org/downtime-factory-plant-industrial-costs-risks
[210] European Commission (2020). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Chemicals Strategy for Sustainability Towards a Toxic-Free Environment. Available at: Link
[211] MSR working group (2017) Made Smarter Review. Available at: Link
[212] Chemical Industries Association (2021) Digitisation in the chemical industry. Available at: Link

noted that some older processes with lower margins may not have historically received high levels of investment therefore there may be more scope to improve efficiencies.

Improving batch process efficiency

Batch processes typically produce more wastes as the process needs to be cleaned between batches and there is more opportunity of error resulting in bad batches. Nevertheless, operators continually seek to reduce waste (and therefore value leakage) through continuous improvements. Improving batch process efficiency can be achieved through various techniques such as through reducing the number of process steps, improving supply planning to reduce expired feedstocks, improved demand forecasting to reduce expired products, reduce product portfolio to reduce process changeovers and improvement monitoring among many others.

4.2 Available sources

4.2.1 Literature review

The literature review identified 16 sources, used in this report, that discussed process efficiencies, although there was little quantitative evidence on the future levels of resource efficiency that could be achieved through this measure. This comprised:

- three industry reports;[213] [214] [215]
- one technical report; [216]
- two academic papers; [217] [218]
- one policy documents; [219] and

[213] Arthur D Little (2023) DIGITAL TECHNOLOGIES FOR SUSTAINABILITY IN THE EUROPEAN CHEMICAL INDUSTRY. Available at: Link
[214] PwC (2019) Circular economy: A new source of competitive advantage in the chemicals industry. Available at: Link
[215] Chemical Industries Association (n.d.) Sustainability. Available at: Link
[216] WSP (2023) Key Performance Indicators for the Chemicals Strategy for Sustainability. Available at: Link
[217] Phan et al. (2015) GREEN MOTION: A new and easy to use green chemistry metric from laboratories to industry. Available at: Link
[218] Amos Ncube, Sandile Mtetwa, Mahak Bukhari, Gabriella Fiorentino and Renato Passaro (2023) Circular Economy and Green Chemistry: The Need for Radical Innovative Approaches in the Design for New Products. Available at: Link
[219] European Commission (2020). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Chemicals Strategy for Sustainability Towards a Toxic-Free Environment. Available at: Link

- nine website articles. [220] [221] [222] [223] [224] [225] [226] [227] [228]

A full list of the sources used in this measure are listed in Appendix C.

The relevant sources were considered of medium applicability and credibility when assessed against the data assessment framework, which recognises the relevance of the sources and the strength of the methodology within each. The sources exhibited an average IAS of 3.5 (out of 5), with five sources exhibiting a score of 4 or above. All but one source was published within the last 5 years, but only two literature sources were UK-specific. Nevertheless, the sources were deemed to be relevant to the UK chemicals industry. The interviews were used to test the literature review findings and fill knowledge gaps.

4.2.2 Interviews

Stakeholders considered this to be an important measure, but there were differing opinions on the achievable levels of efficiency and practical feasibility. They pointed out that there are two contrasting approaches and a reasonable target could be found somewhere in the middle.

On one hand, introducing disruptive/innovative technologies, which could replace outdated technologies ones, thereby enhancing efficiency and sustainability. These technologies, while resource and energy efficient, require substantial investment and pose challenges like stranded assets for existing facilities. Improving efficiency often depends on innovation, e.g. invention or application of a new catalyst, solvent, or process, which is difficult to predict. While the introduction of disruptive technologies is underway, widespread adoption within the timeframe covered in this report is unlikely.

On the other hand, existing processes can be iteratively improved, focusing on efficiency and sustainability. For large-scale continuous processes, which make up a significant proportion of the chemicals industry, options for improvement are somewhat limited because much of the design work is front-end for a specific operating range. Nevertheless, improvements could involve resource modification, optimising for higher-value products, or retrofitting for monitoring devices.

Tier 3 and some Tier 2 industries may have more room for improvement. Iterative improvements are possible for both continuous and batch processes, however inefficiencies are often more pronounced in batch processes and larger quantities of waste are generated, especially during cleaning between batches. Stakeholders noted that there are numerous ways in which process efficiencies in batch processes could be improved, such as better demand

[220] EY (2022) Why the chemical industry is prioritising digitalisation. Available at: Link
[221] MSR working group (2017) Made Smarter Review. Available at: Link
[222] Chemical Industries Association (2021) Digitisation in the chemical industry. Available at: Link
[223] Deloitte, (n.d.) The future of digitalization in the chemical industry. Available at: Link
[224] KPMG (2020) Reaction: the new reality for the global chemical industry. Available at: Link
[225] The World Bank (2023) Digital Development. Available at: Link
[226] Strategy& (2019) Digitization for economic growth and job creation, Regional and industry perspectives, Available at: Link
[227] Eurostat, 2020. Generation of waste by waste category, hazardousness and NACE Rev. 2 activity. Available at: Link
[228] Eurostat, (2021) Production and consumption of chemicals by hazard class. Available at: Link

forecasting, minimisation of product line changes and designing processes to have fewer steps.

Nevertheless, stakeholders noted that operators across all tiers already try to minimise waste. For example, when there is a poor quality batch or a product with inadequate specifications, it is typically not disposed of as waste. In the worst-case scenario, such products can either be reused as a low-spec input within the internal systems or returned to the supplier, with the former being the more common practice according to stakeholders..

Efficiency in existing chemical processes, particularly in Tier 1 and Tier 2 sectors, is considered high, with limited room for improvement due to practical trade-offs. Stakeholders acknowledged some opportunities for enhancement, particularly in smaller-scale batch processes more prevalent in Tier 3.

One stakeholder highlighted the inclusion of process emissions in the measure, though data specifically excluded gaseous emissions from waste statistics. The indicator was therefore updated to encompass overall process (atom) efficiency rather than just waste generation.

4.2.3 Workshop

The general consensus during this workshop was that process efficiencies are already being optimised as far as possible, especially by high-tonnage and high-throughput industries. However, there are examples where further improvements could be made. One stakeholder discussed the case of pharmaceuticals manufacturing, whereby the processes utilised are often highly inefficient due to their multi-step nature and exceptionally high-quality assurance processes. Tier 3 was seen as having the biggest opportunities for process improvements due to the reliance in batch processing, but changes in Tier 1 could also be promoted with additional investment. Another stakeholder argued that yields are only important where reactive chemistry exists, which is not the case for Tier 3 as it revolves around formulations which require relatively little reactive chemistry in comparison (mostly mixtures of chemicals). Nevertheless, process yield, as defined within this measure, includes the generation of product per unit weight of inputs therefore this measure is applicable to all Tiers.

Stakeholders noted the enormous range of process efficiencies achieved within the sector, noting that pharmaceutical yields are orders of magnitude lower than for some bulk continuous processes. As a result, estimating the levels of efficiency for the entire sector is challenging and difficult to disaggregate. Therefore, for simplicity, levels of efficiency have been expressed for the entire chemicals sector, whilst recognising the large range of efficiency improvements that could be made on a case by-case basis. Stakeholders did not consistently vote on disaggregated basis.

The remaining discussion highly focused on the drivers and barriers surrounding this measure, which are expanded upon in the following section.

The level of engagement in the workshop was as follows:

- Four stakeholders across industry and academia were active on the mural board and four stakeholders actively contributed to verbal discussion. The limited engagement reflects the relatively low confidence in responses.

4.3 Drivers & Barriers

4.3.1 Drivers

Table 15 below shows the main drivers for Measure 4. The most significant driver(s) are shown in bold as voted for by stakeholders in the workshop.

Table 15: Drivers for chemicals measure 4

Description	PESTLE	COM-B
Cost savings from increased material efficiency	**Economic**	**Opportunity – physical**
Regulations on carbon footprint/embedded carbon of products	Political / Legal	Capability – physical
Consumers demand more sustainable products	Social	Opportunity – social
Company sustainability commitments	Environmental	Motivation – automatic
Availability of investment for scale-up tech and processes	Economic	Opportunity – physical
Increased revenue	Economic	Motivation – reflective

Cost savings from increased material efficiency

Stakeholders noted that cost savings are the primary driver for this measure. Wastage is seen as value leakage across the chemicals supply chain. Most, if not all, chemical manufacturers, optimise their processes to improve product yield, therefore there is a strong economic incentive to reduce the cost of input materials and disposal of process waste. As a result, wastes are already treated as value leakage which should be avoided. Especially for bulk chemicals with low margins (Tier 1), processes are generally considered to already be very efficient. Most operators will reuse their waste within the process where possible and seek alternative markets for it where this is not possible – see Measure 6 (collaborative consumption). As these methods are proven to result in significant cost reductions, they are likely to drive changes towards more efficient chemical processing. In the workshop, one stakeholder corroborated that this is already a key driver to improving resource efficiency.

Regulations on carbon footprint/embedded carbon of products

The stakeholders identified regulations on carbon footprint/embedded carbon as a potential driver for resource efficiency. As discussed previously in other measures, this can pressure operators into improving their processes to reduce carbon emissions per tonne of output, both as a byproduct (e.g. CO_2 side product) and from energy consumption to reduce carbon leakage from the economy. Carbon in the form of gaseous emission is a loss of valuable resource that could be utilised more effectively.

Consumers demand more sustainable products

Consumer demand for greener products with lower resource use and carbon intensity, is one of the key drivers identified in literature, with one source noting that consumer product companies who can provide more sustainable offerings have benefitted greatly from increased consumer awareness and demand for such products.[229] However, stakeholders noted that this driver is stronger in certain segments than others. For example, consumer facing industries such as Tier 3 and downstream manufacturers are more driven by this aspect. This can however, have ripple effects up the supply chain, as product designers who are often downstream of the chemicals sector, influence the material choices and subsequently the chemical products needing to be produced by the chemicals industry. Additionally, one stakeholder pointed out in the workshop that process efficiencies do not necessarily translate to a more sustainable product due to wider environmental factors considered at design stage, such as energy consumption and eco(toxicity) etc.

Company sustainability commitments

With many chemical companies having established their own net zero commitments, it is likely that new operating systems will be developed to improve both resource and carbon efficiency. Due to existing investment in such solutions, particularly among companies who are part of planned industrial CCUS clusters in the UK, improved processing technologies will be promoted to drive the production of more sustainable products with higher resource efficiencies.[230]

Availability of investment for scale-up tech and processes

One stakeholder noted that process efficiencies can always be improved, even in the most optimised processes. Since it is often expensive, additional internal/private (and public) funding would improve efficiencies. However, the cost benefit may not be worthwhile and should be considered on a case-by-case basis.

[229] Ncube, A., Mtetwa, S., Bukhari,M., Fiorentino, G and Passaro, R (2023) Circular Economy and Green Chemistry: The Need for Radical Innovative Approaches in the Design for New Products. Available at: Link
[230] Green alliance (2023) A new formula: Cutting the UK chemical industry's climate impact. Available at: link

Increased revenue

During the workshop, one manufacturing stakeholder suggested that a key driver is increased revenue through better process efficiency. It was specified that projects often involve an approach towards cost savings and cost avoidance, but there are also methods that increase throughput and generate more profit. If a more efficient process is employed, asset utilisation increases and the overall throughput increases as well, which leads to higher product availability for selling and thus increased profit or revenue. Therefore, the possibility to increase revenue should be considered alongside cost savings as a driver.

4.3.2 Barriers

Table 16 below shows the main barriers for Measure 4. The most significant barriers are shown in bold as voted for by stakeholders in the workshop.

Table 16: Barriers for chemicals measure 4

Description	PESTLE	COM-B
Uncertainty over winning technologies	**Technological**	**Capability – physical**
High costs in developing new production processes	**Economic**	Opportunity – physical
High costs in improving existing production processes	Economic	Opportunity – physical
Limited process improvements possible once operational	Technological	Capability – physical
Knock-on effects of capacity changes to value chains	Economic	Opportunity – physical
Market demand often leads to overproduction	Economic	Opportunity – physical

Uncertainty over winning technologies

With the current uncertainty over which technological solutions offer the best direction for resource efficiency, it is difficult for the sector to decide on effective solutions. As a result, the sector tends to follow government decisions and conservative investments, instead of investing in more innovative solutions. To facilitate large improvements in processing efficiencies, operators would have to invest in novel technologies which either require significant overhaul of existing assets or entirely new facilities. However, investment in these technologies carries risk and uncertainty in direction of travel in the political landscape which prevents confident investment. One stakeholder added in the workshop that they see a particularly high investment risk in the UK as a result of the current regulatory landscape which does not provide convincing investment signals to industry. This was a recurring theme in interviews, although limited further information was obtained. One stakeholder noted that due to the global nature of supply chains in the chemicals industry, UK influence is relatively limited compared to other markets such as the EU and therefore many producers would be looking to follow EU signals. Furthermore, stakeholders pointed to countries like the US which are offering attractive investment environments for low carbon technologies which they acknowledged the UK does not currently compete with.

High costs in developing new production processes

A key barrier identified by stakeholders to Measure 4 is the high cost of developing new and innovative processes. As a result, operators aim to maintain their existing assets in use for as long as possible (often for many decades at a time). Subsequently, it takes a long time for innovative technologies to enter widespread use, especially when they require new infrastructure to be supported. Stakeholders argued that notable sector-wide improvements could be made by using disruptive new technology, e.g. using alternative or fewer process steps; however, this often requires complete redesign of the process and/or construction of a new facility. Therefore, the costs associated with this are prohibitively high for widespread implementation by 2035. Nevertheless, other innovations could be applied retrospectively relatively cheaply. For example, information technology that helps identify or predict production issues require limited alterations to the design and can be applied cost effectively. In the workshop, one stakeholder added that high costs are always a barrier to changes in the production process.

High costs in improving existing production processes

The chemicals industry has demonstrated a tendency towards maximisation of existing resource use, with limited appetite to improve current production processes where it is not economically advantageous. This is due to the idea that transitions, such as enhanced optimisation of process or shifts in processing methodology, would be accompanied by considerably high costs which require additional investment. This was supported by two stakeholders who remarked that a high Capex is associated with a significant overhaul of the production process.

Limited process improvements possible once operational

Since much of the optimisation occurs during the initial design phase, there is often limited room for major adjustments once the operation is underway. Making alterations or tuning improvements to the process typically demands substantial additional investments and such changes are restricted throughout the operational lifetime. These modifications frequently involve significant investment for relatively marginal enhancements, resulting in diminishing returns on that investment. Consequently, only products with higher profitability are more likely to attract additional investment because they offer a more favourable return on investment.

Additionally, the infrastructure for extracting, producing and manufacturing raw materials is extremely costly, locking in polluting processes and creating barriers to technological change.

Knock-on effects of capacity changes to value chains

Changes in the market (i.e., through increasing capacity through process upgrades or new processes) affect entire product value chains that may be interconnected at a global level. Application of more efficient, alternative processes may prove to generate a favourable output in one stage of manufacturing, but this output may not be suitable for use as an input in subsequent processes. This is further discussed in measure 6 (collaborative consumption).

Market demand often leads to overproduction

One workshop participant mentioned that a key barrier to further process efficiency improvements is overproduction. This is directly connected to market demand which, as previously mentioned, fluctuates. Overproduction causes an excess in inventory, with the excess products often being sold to the market for a lower price. As the cost decreases, the product loses its value. Therefore, to fully shift the focus to improving process efficiencies, the sector needs better connection to, and therefore forecasting of, market demand. The pharmaceuticals industry was used as an example of this, suggesting that due to ever-changing market demands, as well as health and safety concerns on products, batches are often overproduced and often disposed of, which leads to very high waste generation.

Another stakeholder added that market demand also influences product changeovers, which is very inefficient for continuous processes, since they have been designed to meet certain specification and requires significant downtime to address. This occurs when the market demands different products that require different process lines. This is also commonplace in batch processing where market demand does not justify continuous processing. Batch processing is more flexible in some ways but still requires good market forecasting.

4.4 Levels of efficiency

Table 17: Levels of efficiency for chemicals measure 4

Indicator: % improvement in process yield compared to 2023 levels			
Level of efficiency	Current	Maximum in 2035	Business-as-usual in 2035
Value	0%	6 - 10%	3 – 5%
Evidence RAG	Not applicable	Amber	Amber

4.4.1 Current level of efficiency

Current process yields are highly site-specific and a range of yields is possible. However, this information is not publicly recorded. Although data on reaction yields/process efficiency in the UK chemicals sector is lacking, information on typical E-factors (ratio of waste to product produced by a reaction, by mass) indicates that reaction yields can vary significantly by segment and by tier. For example, Phan et al. (2015) report typical E-factors of one to five for bulk chemicals (Tier 1), five to 50 for fine chemicals (Tier 2) and 25 to over 100 for pharmaceuticals (Tier 3).[231]

During interviews, stakeholders noted that chemical manufacturing, particularly in the large-scale continuous process operations of the Tier 1 and Tier 2 industries, which represent around 50% of UK chemicals sector GVA[232], has been optimised over several decades with plateauing improvement since 1970s. As a result, these processes are likely already operating at high efficiency because profit margins are slim and minimising waste is a priority. Achieving further improvements in efficiency is therefore expected to be extremely challenging within these tiers. There are opportunities to enhance the efficiency of batch processes, which tend to produce more waste, especially during washout between batches. However, stakeholders noted that operators of batch processes are actively working to reduce this waste because it represents a cost.

Stakeholders were unable to provide a specific figure for the current average yield achieved at facilities as this is highly site specific. Therefore, an index was used to estimate the level of improvement that was possible, and so relative to current levels, the estimated level of efficiency is set at 0%, serving as a baseline for subsequent scenarios. The evidence RAG rating for this efficiency level is therefore not applicable.

4.4.2 Maximum level of efficiency in 2035

While stakeholders suggested that the level of efficiency in improving process yield in certain segments may be approaching its limits, they also acknowledged that further actions could be taken to minimise waste at the facility level in others, particularly in batch-scale processes. Nevertheless, these improvements are likely to be minimal. For example, stakeholders noted that operators of more speciality chemicals might look to switch to a continuous process to improve process efficiencies, but only if it is economically viable to do so.

Despite the potential for improvements, there will always be some level of waste inherent to iterative improvements due to technical limitations. While more can be done to improve efficiencies, they are likely to be very limited and often highly depend on how a plant has been run in the past and on the level of investment the operator is prepared to make. In the workshop, stakeholders voted mostly for >8% (three votes) as the maximum level of efficiency with two votes for 6-8% (with high confidence). They noted that while opportunities for higher

[231] Phan et al. (2015) GREEN MOTION: A new and easy to use green chemistry metric from laboratories to industry. Available at: Link

[232] Assuming Tier 1 and Tier 2 comprise primarily of petrochemicals, polymers and basic inorganics. https://www.parliament.uk/globalassets/documents/commons-committees/Exiting-the-European-Union/17-19/Sectoral-Analyses/7-Sectoral-Analyses-Chemicals-Report.pdf

levels exist, these are highly dependent on regulation, innovation and potential changes in feedstock. However, the stakeholders did not elaborate on what level of efficiency above 8% was achievable. Stakeholders noted that, were novel technologies to be rapidly introduced, there could be huge efficiency improvements; however, there are practical limitations. Therefore, it was inferred that maximum levels of efficiency would not be considerably more than the 8% range presented.

As a result, a maximum level of efficiency range of 6-10% has been estimated compared to existing efficiency levels. The evidence RAG rating for this level of efficiency is amber because there is no supporting evidence from literature. However, stakeholders in the workshop voted fairly consistently, with a good level of confidence in agreement with the responses obtained in interviews. There was consensus among stakeholders that achieving substantial efficiency levels beyond the current state is likely to be limited to 10% as a maximum.

4.4.3 Business-as-usual in 2035

Data from stakeholders suggests that whilst chemical production has grown overall[233], total waste generation from the chemicals sector has begun to plateau in recent years[234], suggesting that companies have already maximised process efficiency and improvements on current levels is likely to be difficult. However, it has not been possible to determine the link between chemical production and waste generation in the UK as total chemicals production by unit weight across the chemicals sector could not be obtained.

The BAU level of efficiency is unlikely to be improved much upon the current level of efficiency as operators are likely already implementing resource efficiency measures and further improvements are prohibitively expensive to implements at any meaningful scale. Nevertheless, there may still be some potential for efficiency gains through gradual process evolution and iterative improvements to design as stakeholders noted this is already part of normal business improvement. However, widespread adoption of disruptive technologies to replace aging processes is unlikely in a BAU scenario as corroborated by stakeholders.

As a result, the BAU level of efficiency is expected to improve somewhere within the range between the current and maximum levels of efficiency, approximately between 0% and 5%. This was corroborated by stakeholders in the workshop, where all stakeholders voted for either 0-2% or 3-5%, commenting that these levels are expected as part of normal business improvement. The evidence RAG rating for this level of efficiency is amber because stakeholders couldn’t provide a precise quantitative estimate, but there was consensus among them that achieving significantly higher levels of efficiency beyond the current state is unlikely.

[233] Cefic (n.d.) CHEMICAL INDUSTRY SNAPSHOT. Available at: Link
[234] Chemical Industries Association (n.d.) Sustainability. Available at: Link

5.0 Measure 5 – Water consumption

5.1 Chemicals resource efficiency measure

5.1.1 Description

Reducing water consumption in chemical processes through increased process efficiencies.

Water management has gained increasing attention and importance in recent years due to the impacts of climate change. Europe's severe drought in summer 2022 had repercussions on the manufacturing sector, including the chemical industry as a result of low water availability for operations.[235] The CIA (Chemical Industries Association) include water resource management as a critical consideration in its guidance for developing Climate Change Adaption Plans for chemical businesses.[236]

This measure focuses on increasing the efficiency of water consumption in chemical manufacturing. It has been considered separately to measures for other feedstocks due to the unique resource efficiency aspects associated with this utility. As described in the scoping section, while this measure is applicable to water use within the chemicals sector, the chemicals sector also plays an important role in reducing water consumption downstream as discussed in this section.

The European chemical industry has been developing and implementing water saving technologies, from reducing consumption and recycling water used during production, to lowering water pollution.[237] Within the UK, water treatment companies have called on chemical industry leaders to consider communicating more on water re-use, the value of recycled water, an integrated approach to water use and asking for more streamlined regulation.[238] The CIA note that regulation is increasingly encouraging chemical plant operators to introduce water saving measures.[239]

Much of the water currently consumed in the chemicals sector is used in cooling/heating applications which are more applicable to Tier 1 industries. Nevertheless, this measure is applicable to all water-consuming industries across Tier 1 to Tier 3. For this measure it was not possible to break the data down by the ONS segments listed in Table 2.

235 Cefic (2022) Is Water Management The Next Priority For Europe And The Chemical Industry? Available at: Link

236 CIA (2021) Safeguarding chemical businesses in a changing climate: How to prepare a Climate Change Adaptation Plan. Available at: Link

237 Cefic (2022) Is Water Management The Next Priority For Europe And The Chemical Industry? Available at: Link

238 Chemical Industry Journal (n.d.) Focus on Water in the Chemical Industry. Available at: Link

239 CIA (2021) Safeguarding chemical businesses in a changing climate: How to prepare a Climate Change Adaptation Plan. Available at: Link

5.1.2 Measure indicator

The '**% weight reduction in water consumption by the chemicals sector compared to 2023 levels'** was selected as it demonstrates the overall consumption of water by the UK chemicals sector compared to a baseline year.

5.1.3 Examples in practice

Water is a crucial resource for the chemicals industry, serving primarily for heating, cooling and as a feedstock. As with Measure 4 (process efficiencies), most chemical companies in the UK consider water use during the front-end design phase, striving to reduce consumption while considering other trade-offs such as energy consumption, feedstock choice etc. Therefore, there are limited opportunities to reduce water consumption due to technical limitations once the process is operational. Nevertheless, improvements can also be added retrospectively e.g., in some cases, hybrid water recovery units can be 'bolted onto' existing processes that do not impact the fundamental operation of the process.

Given the increasing scarcity of water resources, many companies have set ambitious targets to reduce water consumption; Nearly three-quarters of 20 large global chemical companies operating in the UK have detailed water usage targets in their strategies and/or investment plans.[240] Johnson Matthey, for instance, has rolled out group-wide guidance from 2022 to improve water management, measurement and reduction efforts across its sites. They also conduct awareness sessions to involve employees in achieving their water-saving goals.[241] Nevertheless, more can be done to improve resilience across the industry.[242]

Water consumption can represent a significant proportion of utility bills for chemical plants, motivating cost-saving measures. In some cases, installing post-design site-wide measures such as more meters to monitor water use by components has led to substantial savings in water use and sewerage charges.[243] Stakeholders also noted that many large water consumers for heating and cooling employ recycling loops through hybrid towers and scrubbers to recover as much water as possible before reuse. However, some water is inevitably lost to evaporation or must be returned to rivers.

The level of potential process efficiency improvements could not be identified in the UK but a case study in Turkey looking at a polyethylene terephthalate manufacturing plant (where significant water and related energy saving potential was present) demonstrated the potential for significant water and energy savings through process optimisation, resulting in a 46.7% reduction in cooling water consumption and substantial cost savings with an investment payback period of 6 months.[244] This demonstrates that significant savings could be achieved in similar plants in the UK.

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[240] CRA, (2021) Sustainability strategies in the chemical sector. Available at: Link
[241] Johnson Matthey (2022) Sustainability. Available at: Link
[242] CRA, (2021) Sustainability strategies in the chemical sector. Available at: Link
[243] Chemical Industry Journal (n.d.) Focus on Water in the Chemical Industry. Available at: Link
[244] Alkaya, E., Demirer, G., (2015) Reducing water and energy consumption in chemical industry by sustainable production approach: a pilot study for polyethylene terephthalate production. Available at: Link

National chemical associations can support their members' water management efforts by establishing learning networks, offering guidance, sharing best practices and identifying potential savings on a company level. For example, Essenscia in Belgium has initiated a 'Learning Network Water'[245], involving more than 50 chemical and life sciences companies exchanging insights and reporting on water-saving steps.[246]

Another important water-saving aspect highlighted by a stakeholder was the reduction in end consumer water consumption. For example, the chemicals sector has been developing products that reduce water consumption for end consumers, such as washing detergents that achieve the same washing performance with significantly less water, requiring less heating and resulting in cost savings for consumers. Whilst the water saving is beyond the boundary scoped in this report, the design for this product occurs within the chemicals sector therefore it deserves consideration within this report.

5.2 Available sources

5.2.1 Literature review

The literature review identified 12 sources, used in this report, that discussed water consumption, although there was little quantitative evidence on the future levels of resource efficiency that could be achieved through this measure. This comprised:

- two industry report;[247] [248]
- two academic papers;[249] [250]
- two policy documents;[251] [252] and
- six website articles.[253] [254] [255] [256] [257] [258]

The relevant sources were considered of high applicability and credibility when assessed against the data assessment framework, which recognises the relevance of the sources and

245 https://www.essenscia.be/lerend-netwerk-water/
246 Cefic (2022) Is Water Management The Next Priority For Europe And The Chemical Industry?. Available at: Link
247 Johnson Matthey (2022) Sustainability. Available at: Link
248 CIA (2021) Safeguarding chemical businesses in a changing climate: How to prepare a Climate Change Adaptation Plan. Available at: Link
249 Alkaya, E., Demirer, G., (2015) Reducing water and energy consumption in chemical industry by sustainable production approach: a pilot study for polyethylene terephthalate production. Available at: Link
250 Ncube, A., Mtetwa, S., Bukhari,M., Fiorentino, G and Passaro, R (2023) Circular Economy and Green Chemistry: The Need for Radical Innovative Approaches in the Design for New Products. Available at: Link
251 DEFRA (2023) Environmental Improvement Plan 2023. Available at: Link
252 UK Government (2003) Water Act 2003. Available at: Link
253 CRA, (2021) Sustainability strategies in the chemical sector. Available at: Link
254 Cefic (2022) Is Water Management The Next Priority For Europe And The Chemical Industry?. Available at: Link
255 SAMCO (n.d.) What are the Best Ways Manufacturing Facilities in the Chemical Industry Can Reduce Water Usage? Available at: Link
256 RSC (2008) Thirsty work. Available at: Link
257 Chemical Industry Journal (n.d.) Focus on Water in the Chemical Industry. Available at: Link
258 DEFRA (2022) Water abstraction data sets. Available at: Link

the strength of the methodology within each. The sources exhibited an average IAS of 3.8 (out of 5), with six sources exhibiting a score of 4 or above. Six literature sources were UK-specific and all but two sources were published within the last 5 years. The interviews were used to test the literature review findings and fill knowledge gaps as limited information was found specifically for the chemicals sector regarding consumption of water. Most of the information focussed on contamination and treatment of water rather than abstraction and use within the chemicals sector despite this being an area of focus by the environment agency.

5.2.2 Interviews

Industry stakeholders considered this measure as having lower priority in their assessments. They recognised that there might be room for improvement in reducing water consumption, but they pointed out that many operators have already implemented measures to reduce water usage. From their perspective, there is no compelling reason for further improvement in this regard because water is generally inexpensive and there hasn't been significant concern about its availability.

However, this perspective contradicts information from literature, which suggests that many companies are indeed concerned about water consumption and have taken steps to conserve water. It is important to note that the level of water consumption varies significantly among different industry segments and by site. For example, Tier 1 industries require heating/cooling which consumes large quantities of water. Water abstraction[259] is typically a regional issue, often interconnected with other manufacturing sectors in the same area. For example, water consumption within clusters in the North East of England is less of an issue than in the South of England.

While this measure primarily focuses on water abstraction as a resource efficiency measure, stakeholders emphasised that it is crucial to consider other aspects of water sustainability as well, such as the management of harmful chemicals in water discharges which sometimes, take precedence over water consumption due to stricter regulatory controls.

5.2.3 Workshop

A key point that was raised during the workshop was that although water scarcity is a concern, it is not a high priority within the chemicals sector. This is likely to be due to the currently low cost of water in the UK and its availability in sufficient quantities in most regions in the UK. Stakeholders also highlighted that they are not water specialists and could not greatly contribute thoughts on resource efficiency through this measure.

There was some confusion on what the measure is attempting to achieve, with its scope being initially questioned. Workshop participants enquired whether it aims to address water pollution or emissions derived from polluted water, which were clarified to not be in scope. Stakeholders noted that most of the water consumption is for heating and cooling which returns a lot of the water to the river basin.

[259] Where water is taken from a natural source such as rivers lakes etc.

An academic suggested that the origin of the water (for example river, sea, freshwater) in use is of importance. Specifically, water for cooling from seawater would not have the same impacts as fresh water used for heating and therefore it would be difficult to evaluate these aspects under the same category of water consumption. However, this may be more linked to the energy efficiency of a system rather than resource efficiency.

Another stakeholder added that from an operations point of view, water is being highly monitored and the right source of water is crucial. This is because water treatments are very costly and a plant should comply with abstraction consent limits as part of their operating permit. Another participant added to this, stating that reduced water use would mean less water treatment is required and a higher concentration of contaminants in the water which makes it easier to recover the contaminants. Thus, stakeholders noted there is value in applying these measures and opportunity to improve on current processes such as reducing wash water between batch processes.

Overall, stakeholders agreed that lowering water consumption will likely be driven by potential cost savings and worsening water scarcity, which would result in this measure becoming a much higher priority than it currently is for the chemicals sector. Whilst stakeholders believe there are plenty of opportunities to improve infrastructure or formulation methods, without a significant drive from legislation, it is likely to remain low on the priority list.

The level of engagement in the workshop was as follows:

- Four stakeholders across industry and academia were active on the mural board and four stakeholders actively contributed to verbal discussion. This measure received less interest than previous measures due to a lack of expertise and reduced workshop attendance.

5.3 Drivers & Barriers

5.3.1 Drivers

Table 18 below shows the main drivers for Measure 5. The most significant drivers are shown in bold as voted for by stakeholders in the workshop.

Table 18: Drivers for chemicals measure 5

Description	PESTLE	COM-B
Increased cost of water	**Economic**	**Opportunity – physical**
Abstraction regulations limit water use	**Legal**	**Capability – physical**
Company sustainability commitments	**Environmental**	**Motivation – automatic**

Cross-sector collaboration	Economic	Opportunity – social
Consumer demand for more sustainable products	Social / Economic	Opportunity – social
Clearer reporting requirements and measures	Political	Capability – psychological
Regional / geographical conditions	Environmental	Opportunity – physical

Increased cost of water

While reducing water use is a lower priority for manufacturing stakeholders, some indicated that for certain water-intensive operators, such as those requiring heat intensive processes (typically Tier 1 industries such as petrochemicals), it can form a significant part of their costs and is expected to increase for high users of water under the UK's 'New charging framework to protect the environment and England's long-term water supply'.[260] Some facilities in the chemical industry have already opted to save water used in production by implementing a closed-loop process and optimising water treatment technologies for treating the water more efficiently and recycling the water for reuse.[261]

Abstraction regulations limit water use

Stakeholders have highlighted the significance of water abstraction regulations as a key driver for the discussed measure. The Water Act of 2003[262] regulates how water is utilised and returned to the environment and current policies, including 'new water saving measures to safeguard supplies'[263] focus on promoting water sustainability and reuse. Stakeholders have observed that many operators are proactively cooperating with regulators to enhance efficiencies. They are motivated by ambitious targets outlined in national strategies, such as the Environmental Improvement Plan for 2023 (EIP 2023) which includes targets to reduce the non-household (business/ industrial) use of water by 9% by 2038, with interim targets discussed in the levels of efficiency.[264] Furthermore, the CIA outlined in their Climate Change Adaptation Plan guidance to members that the 2021 Environment Bill will give the Environment Agency the power to revoke abstraction licences without compensation from 2028 and advises their members to adopt plans to cope with drought scenarios.[265]

Company sustainability commitments

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260 https://www.gov.uk/government/news/changes-to-environment-agencys-abstraction-charges-to-safeguard-water-supplies-for-people-and-wildlife
261 SAMCO (n.d.) What are the Best Ways Manufacturing Facilities in the Chemical Industry Can Reduce Water Usage?. Available at: Link
262 UK Government (2003) Water Act 2003. Available at: Link
263 https://www.gov.uk/government/news/new-water-saving-measures-to-safeguard-supplies
264 DEFRA (2023) Environmental Improvement Plan 2023. Available at: Link
265 CIA (2021) Safeguarding chemical businesses in a changing climate: How to prepare a Climate Change Adaptation Plan. Available at: Link

With many chemical companies establishing their own sustainability commitments, it is expected that water consumption will be a key resource saving target for manufacturing.[266] Stakeholders noted that companies with ambitious sustainability goals will be the most likely to employ alternative processing methods that ensure less reliance on water where possible, to both avoid unnecessary additional input, as well as prevent high levels of wastewater generation.

Cross-sector collaboration

Enhancing water management is driven by the need for a systemic shift, requiring collaboration among companies across different sectors within a region, as water availability is typically a regional concern. While the chemical industry has made efforts in implementing water-saving technologies at the company level, the critical next step is to advance a cross-sectoral, local (cluster) approach.[267] Some chemical associations are actively promoting improved water management among their members through the organisation of learning networks, the development of guidance and best practices and the assessment of water savings potential on a company level. For example, Essenscia, a Belgian association, has introduced a 'Learning Network Water,' bringing together over 50 companies from the chemical and life sciences sectors to share insights and strategies for water conservation and reuse and drive improved uptake of this measure.[268]

Consumer demand for more sustainable products

Consumer demand for greener products with lower resource use and carbon intensity is one driver identified in literature, with one source noting that consumer product companies who can provide more sustainable offerings have benefitted greatly from increased consumer awareness and demand for such products.[269] In certain products, there is consumer demand for products that consume less water. For example, washing detergents that require less water for their function have been developed. This saves the consumer on water and heating costs as less is required. This has been driven alongside the development of more water and energy-efficiency washing machines. Whilst the water saving is made downstream of the chemicals sector, the design of the product occurs within the chemicals sector.

Clearer reporting requirements and measures

In the workshop, one stakeholder added that clearer reporting requirements and measures are needed to drive a reduction in water consumption. Stricter and clearer reporting requirements would increase transparency of water usage and could lead to stakeholder pressure to reduce water consumption. However, this was not expanded upon in workshop discussion.

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[266] CIA (2021) Safeguarding chemical businesses in a changing climate: How to prepare a Climate Change Adaptation Plan. Available at: Link

[267] Cefic (2022) Is Water Management The Next Priority For Europe And The Chemical Industry? Available at: Link

[268] Cefic (2022) Is Water Management The Next Priority For Europe And The Chemical Industry? Available at: Link

[269] Ncube, A., Mtetwa, S., Bukhari,M., Fiorentino, G and Passaro, R (2023) Circular Economy and Green Chemistry: The Need for Radical Innovative Approaches in the Design for New Products. Available at: Link

Regional / geographical conditions

One stakeholder observed that this issue is more relevant in certain UK regions than in others. For instance, water resources are more abundant in the North West of England compared to locations in the South East of England, which receive less rainfall. Consequently, in some geographical regions, there is a greater imperative to reduce water consumption, making it a driver for implementing this measure.

5.3.2 Barriers

Table 19 below shows the main barriers for Measure 5. The most significant barriers are shown in bold as voted for by stakeholders in the workshop.

Table 19: Barriers for chemicals measure 5

Description	PESTLE	COM-B
Low return on investment	**Economic**	**Opportunity – physical**
Technical limitations	Technological	Capability – physical
Other sustainability aspects take precedence	Environmental	Opportunity – social

Low return on investment

Stakeholders argued that due to the relatively low cost of water, reducing water consumption tends to be a low priority for operators. One stakeholder noted that the potential cost savings from implementing water efficiency measures are relatively small, making further investment less appealing in terms of return on investment. Moreover, opportunities for enhancing resource efficiency beyond existing measures are expected to be limited. From a resource perspective, there are relatively few additional possibilities beyond what is already being implemented as, despite the low cost of water, industrial plants are typically designed to use water efficiently. Stakeholders widely agreed that the “low-hanging fruit” have already been implemented by the industry and achieving further improvements would necessitate significant additional investment.

Technical limitations

Many operators already operate at high levels of efficiency and reducing water further could result in technical issues. For example, during polymer production, water consumption is optimised for the process and could result in malfunction or plant damage if lower levels are used. During the workshop, one stakeholder added that water use could be reduced through separating dilute product/water mixtures, however the energy requirements to do so would far outweigh the environmental benefits of reducing water use.

Other sustainability aspects take precedence

One stakeholder noted that operators must also consider various other aspects of water usage, including managing the presence of harmful chemicals in water discharges and controlling the temperature of discharges. These aspects have stricter regulatory controls, often with substantial penalties for non-compliance. In contrast, operators generally have relatively generous predefined limits for water abstraction. Consequently, these other sustainability considerations may take precedence over water consumption due to the more stringent regulatory controls associated with them. Additionally, in the workshop a stakeholder emphasised that water consumption is often seen as lower priority than other carbon saving initiatives such power reduction which could prevent action on this measure.

5.4 Levels of efficiency

Table 20: Levels of efficiency for chemicals measure 5

Indicator: % weight reduction in water consumption by the chemicals sector compared to 2023 levels			
Level of efficiency	Current	Maximum in 2035	Business-as-usual in 2035
Value	0%	11-15%	0-10%
Evidence RAG	Not applicable	Red-Amber	Red-Amber

5.4.1 Current level of efficiency

Currently, water-using operators are generally water efficient as companies seek ways to reduce their water costs. The chemicals industry has been making investments in water efficiency measures for many years.[270]

While stakeholders were unable to provide estimates for the current level of water use specifically within the chemicals sector and data on water abstraction rates for this sector couldn't be located, it was found that overall water abstraction in England for 'other manufacturing industries' (which includes chemicals) decreased by an average of 41% between 2000 and 2015.[271]

As the indicator for this measure is an index, relative to current levels, the estimated level of efficiency is set at 0%, serving as a baseline for subsequent scenarios. The evidence RAG rating for this efficiency level is therefore not applicable.

[270] RSC (2008) Thirsty work. Available at: Link
[271] DEFRA (2022) Water abstraction data sets. Available at: Link

5.4.2 Maximum level of efficiency in 2035

Stakeholders were unable to provide estimates for the maximum level of reduction in water usage by the chemicals sector in the interviews. However, interim targets set out in DEFRA's Environmental Improvement Plan (EIP) 2023[272] suggest that UK non-household (i.e. business and industrial) water consumption will need to be reduced by 9% by 2038 against a 2019/20 baseline.[273] It is uncertain as to whether this level of water reduction is achievable in the chemical sector due to technical limitations. This value was presented to stakeholders as a reasonable estimate to the level of efficiency that could be achieved by 2035. In the workshop two stakeholders indicated that they thought 11-15% was a realistic maximum level of efficiency as therefore this was taken as a maximum range. Whilst stakeholders believe there are plenty of opportunities to reduce water consumption, without a significant drive from legislation, this is likely to remain low on the priority list. The evidence RAG rating for this level of efficiency is red-amber due to the low number of votes received.

5.4.3 Business-as-usual in 2035

Similarly, stakeholders were unable to provide estimates for the BAU level of water use by the chemicals sector in the interviews. Nevertheless, stakeholders did highlight that the chemicals industry is actively considering water efficiency in its designs and improvements are ongoing although this remains a low priority, particularly in regions with higher rainfall such as the North East of England.

One of the stakeholders mentioned that the amount of water used for heating and cooling might decrease as we shift away from the use of virgin petrochemicals as this segment is a high consumer of water for heating and cooling. However, they also pointed out that biorefineries (using biobased feedstocks) might demand substantial volumes of water. It is important to note, though, that the nature of this water usage differs from current abstraction methods. In this case, water would be retained for longer periods, serving as a growth medium rather than for heat transfer. This means that water can be abstracted during periods of high rainfall, stored and will be less affected by declines in water availability during drier periods.

The targets outlined in the EIP 2023 suggest that interim nation-wide (including all industries and consumers) water reduction goals of 9% by 2027 and 14% by 2032 are feasible. Using business (non-household) targets of 9% for 2038 and extrapolating the household target to 2038, and business consumption pro-rated would be 4% and 6% respectively.[274] This range (4-6%) was presented to stakeholders in the workshop for discussion. Three stakeholders thought that 0-5% was more likely with on one stakeholder voting for 6-10%, however confidence on this statement was fairly low although findings indicate that the industry is gradually shifting towards reducing water usage under a BAU scenario. A range of 0-10% has been concluded from stakeholder voting. The evidence RAG rating for this level of efficiency is

[272] DEFRA (2023) Environmental Improvement Plan 2023. Available at: Link
[273] DEFRA (2023) Environmental Improvement Plan 2023. Available at: Link
[274] DEFRA (2023) Environmental Improvement Plan 2023. Available at: Link

red-amber because stakeholders generally agreed on this range as a level of efficiency despite low number of votes received and low confidence.

6.0 Measure 6 – Collaborative consumption of resources

6.1 Chemicals resource efficiency measure

6.1.1 Description

Increased sharing of resources and industrial symbiosis to increase overall material efficiencies in the chemicals sector.

This measure primarily centres around promoting greater collaboration in the sharing of resources among neighbouring operators or industries. This collaboration includes shared usage of feedstocks, utilities, by-products, recovered reagents and unused chemicals, a concept often referred to as "industrial symbiosis".

It is important to distinguish this from secondary materials that have already fulfilled their initial primary purpose, which fall under Measure 3 (secondary material content). However, it is worth noting that despite these distinctions, these measures have similarities and are closely interconnected, as discussed in the interdependencies section.

Industrial symbiosis often occurs between neighbouring sites within clusters but it can also occur between operators or industries further afield. For example, byproducts from one manufacturing process could be sold as a feedstock to another within the same sector or to other sectors.

This measure is relevant to all tiers within the chemicals sector. Stakeholders corroborated that industrial symbiosis is already relatively well implemented particularly among Tier 1 and Tier 2 industries situated in clusters. However, they also noted that further opportunities for collaboration exist at all levels. For this measure it was not possible to break the data down by the ONS segments listed in Table 2.

6.1.2 Measure indicator

The **'% weight of production waste avoided by the chemicals sector through increased sharing of resources compared to 2023 levels'** levels was selected as an indicator for this measure. It demonstrates how much material could be recovered at sector level that would otherwise be classified and treated as waste by improving industrial symbiosis.

6.1.3 Examples in practice

Industrial symbiosis is common within the chemicals sector, particularly in regional clusters where chemical plants collaborate by sharing utilities and exchanging by-products and feedstocks between each other. According to stakeholders, the practice of sharing resources between sites was proliferated by Imperial Chemical Industries (ICI)[275] who had ownership and oversight of facilities which enabled interactivity between sites. However, following divestment of in the 1990s, sharing of resources became more difficult although legacy infrastructure continues today.

In 2003, NISP, the world's first national industrial symbiosis program, originated from successful pilot schemes, was set up in the UK. It claims to have helped divert 47 million tonnes of industrial waste from landfill, generated £1 billion in new sales, and reduced carbon emissions by 42 million tonnes. The initiative has also led to a £1 billion cost reduction by minimising disposal, storage, transport, and purchasing expenses and has played a pivotal role in creating and safeguarding over 10,000 jobs. Moreover, it has saved 60 million tonnes of virgin material, conserved 73 million tonnes of industrial water and reused 1.8 million tonnes of hazardous waste. Participants, ranging from micro- and small- to-medium-sized businesses, as well as multinational corporations across various sectors including chemicals, have collectively contributed to fostering sustainable industrial practices and economic growth. It has since been replicated in 20 countries.[276]

However, beyond industrial clusters, stakeholders have observed that the trading of by-products and unused reagents is relatively limited unless there is a substantial market demand for these materials. In most cases, operators aim to maximise their revenue by first identifying internal uses for by-products. If it is not feasible to use these by-products internally, operators then seek external markets to sell them to. Typically, waste generated by the chemicals industry is relatively consistent in composition, which generally facilitates finding markets for these by-products. However, this is not a universal rule and the sector still generates ad-hoc waste, particularly in batch processing. While some companies do sell their by-products as raw materials to other businesses, stakeholders have noted that this is a less common activity compared to reusing the by-product within the same on-site process. Moreover, this practice is generally restricted to specific segments of the chemical industry where the by-product has a strong market demand that enables this approach to function effectively.

A notable example of this is the supply of gases to the food and beverage sector. For instance, a stakeholder noted that waste gas streams can be converted, through bioconversion methods, into zinc cell protein, which can then be used as feed for salmon. Similar processes are used to produce products like Quorn through bioconversion methods.

As discussed previously, many companies are making commitments to reduce their environmental impacts. For example, at Kemira, 38% of raw materials across the business came from recycled sources or industrial by-products from external partners in 2022 (improved from 27% in 2016)[277]. 70-80% of raw materials to produce inorganic coagulants came from recycled materials. Kemira has recently started production in its two new coagulant plants. For these plants Kemira uses by-products generated by another chemical company Covestro at

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[275] Imperial Chemical Industries (ICI) is a now defunct British chemical company founded in 1926. It used to be the largest chemicals manufacturer in the UK but its assets were acquired by AkzoNobel in 2008 and parts of it were later sold to Henkel AG & Co. KGaA.
[276] International Synergies (n.d.) Projects: NISP® Available at: Link
[277] Kemira, n.d Adding Circularity to our Economy. Available at: Link

the same production sites from smelters, steel and metal manufacturing and other industries.[278]

Stakeholders noted that larger businesses are often able to collaborate between facilities within clusters more easily as they can streamline internal operations because of greater visibility of supply and demand between facilities that may otherwise be deemed sensitive to competitors. Furthermore, they have capacity and resources to implement infrastructure. For example, stakeholders noted that the BASF Ludwigshafen site[279] in Germany is highly integrated which results in "huge efficiencies". Stakeholders noted that the breakup of the ICI facilities at Wilton into individual private enterprises may have hindered some efficiencies that would have been easier to implements by a single entity.

Cross-sector collaboration can maximise the efficiency of resources by increasing the potential uses available to a material beyond just the chemicals sector. An example of this is where CEMEX[280], using liquid waste from INEOS[281] and a chalk reject material from OMYA[282], is able to return its cement kiln dust to OMYA's quarry.[283]

Cross-sector collaboration is critical in developing technologies and alternative uses of materials. Companies often partner with other organisations to find innovative uses of their materials. For example, companies such as BASF have strengthened relationships with a network of universities, research institutes and industry partners to benefit from their knowledge.[284]

6.2 Available sources

6.2.1 Literature review

The literature review identified 13 sources, used in this report, that discussed Collaborative consumption of resources, although there was little quantitative evidence on the future levels of resource efficiency that could be achieved through this measure. This comprised:

- five industry reports;[285] [286] [287] [288] [289]

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[278] Cefic (2021) Making Chemical Plants More Resource Efficient. Available at: Link
[279] https://www.basf.com/global/en/who-we-are/organization/locations/europe/german-sites/ludwigshafen.html
[280] https://www.cemex.co.uk/
[281] https://www.ineos.com/
[282] https://www.omya.com/
[283] Cefic (n.d.) Exchanging By-Products To Improve Resource Efficiency. Available at: Link
[284] PwC (2019) Circular economy: A new source of competitive advantage in the chemicals industry. Available at: Link
[285] PwC (2019) Circular economy: A new source of competitive advantage in the chemicals industry. Available at: Link
[286] Green alliance (2023) A new formula: Cutting the UK chemical industry's climate impact. Available at: Link
[287] Cefic (2021) Cefic position statement on circular economy 2.0 – Towards a carbon-smart circular future. Available at: Link
[288] OECD (2017) Economic Features of Chemical Leasing. Available at: Link
[289] Chemical Industries Association (n.d.) Sustainability. Available at: Link

- one technical report;[290]
- one academic paper;[291]
- one policy document;[292] and
- five website articles.[293] [294] [295] [296] [297]

The relevant sources were considered of high applicability and credibility when assessed against the data assessment framework, which recognises the relevance of the sources and the strength of the methodology within each. The sources exhibited an average IAS of 4 (out of 5), with nine sources exhibiting a score of 4 or above. Only three literature sources were UK-specific and all but one source was not published within the last 5 years. The interviews were used to test the literature review findings and fill knowledge gaps, particularly with respect to the levels of efficiency, as it was difficult to estimate industry-wide figures from literature.

6.2.2 Interviews

Stakeholders recognised that this measure holds significant potential for enhancing resource efficiency. Many stakeholders emphasised that there is room for improvement in fostering cross-sector collaboration, even within industrial clusters. Stakeholders pointed to an example in the North East of England Process Industry Cluster (NEPIC), which has attempted to improve resource efficiency through the creation of a register or database of the materials being used. However, stakeholders noted that several barriers including commercial sensitivity of data has prevented its successful uptake.

Furthermore, stakeholders highlighted that outside of these industrial clusters, there has been limited adoption of resource sharing among companies. This limitation is primarily attributed to factors such as a lack of suitable markets and transportation costs. However, stakeholders acknowledged that there could be opportunities for improvement in this area. Some companies may possess valuable by-products, yet they may lack the resources to explore alternative uses or develop markets for these products.

6.2.3 Workshop

Some stakeholders noted that the 'low hanging' options have already been achieved and that further optimisation may be small and involve working with other industrial sectors. Stakeholders noted that numerous activities are being undertaken to improve this, but most get to the same point, where things occur more because of serendipity than planned co-ordination. Other stakeholders were unaware of many successful examples beyond those developed/inherited on industrial clusters. Of those examples, most did not last for a number of

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290 EEA (2021) Designing safe and sustainable products requires a new approach for chemicals. Available at: Link
291 CREDS (2021) Resource efficiency scenarios for the UK: A technical report. Available at: Link
292 UK Government (2020). Pollution inventory reporting – incineration activities guidance note. Environmental Permitting (England and Wales) Regulations 2016 Regulation 61(1). Available at: Link
293 European Commission (2009) National Industrial Symbiosis Programme (UK). Available at: Link
294 Cefic (n.d.) Exchanging By-Products To Improve Resource Efficiency. Available at: Link
295 Cefic (2021) Making Chemical Plants More Resource Efficient. Available at: Link
296 International Synergies (n.d.) Projects: NISP® Available at: Link
297 Kemira, n.d Adding Circularity to our Economy. Available at: Link

reasons, including uncertainty over data quality, uncompetitive pricing, too little or inconsistent supply or demand and concerns about commercial sensitivities.

However, most stakeholders agreed that there is a significant opportunity to improve collaboration both within the chemicals sector and other industries, but greater awareness and agreement will be needed which can be challenging. Stakeholders expressed medium-high confidence that more can be done on this if barriers can be removed. Without intervention, development of markets is likely to be difficult. One stakeholder expressed concern that not much can be done at scale for disparate industries but that high-value, niche applications are possible.

Workshop participants suggested that it would be difficult to quantify the levels of resource efficiency achieved through this measure, as data for this does not currently exist. Furthermore, commercial sensitivity and the limited number of players in certain market segments can prevent the development of an open trading platform.

The level of engagement in the workshop was as follows:

- Six stakeholders across industry and academia were active on the mural board and five stakeholders actively contributed to verbal discussion.

6.3 Drivers & Barriers

6.3.1 Drivers

Table 21 below shows the main drivers for Measure 6. The most significant drivers are shown in bold as voted for by stakeholders in the workshop.

Table 21: Drivers for chemicals measure 6

Description	PESTLE	COM-B
Wastes are treated as value leakage	**Economic**	**Opportunity – physical**
Increased standardisation could facilitate shared resources	**Technological**	**Capability – physical**
Increased revenue	**Economic**	**Opportunity – physical**
Legislation/fines for disposal of waste	**Legal**	**Capability – psychological**
Support for innovative SMEs	Economic	Motivation – automatic

Better collaboration identifies further opportunities	Economic	Opportunity – social

Wastes are treated as value leakage

Waste is seen as value leakage across the supply chain, meaning that chemical producers will look at ways to reduce waste to reduce value loss. One way to do this is improved collaborative consumption of resources which ensures by-products and other remaining resources that would otherwise be wasted are used. Reducing waste will also help producers to avoid disposal costs.

Increased standardisation could facilitate shared resources

Increased standardisation in processes, reporting, marketing of product and waste specification could facilitate the collaborative use of resources by chemical manufacturers, as consistency in supply enables better use as a feedstock.[298] Furthermore, an understanding of the availability of material held by operators (such as through a shared database) could promote the sharing of resources. In the workshop, one stakeholder added that knowing the content of a product is fundamental for easy adoption of shared resources, while another stakeholder added that standardisation of both materials and material characterisation are important aspects of this driver.

Increased revenue

The key driver for promoting industrial symbiosis is the increased revenue that could be achieved through the sale of industrial by-products. There is financial incentive to identify end markets for material that would otherwise become waste. In the workshop, one stakeholder added that it would not only increase revenue but also reduce costs associated with disposal. Another stakeholder argued that generating revenue from collaborative consumption is seen as an opportunity but can be dismissed as it is seen as distraction from the core business. Stakeholders noted that to make meaningful progress in this area a more intentional approach from the company would be required.

Legislation/fines for disposal of waste

In the workshop, several stakeholders argued that current legislation is not designed to drive resource efficiency or industrial symbiosis, and that updating legislation to support appropriate handling of waste, such as the existing landfill tax, could help drive collaborative consumption.

Support for innovative SMEs

Available finance for short- and long-term investments, such as earmarked funds to support small and medium-sized enterprises (SMEs), can support the development of their supply

[298] Green alliance (2023) A new formula: Cutting the UK chemical industry's climate impact. Available at: Link

chain and develop more sustainable business models.[299, 300] Funds can also be used to help them invest in the required infrastructure to better collaborate with partners. One stakeholder added in the workshop that SME-scale businesses are likely to be more sustainable in the chemical industry.

Better collaboration identifies further opportunities

Collaboration with value chain partners, trade associations, as well as with industry, universities and research organisations could identify new opportunities for innovation which could include collaborative consumption.[301] Additionally, engagement with policy-makers, regulators and government agencies could be vital to support the establishment of an ecosystem of suppliers and customers. Such an ecosystem will require that companies put in place the right incentives and regulations.[302] Stakeholders noted that as industry is increasingly pressured to understand their supplier value chains (i.e., such as increased scope 3 carbon reporting and other voluntary company commitments), the increased level of communication can lead to identifying other areas for collaboration within the supply chain.

Trade associations can play a role in advertising material streams from members that could become useful feedstocks for others. Programs such as the National Industrial Symbiosis Programme (NISP)[303] have applied and facilitated industrial symbiosis to achieve substantial resource efficiency. Between 2005 and 2009 the program diverted more than 5.2 million tonnes of industrial waste from landfill, eliminated 357,000 tonnes of hazardous waste, prevented the use of 7.9 million tonnes of raw materials, prevented the use of 9.4 million tonnes of industrial water, delivered member cost savings of £131 million and generated £151 million in new sales for members.[304]

6.3.2 Barriers

Table 22 below shows the main barriers for Measure 6. The most significant barriers are shown in bold as voted for by stakeholders in the workshop.

Table 22: Barriers for chemicals measure 6

Description	PESTLE	COM-B
Infrastructure and transport costs	**Economic**	**Opportunity – physical**

[299] EEA (2021) Designing safe and sustainable products requires a new approach for chemicals. Available at: Link
[300] PwC (2019) Circular economy: A new source of competitive advantage in the chemicals industry. Available at: Link
[301] Cefic (2021) Cefic position statement on circular economy 2.0 – Towards a carbon-smart circular future. Available at: Link
[302] PwC (2019) Circular economy: A new source of competitive advantage in the chemicals industry. Available at: Link
[303] https://www.nispnetwork.com/
[304] European Commission (2009) National Industrial Symbiosis Programme (UK). Available at: Link

Lack of transparency in supply of shareable resources	**Technological**	**Opportunity – physical**
Regulatory barriers	**Legal, Political**	**Capability – psychological**
Low feasibility for smaller operators	**Economic, Technological**	**Opportunity – physical**
Knock-on effects of capacity changes to value chains	Technological	Capability – physical

Infrastructure and transport costs

To promote greater resource sharing, it is essential to establish the necessary infrastructure for material transfer. When operators are located near each other, this might involve constructing pipelines or rail connections between their sites where there is a high volume of throughput. However, for operators situated at greater distances, expenses related to vehicle logistics may be incurred. These infrastructural developments can be costly for operators. Therefore, feasibility studies need to be undertaken to determine whether there is a net financial benefit to improving resource sharing. One stakeholder added in the workshop that additional transport also increases the emissions associated with the product. The business case for transporting materials is likely to vary depending on the product. Considerations include the nature of the chemicals in question. For example, transporting a small volume of high-value chemical across longer distances may be economically justified compared to a low-value one. Storage and transport costs can also differ among chemicals. For instance, hazardous chemicals may necessitate more expensive risk mitigations, impacting the overall cost-effectiveness of transportation.

Lack of transparency in supply of shareable resources

Stakeholders noted that the absence of transparency in information about the availability and supply of resources, is a barrier to uptake of industrial symbiosis. The lack of visibility into resource availability, due to commercial sensitivity, makes it challenging for manufacturers to consistently utilise wastes/byproducts as a resource. Stakeholders have mentioned that previous attempts to develop such databases have been limited due to concerns related to protecting commercial interests and limited business case. Stakeholders also noted that much of the industrial symbiosis in clusters today are remnants of the ICI[305] era where assets once belonged to a single entity. Stakeholders noted that it is harder to integrate two private businesses in the same way due to concern over commercial sensitivity and information sharing barriers. However, individual private operators do continue to share resources within individual clusters or chemical parks but this could be improved with increased supply

305 Imperial Chemical Industries (ICI) is a now defunct British chemical company founded in 1926. It used to be the largest chemicals manufacturer in the UK but its assets were acquired by AkzoNobel in 2008 and parts of it were later sold to Henkel AG & Co. KGaA.

transparency. The significance of this barrier was further highlighted in the workshop where stakeholders emphasised that commercial sensitivities are the main roadblock to removing this barrier. Due to the relatively low number of market players for certain products, the availability of product can be determined by competitors. Stakeholders suggested that there is an additional issue of quality assurance and authenticity when it comes to shared resources. Manufacturers are not aware of the true specification of a previously-used material or by-product and will therefore opt to not integrate it in their processes to avoid risks that would compromise final product quality.

Regulatory barriers

As discussed in Measure 3 (secondary material content), stakeholders noted that another major barrier to collaborative consumption is related to the complexities around waste legislation which complicates and obstructs the handling of certain materials and prevents it from being used as a feedstock. An example of this is the strict emission limits and reporting of dioxins and furans contained in waste plastics which prevents wastes like vehicle tyres from being used as alternative feedstocks.[306] Stakeholders added that regulations should consider a wider pool of stakeholders to prevent siloed decision-making.

Low feasibility for smaller operators

Stakeholders highlighted that, especially for smaller manufacturers, collecting waste materials on a scale that makes them economically valuable as a product is often not seen as worthwhile. As a result, these manufacturers incur costs for waste disposal. In some cases, these discarded resources could indeed have value, but manufacturers often lack the necessary resources to explore alternative uses or produce them in quantities large enough to justify the associated expenses, such as storage and bulking. Smaller decentralised operators face additional challenges in finding a consistent market for their by-products at a scale that would make it financially viable. Furthermore, due to the typically larger distances between smaller sites, there are additional transportation costs which make it infeasible in many cases. In the workshop, one stakeholder added that the rate of production of these materials is often inconsistent as many of these smaller operators operate batch processes, whereas to find a market for it often requires a continuous or reliable flow.

Knock-on effects of capacity changes to value chains

Changes in one process can impact the production of feedstock for another. Manufacturing systems are extensively interconnected, with many product value chains operating at the global level. Implementing change in one part of the system therefore has knock-on effects and implementing safe and sustainable by design approaches requires effective collaboration throughout the product value chain, from production through to waste management, reuse and recycling. One stakeholder added that one of the knock-on effects could be that the availability

[306] UK Government (2020). Pollution inventory reporting – incineration activities guidance note. Environmental Permitting (England and Wales) Regulations 2016 Regulation 61(1). Available at: Link

and quality of shared resources are variable which would require processes to be tuned accordingly and may result in process efficiency losses and further ripple effects.

6.4 Levels of efficiency

Table 23: Levels of efficiency for chemicals measure 6

Indicator: % increase in weight of production waste avoided by the chemicals sector through sharing of resources compared to 2023 levels			
Level of efficiency	Current	Maximum in 2035	Business-as-usual in 2035
Value	0%	11 – 15%	0 – 5%
Evidence RAG	Not applicable	Amber	Amber

6.4.1 Current level of efficiency

In most cases, operators aim to maximise their revenue by either identifying internal uses for by-products or by seeking external markets to sell them to. Nevertheless, the sector generates significant waste, although there has been considerable improvement since 2004.[307]

Notably, the proportion of waste from England's chemical industry sent for recovery (prevention, reduction, recycling and reuse) more than doubled over the 15-year period from 2004 to 2019, increasing from 19% to 47% in 2019.[308] Stakeholders noted in interviews that total chemical waste production during this period saw only a slight increase. While data for other UK nations was not available, it has been assumed that this trend holds true for the entire UK. This data was corroborated by stakeholders in interviews however this contradicts chemical waste data from Eurostat[309] although this data may have a different methodology to the data quoted by stakeholders.

However, it cannot be ascertained as to where these savings were made as there is no specific data on waste associated with sharing resources and it is impossible to disaggregate this measure from the total waste savings. In order to capture the impacts of this measure only, the indicator for this measure was taken forward as an index, relative to current levels. The estimated level of efficiency is set at 0%, serving as a baseline for subsequent scenarios. The evidence RAG rating for this efficiency level is therefore not applicable.

[307] Chemical Industries Association (n.d.) Sustainability. Available at: Link
[308] Chemical Industries Association (n.d.) Sustainability. Available at: Link
[309] Eurostat (2020) Generation of waste by waste category. Available at: Link

6.4.2 Maximum level of efficiency in 2035

The proportion of waste from England's chemical industry that was sent for recovery increased by almost 30 percentage points over the 15-year period from 2004 to 2019.[310] However, stakeholders pointed out that this significant increase occurred because the industry effectively addressed the most readily achievable improvements during that time. Furthermore, improvements because of enhanced collaboration would only make up a portion of this overall waste reduction. As a result, achieving similar large-scale increases in recovery rates in the next 15 years leading up to 2035 is unlikely without substantial investments. Stakeholders in interviews concurred that a further 30 percentage point increase would be extremely ambitious given that waste sent for recovery has plateaued in recent years.[311] In the workshop, stakeholders voted mostly for a value of 11-15% (four votes) with one vote for 6-10%, however all votes were with either low or medium levels of confidence. In the workshop, one stakeholder noted that there may be significant potential for this measure for certain materials or product but this is unlikely to be across the entire chemicals sector. Others agreed that large barriers would need to be overcome across the sector to achieve significant levels of efficiency as reflected by voting.

On reflection of this input, a range of 11-15% has been concluded as stakeholders agreed that there is opportunity for improvement but much greater awareness and agreement across the industry will be needed to develop appropriate markets. The evidence RAG rating for this level of efficiency is amber despite there being no supporting literature, stakeholders voted consistently in the workshop (albeit with a limited level of confidence) that this range is appropriate. There was consensus among stakeholders that achieving substantial efficiency levels beyond the current state is possible but likely not to exceed 15%.

6.4.3 Business-as-usual in 2035

Despite stakeholders suggesting plateauing levels of waste recovery in recent years, the CIA notes that members are in the process of establishing new baselines and setting waste recovery targets following site changes.[312] Therefore sites are likely to continue identifying markets for by-products and recyclers. This means there is a likelihood that this measure could improve in a BAU scenario. Forecast data is unavailable in literature, however stakeholders noted that the most easily attainable opportunities have already been addressed. They also agreed that additional possibilities are further opportunities are likely to be limited, have a reduced immediate effect, or be relevant only to specific materials and activities influenced mainly by market conditions.

This was corroborated by the stakeholders in the workshop, whose votes were split between 0-2% and 3-5%, with slightly higher confidence in the lower range. Therefore, a BAU scenario range of a 0 – 5% improvement has been estimated. The evidence RAG rating for this level of efficiency is amber because there is no identified evidence in the literature and stakeholders were unable to provide a precise quantitative indication of its implementation in interviews.

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[310] Chemical Industries Association (n.d.) Sustainability. Available at: Link
[311] Chemical Industries Association (n.d.) Sustainability. Available at: Link
[312] Chemical Industries Association (n.d.) Sustainability. Available at: Link

However, in the workshop, stakeholders voted consistently (with a reasonable level of confidence) that the suggested range is an achievable maximum.

7.0 Interdependencies

This report has discussed each of the measures identified for the chemicals sector and presented estimates for the maximum and BAU level of efficiency they could achieve independently, that is, not considering any interdependencies or interactions between measures.

However, in practice these measures are likely to occur in tandem and the levels of efficiency that are reached in each will depend on progress against other measures. The precise nature of these interdependencies should be considered when using any of the level of efficiency estimates from this report in further research or modelling exercises that attempt to produce an estimate of the cumulative impact of these measures over time.

A summary of the key interactions/interdependencies between the measures in this report with other measures in the sector and with measures in other sectors is presented below.

Note, the estimates for the current level of efficiency will by their nature reflect the interactions and interdependencies between measures as they currently occur.

7.1 Interdependencies within the sector

Measures 2, 3, 4 & 6

Measures 2 (substitution of virgin fossil-based organic feedstocks), 3 (secondary material content), 4 (process efficiencies) and 6 (collaborative consumption) are closely interconnected because they all revolve around the increased utilisation of secondary or by-products within the industry as a strategy to reduce waste. These measures encompass materials that would otherwise end up as waste, including recycling, reusing, or remanufacturing waste chemicals and products into secondary products. However, each of these measures focuses on a specific aspect of waste reduction.

Measures 2 & 3

Measure 2 (substitution of virgin fossil-based organic feedstocks) centres on alternative carbon sources. This differs from Measure 3 (secondary material content), which concentrates on the recovery of other end-of-life materials within the chemicals industry, including inorganic substances. Measure 3 (secondary material content) also incorporates various recycling and reuse measures beyond the chemical recycling of plastics.

Stakeholders encountered confusion with Measure 3 (secondary material content) due to its close association with Measure 2 (substitution of virgin fossil-based organic feedstocks), particularly with respect to secondary carbon feedstocks from plastic chemical recycling. Furthermore, Measure 3 is heavily dependent on post-user and post-consumer waste which is downstream of the chemicals sector and falls under the scope of other sectors studied in the wider research project, particularly mechanical recycling of plastics which is considered within the plastics sector scope. As a result, stakeholders were unsure which materials would be directly covered and were only able to provide limited information on the expected levels of efficiency for this measure.

Measures 3 & 6

Measure 6 (collaborative consumption) focuses on trading of resources between operators and it includes the recovery of reaction by-products, which tend to be more consistent and homogeneous than post-user waste considered under Measure 3 (secondary material content). However, both are linked as there is often ambiguity within the industry between recycled and regenerated content. Most data focusses on waste reduction and does not distinguish the reasons for this (e.g. via reuse, recycling, selling as a byproducts, regeneration etc.). This also extends to Measure 4 (process efficiencies).

Measures 4 & 6

Measure 4 (process efficiencies) was a lot easier to define and understand by stakeholders as it is restricted by the process boundary. Measures 4 (process efficiencies) and 6 (collaborative consumption) are closely interlinked as they both pertain to the increased use of reaction by-products. Measure 4 (process efficiencies) is limited to within specific industrial processes, while Measure 6 (collaborative consumption) assesses this at the sector level. It is difficult to disaggregate data between these two measures as companies typically report on their waste generation. Selling byproducts does not constitute waste and is not reported. Therefore, it is difficult to determine how much waste is reduced by recovering internally (within the production process) or by sharing with other operators. In either case, these measures are heavily intertwined and should be considered together to maximise resource efficiency within the sector.

Measures 2 & 5

Measure 5 (water consumption) is linked to the other measures, in that any change to a product production process or business model could result in a change in water use. For example, greater adoption of biorefineries (using biobased feedstocks) under Measure 2 (substitution of virgin fossil-based organic feedstocks) might demand substantial volumes of water used in a different manner to existing or legacy processes. This measure, along with other environmental and socio-economic issue should therefore be considered when developing resource efficiency measures.

7.2 Interdependencies with other sectors

All sectors

As highlighted throughout this report, the chemicals sector is deeply interconnected with other sectors that are examined both within the report and in the broader project. The chemicals sector is responsible for producing chemicals used in more than 90% of manufactured goods.[313] Consequently, many of the measures implemented in the chemicals sector will have a ripple effect downstream into various applications and industries. Conversely, efficiency improvements made downstream from the chemicals sector can lead to overall efficiency gains within the chemicals sector and ultimately affect overall material extraction. For instance, if products are designed to be lighter, it will result in lower consumption of chemicals and, subsequently, a reduction in overall material extraction.

Of the other sectors investigated as part of the wider research project, the chemicals sector is most closely linked to the plastic sector, serving as the primary producer for plastic products. The two sectors share a value chain, meaning measures taken in one sector affect the other. For instance, designing lighter products in the plastic sector reduces chemical consumption and overall material extraction in the chemicals sector. Increasing recycling rates in plastics also decreases the demand for chemicals in polymer production. Any resource efficiency improvement in the plastic sector has a ripple effect, reducing the demand for fossil-based plastics feedstocks from the chemicals sector. Therefore, it is crucial to consider not only the chemicals sector itself but also both the upstream and downstream sectors, even if they are not the central focus of this report. These sectors play a significant role in the supply chain and can significantly contribute to overall efforts aimed at achieving resource efficiency. Specific interdependencies by measure are listed below.

Measure 1 (Reducing net resource input)

This measure sits primarily at the Tier 3 company level and crosses over into downstream industries as the formulation is heavily dependent on the design of the final product. Therefore, there is limited intervention that can be made by the chemicals industry alone. To facilitate this measure, it is vital that downstream suppliers collaborate with the chemicals industry when designing products. The downstream effects of this measure will eventually work their way up the supply chain, for example by requiring fewer, higher specification, feedstocks. The example of a plastics bottle given by one stakeholder demonstrates how design decisions for final products have impacts upstream in the chemicals sector (see plastic and glass reports).

Measure 2 (Substitution of virgin fossil-based organic feedstocks)

The chemicals industry has developed over decades in close association with various sectors, particularly the energy sector, which has traditionally relied on fossil fuels. With the ongoing push to shift away from fossil fuels, the chemicals industry must align itself with this transition to ensure it has access to suitable organic feedstocks.

Moreover, the chemicals sector is intricately linked with the energy sector, as energy is essential for transforming materials. To successfully advance the chemicals sector, it is imperative to have consistent access to low-cost renewable energy.

This measure is closely connected to other sectors, particularly in terms of the demand for alternative feedstocks. For instance, the food industry requires CO_2, while biomass is essential

[313] Green alliance (2023) A new formula: Cutting the UK chemical industry's climate impact. Available at: https://green-alliance.org.uk/publication/a-new-formula-cutting-the-uk-chemical-industrys-climate-impact/

in sectors like paper production. As mentioned earlier, the demand for secondary plastics for mechanical recycling will also compete with the plastics needed for this specific measure.

Measure 3 (Secondary material content)

Measure 3 is heavily dependent on post-user and post-consumer waste which is generated downstream of the chemicals sector and falls under the scope of other sectors studied in the wider research project. Therefore, the chemicals industry must collaborate with downstream industries, including waste handlers to develop systems to capture and utilise this material.

Measure 4 (Process efficiencies)

This measure is contingent upon market fluctuations. While the primary objective of the chemicals sector is to generate consistent supplies to fulfil market demand, achieving this equilibrium is strongly reliant on external factors, including influences from other upstream and downstream sectors.

Measure 5 (Water consumption)

This measure stands out as the most independent among those discussed in this report, as it is less influenced by other industries and measures. However, water demand in the chemicals industry faces competition from various sectors. Additionally, as with Measure 4, production and resource consumption, including water, are subject to market factors. An interesting observation from a stakeholder is that downstream industries can impact production within the chemical industry. For instance, the demand for detergents with low water usage in washing machines was driven by the need for more energy-efficient washing machines, which use and heat less water. Legislation affecting other product sectors can therefore influence the design and production of chemicals.

Measure 6 (Collaborative consumption of resources)

Measure 6 is closely tied to other industries. In addition to investigating the collaborative use of resources within the chemicals industry, the sector should actively seek connections with other industries. For instance, inert chemical waste (e.g. Slags, silicates or carbonates etc.) has the potential to be repurposed in sectors such as construction as filler material or as Supplementary Cementitious Materials (SCMs) in low carbon concrete (see Unlocking Resource Efficiency: Phase 1 Cement & Concrete report). While operators currently seek markets for byproducts, enhancing the interaction between industries could further optimise this process, presenting opportunities to create high-value products.

Glossary and abbreviations

Glossary	Definitions
Batch process	A manufacturing method where a fixed quantity of raw materials is processed at once, producing a limited quantity of product before resetting for the next batch
Biobased	Products derived from renewable biological resources
Black mass	Mixed substances obtained from electronic waste or lithium-ion battery recycling, which includes valuable materials like lithium, cobalt and nickel
Byproduct	A secondary or incidental product produced during a manufacturing process, in addition to the primary intended product
Carbon Capture Utilisation and Storage	Technologies and processes designed to capture carbon dioxide emissions from industrial sources, utilise or store them
Chemical leasing	An outcome-based model used within the chemicals industry. It is a collaborative business model where the chemical supplier is compensated based on the performance, rather than the volume of chemicals sold
Circular economy	An economic system that emphasises the recycling, reuse, and regeneration of products to minimise waste and environmental impact
Continuous process	Ongoing production with a steady flow of materials, allowing for uninterrupted and constant output
E-factors	Ratio of waste to product produced by a reaction, by mass
Formulation	The composition and arrangement of ingredients in a product by mixing rather than as a chemical reaction
Hydrocarbon	A compound consisting of hydrogen and carbon, often the basis for fossil fuels and other organic compounds
Industrial symbiosis	Collaborative relationships between industries to share resources and reduce waste in a mutually beneficial manner
Lightweighting	Reducing the weight of products to maintain functionality

Net Zero	Achieving a balance between the amount of greenhouse gases produced and removed from the atmosphere
Organic chemicals	Compounds primarily consisting of carbon and hydrogen, often derived from living organisms or their byproducts
Outcome based business model	Term for a business model where payment is contingent on the achievement of specific results or outcomes rather than the volume of product sold
Polymer	A large molecule composed of repeating structural units, commonly used in plastics and other materials
Process yield	The amount of desired product obtained from a manufacturing process, expressed as a percentage
Producer responsibility schemes	Programs that hold manufacturers accountable for the environmental impact of their products, including waste management
Product-as-a-service	A business model where consumers pay for access or use of a product rather than owning it outright. It can be applied in any sector
Secondary material	Material derived from recycled or reused sources rather than primary raw materials
Segment	A distinct portion or section of a market or industry
Tax	Mandatory financial charges imposed by governments on individuals or businesses
Tier	A step or position in the value chain categorised as one of three tiers: Tier 1 activities process basic feedstock into bulk commodity chemicals; Tier 2 activities take bulk commodity chemicals and undergo further chemical reactions or blending to create part/finished mixtures; and Tier 3 activities produce final formulations for end markets, incorporating them into articles
Value chain	The series of activities involved in the production and distribution of goods or services, from raw material extraction to end-user consumption
Waste	Unwanted or discarded material, often considered as having little or no economic value
Water abstraction	Water taken from a natural source such as rivers lakes etc.

Abbreviations	Definitions
AI	Artificial Intelligence
BAT	Best Available Technique
BASF	Baden Aniline and Soda Factory
BAU	Business as Usual
BCF	British Coatings Federation
BEIS	Department for Business, Energy & Industrial Strategy
BTX	benzene, toluene and xylene
CCC	Climate Change Committee
CEMEX	Cementos Mexicanos
CCU	Carbon Capture Utilisation
CCUS	Carbon Capture Utilisation and Storage
CEO	Chief Executive Officer
CIA	Chemical Industries Association
CO_2	Carbon Dioxide
COM	Commission
CPI	Centre for Process Innovation
CREDS	Centre for Research into Energy Demand Solutions
DEFRA	Department for Environment, Agriculture and Rural Affairs
EAP	Environmental Action Plan
ECHA	European Chemical Agency
EEA	European Environment Agency
EIP	Environmental Improvement Plan
EU	European Union
FEED	Front End Engineering Design

GDP	Gross Domestic Product
GHG	Greenhouse Gas
IAS	Indicative Applicability Score
IBLF	Industrial Biotechnology Leadership Forum
ICCA	International Council of Chemical Associations
ICI	Imperial Chemical Industries
ILUC	Indirect Land Use Change
INEOS	INspec Ethylene Oxide and Specialities
LCA	Lifecycle Assessment
NEPIC	North East of England Process Industry Cluster
OECD	Organisation for Economic Co-operation and Development
ONS	Office for National Statistics
PGM	Platinum Group Metals
PLF	Polymers in Liquid Formation
PFAS	Per-fluoroalkyl substances
R&D	Research and Development
RAG	Red Amber Green
RE	Resource Efficiency
REACH	Registration, Evaluation and Authorisation of Chemicals
RSC	Royal Society of Chemicals
SAF	Sustainable Aviation Fuel
SCM	Supplementary Cementitious Materials
SSbD	Safe and sustainable by design
SCIP	Shanghai Chemical Industry Park
TiO_2	Titanium dioxide

Appendix A: IAS Scoring Parameters

Table 24: Methodology for the calculation of the IAS

Number of 'high' criteria	Number of 'low' criteria	IAS
Indifferent	3 or more	1
<= 1	2	2
>= 2	2	3
<= 2	1	3
>= 3	1	4
<= 1	None	3
2	None	4
>= 3	None	5

Table 25: IAS Scoring Parameters

Criteria	High	Medium	Low
Geography	Specific to UK	Non-UK but applicable to the UK	Non-UK and not applicable to the UK
Date of publication	< 10 years	10 to 20 years	> 20 years
Sector applicability	Sector and measure-specific, discusses RE and circularity	Sector and measure-specific, focus on decarbonisation	Cross-sector
Methodology	Research methodology well defined and deemed appropriate	Research methodology well defined but not deemed appropriate / Minor description of research methodology	No research methodology
Peer Review	Explicitly mentioned peer review	Not explicitly mentioned, but	Unknown

		assumed to have been peer reviewed	

Appendix B: Search strings

A list of the search strings used to execute the search protocol are listed below:

- Chemical* OR "Chemical industry" AND "circular economy" OR "circular design" OR "resource efficiency" OR "waste reduction" OR "material efficiency" OR sustain* OR environ*
- Chemical* OR "Chemical industry" AND lightweight* OR "light weight*" OR minimis* OR reduce* OR "circular design"
- Chemical* AND material OR mineral OR "critical raw material" OR CRW AND lightweight* OR "light weight*" OR minimis* OR reduce* OR "circular design"
- Chemical* OR "Chemical industry" AND substitut* OR alternative* OR bio-based* OR biofeed* OR ecodesign OR "eco design" OR eco-design
- Chemical* OR "Chemical industry" AND recycl* OR "recycled feedstock" OR "recycled content" OR recover* OR by-product OR secondary OR "secondary feedstock"
- Chemical* OR "Chemical industry" AND process OR produc* OR generat* OR manufact* OR consum* AND efficiency OR yield OR optimis* OR "waste reduction" OR "waste minimisation" OR "efficient design" OR water
- Chemical* OR "Chemical industry" AND leas* OR servitis* OR "circular business model" OR subscr* OR "product-as-a-service" OR PaaS OR outcome-based
- Chemical* OR "Chemical industry" AND "shared resources" OR clusters OR by-product OR interdependence OR interact*
- Chemical* OR "Chemical industry" AND "design for recycling" OR recyclability OR remanufact* OR recover* OR regenerat* OR reconditi* OR reuse

Appendix C: Literature sources

Table 26 below lists the literature sources used for both the background reading of measures and the discussion of measures.

Table 26: List of literature sources for the chemicals sector

Title	URL	Author	Year	IAS
2023 Chemical Industry Awards	link	CIA	2023	4
6th Carbon Budget	link	The Climate Change Committee	2020	5
A chemicals strategy for a sustainable chemicals revolution	link	Royal Society for Chemicals	2020	5
A new formula: Cutting the UK chemical industry's climate impact	link	Green alliance	2023	5
Accelerating Net Zero Series: Energy & Resource Efficiency for Chemistry and Medicines Manufacturing	link	KTN	2021	5
Advancing a Circular Economy	link	Dow	n.d.	4
Advancing REACH - REACH and sustainable chemistry	link	Umwelt Bundesamt (German Environment Agency)	2020	5
Avoiding Regrettable Substitutions: Green Toxicology for Sustainable Chemistry	link	Alexandra Maertens, Emily Golden, and Thomas Hartung	2021	5
BAT reference documents	link	European Commission	n.d.	5
Biomass Policy Statement	link	BEIS	2021	4
Biomass Strategy	link	Department for Energy Security & Net Zero	2023	5
Bio-waste in Europe	link	EEA	2020	4
Caco3 Filler Masterbatches	link	Bedeko	n.d.	2
Carbon capture, usage and storage net zero investment roadmap	link	UK Government	2023	5
Cefic position statement on circular economy 2.0 – Towards a carbon-smart circular future	link	Cefic	2021	4
Cefic Sustainable Development Indicators - cefic.org	link	Cefic	n.d.	5
Challenges and opportunities in assessing sustainability during chemical process design - ScienceDirect	link	Orjuela, Alvaro & Argoti, Andres & Narváez-Rincón, Paulo	2019	5
Chemical data intelligence for sustainable chemistry (rsc.org)	link	Jana M. Weber, Zhen Guo, Chonghuan Zhang, Artur M. Schweidtmann and Alexei A. Lapkin	2021	5

CHEMICAL INDUSTRY SNAPSHOT	link	Cefic	n.d.	4
Chemicals in a circular economy	link	ECHA	n.d.	4
Chemicals in a circular economy	link	European Commission	2022	4
Chemicals in a circular economy - Using human biomonitoring to understand potential new exposures. Available at:	link	HBM4EU / EEA	2022	5
Chemicals Sector Report	link	House of Commons	2018	5
Chemicals Strategy for Sustainability Towards a Toxic-Free Environment.	link	European Commission	2020	4
Chemistry and the Circular Economy	link	Chemistry Europe	2020	2
Circular chemistry to enable a circular economy	link	Keijer, T., Bakker, V. & Slootweg, J.C	2019	5
Circular economy A new source of competitive advantage in the chemicals industry	link	strategy&	2019	4
Circular Economy and Green Chemistry: The Need for Radical Innovative Approaches in the Design for New Products	link	Amos Ncube, Sandile Mtetwa, Mahak Bukhari, Gabriella Fiorentino and Renato Passaro	2023	5
Circular economy design considerations for research and process development in the chemical sciences	link	James H. Clark, Thomas J. Farmer, Lorenzo Herrero-Davila, James Sherwood	2016	4
Circular economy: A new source of competitive advantage in the chemicals industry	link	PwC	2019	4
Combined Application of the Essential-Use and Functional Substitution Concepts: Accelerating Safer Alternatives	link	Roy A, Cousins I, Harriman E, Scheringer M, Tickner J, Wang Z	2022	4
Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions Chemicals Strategy for Sustainability Towards a Toxic-Free Environment	link	European Commission	2020	4
Consistency in Household and Business Recycling in England	link	DEFRA	2021	4
Consistency in recycling collections in England: executive summary and government response	link	UK Government	2019	4
Contributions to the sustainable development strategy: reduction of resource consumption in the chemical sector by instruments of sustainable chemistry	link	Umwelt Bundesamt (German Environment Agency)	2017	5
Coping with Substances in a Circular Economy	link	RIVM	2020	5
Critical Minerals and the Chemical Industry	link	CIA	2023	4
Deep-Decarbonisation Pathways for UK Industry	link	The Climate Change Committee	2020	5
Designing safe and sustainable products requires a new approach for chemicals	link	EEA	2021	4

Development of REACH – Review of evidence on the benefits & costs of REACH	link	Ciatti et al	2021	4
Digital Development	link	World Bank	2023	2
DIGITAL TECHNOLOGIES FOR SUSTAINABILITY IN THE EUROPEAN CHEMICAL INDUSTRY	link	Arthur D Little	2023	5
Digitisation in the chemical industry	link	Chemical Industries Association	2021	4
Digitization for economic growth and job creation, Regional and industry perspectives	link	Strategy&	2019	4
Driving The Circular Economy	link	Cefic	n.d.	2
Eco-innovation index (8th EAP)	link	European Environment Agency	2023	5
Economic Features of Chemical Leasing	link	OECD	2017	5
Enabling the Transition to a Green Economy: Government and business working	link	HMG / Sustainability Exchange	2011	5
Environmental Improvement Plan	link	HMG	2023	5
Environmental Improvement Plan 2023	link	DEFRA	2023	4
Establishing the Best Available Techniques for the UK (UK BAT)	link	The Compliance People	2022	4
Exchanging By-Products To Improve Resource Efficiency	link	Cefic	n.d.	5
Flue2Chem: SCI, Unilever and 13 partners launch £5.4m net zero collaboration project	link	Society of Chemical Industry	2023	5
Focus on Water in the Chemical Industry	link	Chemical Industry Journal	n.d.	4
Foundation Industries	link	Innovate UK KTN	n.d.	4
From fossil to green chemicals: sustainable pathways and new carbon feedstocks for the global chemical industry	link	Lopez, G., Keinar, D., Fasihi, M., Koiranen, T., Breyer, C.,	2023	5
Generation of waste by waste category	link	Eurostat	2020	2
Green Chemistry, Biocatalysis, and the Chemical Industry of the Future	link	Roger A Sheldon, Dean Brady	2022	5
GREEN MOTION: A new and easy to use green chemistry metric from laboratories to industry	link	Phan, T., Gallardo, C., Mane, J.	2015	5
Guidance on waste and recovered substances	link	ECHA	2010	5
Harnessing fruit waste for poly-3-hydroxybutyrate production: A review	link	Bioresource technology	2021	4
How can the new Innovation 4.0 Playbook support research and development in Chemical Sciences?	link	Innovate UK KTN	2022	5
How to substitute?	link	ECHA	2023	5

How will the chemical industry contribute to the circular economy?	link	Politico.eu	2020	2
Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050	link	Department of Energy and Climate Change and the Department for Business, Innovation and Skills	2015	5
Industrial Decarbonisation Strategy	link	UK Government	2021	5
Innovation action plan to transform industrial waste gases to chemicals	link	Innovate UK KTN	2023	5
Is Water Management The Next Priority For Europe And The Chemical Industry?	link	Cefic	2022	4
ISC3 Publications	link	Sustainable Chemistry Collaborative Centre (ISC3)	n.d.	5
Key Performance Indicators for the Chemicals Strategy for Sustainability	link	WSP	2023	5
KNOWLEDGE HUB	link	NICER	n.d.	2
Less in, more out: using resource efficiency to cut carbon and benefit the economy	link	Green Alliance	2018	4
Life Cycle Assessment for the Design of Chemical Processes, Products, and Supply Chains	link	Kleinekorte J, Fleitmann L, Bachmann M, Kätelhön A, Barbosa-Póvoa A, von der Assen N, Bardow A.	2020	5
Made Smart Review	link	MSR	2017	4
Making Chemical Plants More Resource Efficient	link	Cefic	2021	5
Mapping Global Flows of Chemicals: From Fossil Fuel Feedstocks to Chemical Products	link	Levi, P., Cullen, J	2018	5
Material flow accounts: 2023	link	ONS	2023	4
Meet the 2020 consumers driving change Why brands must deliver on omnipresence, agility, and sustainability	link	IBM	2020	4
National Industrial Symbiosis Programme (UK)	link	European Commission	2009	5
Net Zero by 2050: A Roadmap for the Global Energy Sector.	link	International Energy Agency	2021	4
New critical minerals task force will advise UK government on supply chains	link	Society of Chemical Industry	2023	4
New frontiers in enzyme immobilisation: robust biocatalysts for a circular bio-based economy	link	Roger A Sheldon, Alessandra Basso and Dean Brady	2021	5
New Innovate UK KTN report: How can catalysis accelerate the path towards Net Zero?	link	Innovate UK KTN	2022	4
New report by WWF and AstraZeneca on water risks	link	WWF	2021	2
Non-technical challenges to non-mechanical recycling	link	WRAP	2021	4
Our Waste, Our Resources: A Strategy for England	link	HMG	2018	5

PaintCare	link	BCF	n.d.	4
Petrochemical Feedstocks	link	S&P global	2022	5
PGMs and circularity	link	Johnson Matthey	n.d.	4
Planet Positive Chemicals Pathways for the chemical industry to enable a sustainable global economy	link	SystemIQ	2022	5
Plastic packaging tax – chemical recycling and adoption of a mass balance approach [Closed Consultation]	link	UK Government	2023	4
PM 3/21 Chemicals in a circular economy	link	KEMI	2021	2
Pollution inventory reporting – incineration activities guidance note. Environmental Permitting (England and Wales) Regulations 2016 Regulation 61(1).	link	UK Government	2020	5
Production and consumption of chemicals by hazard class	link	Eurostat	2021	2
Projects: NISP®	link	International Synergies	n.d.	5
Publications about resource efficiency	link	EEA	2018-2023	5
RCI Carbon Flows Report: Compilation of supply and demand of fossil and renewable carbon on a global and European level	link	Renewable Carbon Initiative	2023	4
Reaction: New realities for the global chemicals industry	link	KPMG	2020	4
Real time in-line measurement of fluid Rheology in a manufacturing environment for the FMCG sector to significantly reduce waste and increase productivity.	link	Leo	n.d.	4
Recycling CO2 To Generate Renewable Methanol	link	Cefic	n.d.	5
Reducing water and energy consumption in chemical industry by sustainable production approach: a pilot study for polyethylene terephthalate production	link	Alkaya, E., Demirer, G.,	2015	5
Reimagining materials and manufacturing together	link	Innovate UK KTN	2023	4
Relevance of biodegradable and compostable consumer plastic products and packaging in a circular economy	link	EU	2022	4
Report Launch: Unlocking the UK's biomass resources as a feedstock for Chemical Manufacturing	link	Innovate UK KTN	2022	5
Resilience for the Future: The United Kingdom's Critical Minerals Strategy	link	UK.Gov	2022	5
Resource Efficiency for Materials and Manufacturing (REforMM)	link	Innovate UK KTN	2023	4
Resource efficiency scenarios for the UK: A technical report	link	CREDS	2021	5

Rethinking chemistry for a circular economy	link	KLAUS KÜMMERER, JAMES H. CLARK, AND VÂNIA G. ZUIN	2020	5
Role of biocatalysis in sustainable chemistry	link	Roger A Sheldon, John M Woodley	2018	5
Safe and sustainable by design chemicals and materials - Framework for the definition of criteria and evaluation procedure for chemicals and materials	link	Caldeira, C., Farcal, R., Garmendia Aguirre, I., Mancini, L., Tosches, D., Amelio, A., Rasmussen, K., Rauscher, H., Riego Sintes, J. and Sala, S	2022	5
Safeguarding chemical businesses in a changing climate: How to prepare a Climate Change Adaptation Plan.	link	Chemical Industries Association	2021	5
Safer Circles: Managing chemicals in a Circular Economy	link	IES	2023	4
Sixth Carbon Budget	link	The Climate Change Committee	2020	4
Smart Sustainable Plastic Packaging	link	Innovate UK KTN	2023	2
Sufficiency, sustainability, and circularity of critical materials for clean hydrogen	link	World Bank	2022	2
Supporting the Commission in developing an essential use concept	link	WSP	2023	5
Sustainability	link	Johnson Matthey	2022	4
Sustainability	link	Chemical Industries Association	n.d.	3
Sustainability strategies in the chemical sector	link	CRA	2021	4
Sustainability targets	link	Croda	2022	5
Sustainable bio-based materials and manufacture programme	link	Innovate UK KTN	2023	4
The 2035 UK Battery Recycling Industry Vision	link	Innovate UK KTN	2023	4
The benefits of computational chemistry for the circular economy	link	Ilan Gleiser	2023	4
The chemical industry’s overlooked role ushering in the low-carbon economy	link	WEF	2023	4
The Chemistry Council Sector Deal Sustainable Innovation for a Better World	link	Chemistry Council	2017	5
The circular economy and chemicals management	link	Chemical Watch	2023	3
The circular economy and the bioeconomy	link	EEA	2018	4
The Circular economy: To get it right we must address hazardous chemicals	link	Chemtrust	2015	5
The Environmental Permitting (England and Wales) Regulations 2016	link	UK Government	2016	5
The EU Chemical Industry Transition Pathway	link	European Commission	2023	5
The EU Chemical Industry Transition Pathway	link	Cefic	n.d.	4

The future of digitalization in the chemical industry	link	Deloitte	n.d.	4
The GC3 Blueprint of Green Chemistry Opportunities for a Circular Economy	link	Green Chemistry and Commerce Council	2021	4
The PLFs Revolution	link	Royal Society of Chemistry	2023	5
The Potential of Industrial Symbiosis: Case Analysis and Main Drivers and Barriers to Its Implementation	link	Neves, A.; Godina, R.; G. Azevedo, S.; Pimentel, C.; C.O. Matias, J.	2019	5
Thirsty work	link	RSC	2008	4
Towards a circular economy for plastic packaging wastes – the environmental potential of chemical recycling	link	Raoul Meys, Felicitas Frick, Stefan Westhues, André Sternberg, Jürgen Klankermayer and André Bardow	2020	4
Transitioning To A Circular Economy Through Chemical and Waste Management	link	UNDP	2022	5
UK REACH alternative transitional registration model (ATRm)	link	DEFRA	2023	5
UK registration, evaluation, authorisation and restriction of chemicals (REACH)	link	HSE	2023	4
UK supply chain opportunity in materials for permanent magnets	link	Innovate UK KTN	2022	4
UKRI	link	NICER	2023	5
Unilever and Geno launch $120m venture to scale alternative ingredients	link	Unilever	2022	4
VINYLOOP: Closure of operation in Italy / Phthalates issue under REACH brings down European PVC recycling project. Available at: Link	link	PlastEurope.com	2018	4
Waste to Chemicals for a Circular Economy	link	Iaquaniello G, Centi G, Salladini A, Palo E, Perathoner S.	2018	5
Water abstraction data sets	link	DEFRA	2022	4
Water Act 2003	link	UK Government	2003	4
What are the Best Ways Manufacturing Facilities in the Chemical Industry Can Reduce Water Usage?	link	SAMCO	n.d.	2
What we want to achieve: packaging waste recycling targets	link	Defra	2021	5
Why the chemical industry is prioritizing digitalization	link	EY	2022	4
Winning the Consumer with Sustainability	link	BCG	2022	4

Appendix D: List of discarded resource efficiency measures in the chemicals sector

During the literature review, several measures were excluded for various reasons, including overlaps with other selected measures, deviation from the established scope (e.g., involving energy efficiency or land use), or being perceived as supportive elements for the chosen measures (enablers). Some indicators were excluded or amended following discussion with stakeholders for their suitability in practice. These discarded measures are listed below alongside the reason for exclusion.

Table 27: List of discarded resource efficiency measures for the chemicals sector

Theme	Sub-theme	Measure name	Measure indicator	Reason for De-prioritisation
End of life	Remanufacture/ reuse	Remanufacture/ reuse	% increase in reused/ remanufactured products	Merged with other material recovery measures (measure 3)
End of life	Recycling	Recycling/ remanufacture/ reuse	Tonnes of plastic made from chemically recycled material rather than virgin material	Merged with other material recovery measures (measure 2)
End of life	Recycling	Chemical recycling	Tonnes of plastic made from chemically recycled material rather than virgin material	Merged with other material substitution measures (measure 2)
Sale & Use	Collaborative consumption	Collaborative consumption: product-as-a-service	% reduction in weight of chemicals used for desired outcome	Considered to be an enabler for other resource reduction measures

Theme	Sub-theme	Measure name	Measure indicator	Reason for De-prioritisation
				(measure 1 and 6)
Sale & Use	Collaborative consumption	Collaborative consumption: product-as-a-service	Tonnes of plastic made from mechanically recycled material rather than virgin material	Considered to be an enabler for other resource reduction measures (measure 1 and 6)
Sale & Use	Material substitution	Use of chemicals in sustainability solutions	*Discarded before indicator developed*	Merged with other material substitution measures (measure 2)
Manufacture	Fuel switching	Heat electrification	Cubic feet of fossil gas consumption reduced which is replaced by electrification	Energy is out of scope
Manufacture	Fuel switching	Switch fuel to hydrogen	Cubic feet of fossil gas consumption reduced which is replaced by hydrogen	Energy is out of scope
Design	Material substitution	Design for safety and sustainability	Number of chemicals meeting the criteria	Wider safety and sustainability are not the focus of this report
Design	Recycling	Select chemicals to improve recyclability of	Indirectly measured by waste indicators	Not applicable to wider sector. Considered an enabler for

Theme	Sub-theme	Measure name	Measure indicator	Reason for De-prioritisation
		products/articles	(covered elsewhere).	other measures (measure 3)
Design	Material substitution	Lifecycle analysis	*Discarded before indicator developed*	Considered an enabler for other measures (measure 2 and 3)
Design	Production efficiencies	Eco-innovation	*Discarded before indicator developed*	Merged with other material efficiency measures (measure 2 and 3)
Design	Production efficiencies	Process efficiencies	% weight of production waste avoided at facility	Indistinguishable from indicator used for other measure
Design	Material substitution	Alternatives assessment - functional substitution	*Discarded before indicator developed*	Considered an enabler for other measures (measure 2)
Design	Material Substitution	Substitution of inorganic/ critical materials	*% of current critical materials that can be substituted with alternatives*	Lacks specific evidence that meets the scope of material substitution in the scope of this project.
Design	Material substitution	Alternatives assessment - the essential use concept	*Discarded before indicator developed*	Considered an enabler for other measures (measure 2)
Design	Production efficiencies	Reduce land use	*Discarded before indicator developed*	Land use not considered a resource for the

Theme	Sub-theme	Measure name	Measure indicator	Reason for De-prioritisation
				purpose of this research
Design	Material substitution	Digitalisation	*Discarded before indicator developed*	Considered an enabler for other measures (measure 4)
End of life	Recycling	Safe handling of waste	*Discarded before indicator developed*	Wider safety and sustainability are not the focus of this report

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