Department for Energy Security & Net Zero

Unlocking Resource Efficiency

Phase 2 Glass Report

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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 glass 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 DESNZ, DEFRA, 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 and representative sample of the sector – for example we were unable to secure participation from a glass wool manufacturer. 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

Glass is a non-crystalline solid that is often transparent, brittle and chemically inert. It has widespread practical, technological, and decorative use across several industries and applications, including the food and drink, construction, automotive, and electronic technology industries.

The process of producing a primary glass product can be broken down into four key stages:

- Stage 1: material sourcing
- Stage 2: raw material processing
- Stage 3: primary product
- Stage 4: secondary processing

The first stage is sourcing the raw materials needed for production. The main raw materials comprise silica sand (silicon dioxide), soda ash (sodium carbonate) and limestone (calcium carbonate).

Glass offcuts and broken glass (known as glass cullet) are another key raw material in the production of glass. Rejects from the process in container and flat glass production are remelted in the furnace. Pre-consumer glass cullet refers to material that is recycled before the point of reaching consumers, for example offcuts or breakages that result from the fabrication process. Post-consumer glass cullet refers to glass that has been retrieved from waste collection services after it has been used by an end consumer and is fed back into the production of glass. The benefit of using glass cullet as a raw material is that melting it to produce new glass requires less energy than using primary raw materials, thereby reducing the energy intensity per unit of output whilst also reducing demand for primary material resources (more on this in Measure 4 of the report).[1,2,3]

The second stage involves the processing of these raw materials to make the primary product. First, the primary raw materials are mixed together, cullet (recycled glass) is added (if it is being used), and this mixture is heated in a furnace to temperatures of up to 1600°C (the greater the proportion of cullet used, the less energy is required, all other things being equal). The glass mixture is cleared of bubbles and homogenised through a ‘fining’ process.

The molten glass is kept at a high temperature before it enters the third stage, which is where the molten glass is either a) directed into a mould and blown (for container glass), b) ‘floated’ on a bath of molten tin (for flat glass), or c) blown and merged with a binder (for glass wool). The glass is then finally cooled. To avoid the internal stress due to the rapid temperature

[1] Forsulnd. H, Björklund. M (2018) Toward Circular Supply Chains for Flat Glass: Challenges of Transforming to More Energy-Efficient Solutions. Available at: link
[2] Hartwell, Coult, Overend (2022) Mapping the flat glass value-chain: a material flow analysis and energy balance of UK production. Available at: link
[3] Institute for Prospective Technological Studies (2013) Best Available Techniques (BAT) reference Document for the Manufacture of Glass. Available at: link

change, the glass is passed through an annealing chamber called a lehr, that slowly cools the glass from 600 to 60 °C, forming the primary product.

After this process, the glass product undergoes rigorous quality checks. For flat glass, it is then cut into sheets of varying sizes which are then automatically stacked, stored and ready for transport. Following the manufacturing of the primary glass product (e.g. flat glass), glass can then undergo secondary processing, such as toughening treatments, application of coatings and/or lamination with interlayer products.

UK Glass Sector

In 2019, the UK glass industry emitted 1.5 million tonnes of Emission Trading Scheme (ETS) CO_2 emissions, with 75-85% accounted for by fossil fuel combustion in the furnace (to produce the heat to melt the raw materials), and 15-25% as CO_2 emitted from the raw materials during the manufacturing process' chemical reaction, depending on the amount of recycled cullet used (recycled cullet does not release CO_2 when remelted).[4] The sector accounts for around 3% of UK industrial greenhouse gas (GHG) emissions.[5]

The glass industry contributes almost £2 billion to the UK economy each year and directly employs around 6,000 people, and indirectly supports an estimated 150,000 jobs.[6]

As part of their net zero strategy, the UK trade association for the glass sector, British Glass, has developed a model which looks at how the glass sector can work towards net zero by 2050.[7]

The majority of UK glass production is of container glass, followed by flat glass. In 2019, the UK produced 2,500 kt of container glass (which represented 60% of total UK glass production), 950 kt of flat glass (23% of production) and 288 kt of glass wool (7% of production).[8] Other applications, such as decorative and specialty glass products, account for the remaining 10% of production (395 kt).

Sector scope

This report covers resource efficiency opportunities and data relating to glass products produced, consumed and/or treated as waste in the UK. Based on the estimated production volumes in the UK, the following product categories (sub-sectors) are in scope:

- container glass;
- flat glass (construction and automotive); and
- glass wool (mainly going into building insulation).

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[4] British Glass (2020) Glass Sector Net Zero Strategy. Available at: link
[5] Griffin, Hammond, and McKenna (2021) Industrial Energy Use and Decarbonisation in the Glass Sector. Available at: link.
[6] British Glass (2020) Glass sector net zero strategy. Available at: link.
[7] British Glass (2023) Glass Products. Available at: link.
[8] Hartwell, Coult, Overend (2022) Mapping the flat glass value-chain: a material flow analysis and energy balance of UK production. Available at: link

The following processes are in scope:

- design and primary manufacture;
- secondary manufacture (e.g., the manufacture of double glazing using flat glass, or the filling of container glass with product);
- installation (for flat glass);
- in use (with potential for life extension); and
- end of life (with potential for reuse and recycling).

Due to lower production volumes in the UK the following glass applications are out of scope:

- hollow glass (such as tubing and vials);
- photonic components (optical technology used in systems for navigation, satellite communication and more);
- glass beads (used in, for example, reflective paint, wet and dry blast cleaning and water filtration);
- domestic glassware (tumblers, stem glass, vases); and
- glass fibre for non-insulating products such as wind turbine blades[9], automobile bodies and more.[10]

The key focus of this report is on actions that improve material resource efficiency. Therefore, energy efficiency measures and heat energy recycling, which are actions that reduce energy use/carbon emissions but do not impact resource use or resource efficiency, are outside the scope of this study. Other processes that are outside of scope include hydrogen energy, as this relates to alternative sources of decarbonised energy rather than material resources, and carbon capture, as this aims to reduce CO2 emissions without improving resource efficiency.

Container Glass

Glass used in packaging and consumer products is classified as container glass. This is glass which is used to produce beverage bottles for wine, beer, spirits and soft drinks, as well as food containers such as jars for sauces, pickles, and jams. Glass is a good packaging material because it is non-toxic, forms an impermeable barrier which keeps food and drink fresh, and preserves product quality. It is also valued for its transparency and inertness.

According to a trade association and a manufacturer interviewed, beer bottles account for approximately 30% of container glass production in the UK (750kt), wine bottles for 30% (750kt), spirits for 20% (500kt) and the remaining 20% (500kt) is accounted for by container glass for soft drinks and food.

[9] Glass Fibre Europe (2023) Continuous Filament Glass Fibre. Available at: link
[10] British Glass (2023) Glass Products. Available at: link.

According to a 2019 report by Valpak, in terms of UK production volumes by container colour, clear (flint) glass accounts for 48% of container glass production (1,204kt), green glass for 41% (1,014kt) and amber glass for 11% (282kt).[11]

The UK is a net importer of container glass, with slightly more (100 kt) imported than exported.[12]

Flat Glass

Flat glass refers to glass manufactured in sheets, including float glass. There are a wide range of flat glass applications from building glazing (construction) to windscreens and mirrors (automotive) to applications such as furniture and other decorative elements, the optical industry, and the electronics (e.g., touchscreens) and photovoltaic sectors.

In 2019, 950kt of final flat glass products were placed on the market in the UK. Of this, 798kt (84%) was construction flat glass.[13] In construction, flat glass is used in windows, facades and internal partitions (e.g., office meeting rooms). The remaining 152kt (16%) was automotive flat glass, including windshields, side windows and rear windows.[14]

Primary manufacturing of construction flat glass takes place in the UK. However, this is not the case for automotive flat glass – primary manufacturing of automotive flat glass (for use in the UK) takes places overseas instead[15], as was confirmed by a number of interviewees. These primary products are produced abroad, and then imported into the UK where they undergo secondary processing and fabrication (secondary manufacturing such as shaping, strengthening, toughening and laminating) into the final glass product for the UK automotive sector. Therefore, excluding the 152 kt of secondary manufacturing of automotive flat glass, only 798 kt of primary production of flat glass happens in the UK, with all this primary production being construction flat glass.

Glass Wool

Glass wool is made by spinning the glass through holes in a rotating drum and is used for heat and sound insulation. A total of 288 kt of glass wool is made in the UK.[16]

Literature review approach

The literature review identified a total of 131 sources that discussed resource efficiency and/or decarbonisation in the glass sector or other sectors. Of these, 83 sources specifically discussed resource efficiency in the glass sector. These were identified using a range of search strings relating to resource efficiency, the circular economy and the glass sector. The

[11] Valpak/WRAP (2019) GlassFlow 2025. Available at: link
[12] Zero Waste Europe, Eunomia (2022) How Circular is Glass? Available at: link.
[13] Hartwell, Coult, Overend (2022) Mapping the flat glass value-chain: a material flow analysis and energy balance of UK production. Available at: link
[14] Ibid
[15] Ibid
[16] Ibid

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.

The total of 131 sources comprised of:

- 35 industry reports;
- 18 academic papers;
- 13 technical studies;
- 4 policy documents;
- 60 website articles; and
- 1 academic report.

The sources were generally 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 3.9 (out of 5), with 44 sources exhibiting a score of five, 33 exhibiting a score of four, 51 exhibiting a score of 3 and only three sources exhibiting a score of two. A total of 87 sources (66%) were UK-specific, 118 sources (90%) were from the last 10 years (i.e. 2014 or later), and 94 sources (72%) were specific to the glass sector and resource efficiency measures. Overall, the literature was deemed to be highly applicable to the current UK glass sector. Nevertheless, there was limited literature focused on glass wool, and the repair of automotive glass, with just five sources discussing glass wool and three sources discussing automotive repair.

In many cases quantitative data on the levels of efficiency was not available. The majority of data points collected on levels of efficiency were only relevant to Measure 4 (reincorporation of glass waste back into glass manufacture) and Measure 8 (post-consumer recycling of glass waste). Therefore, the levels of efficiency for the other measures covered in this report relied more on qualitative input from stakeholders via the interviews and workshop.

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

Interview approach

A total of eleven stakeholders from nine organisations were interviewed; of the nine organisations, three were manufacturers, one raw material supplier, two trade associations, and three researchers.

Workshop approach

There were eight participants across seven organisations in attendance at the workshop: two researchers, two manufacturers, one raw material supplier and three participants from trade associations.

Participants also provided supplementary information post-workshop. A post-workshop survey was circulated to capture additional thoughts on what was covered in the workshops. One participant responded to the post-workshop survey, feeding back with their estimates on historic (i.e., pre-current levels) and future (2050) levels of efficiency. Another participant provided additional information each measure by email.

List of resource efficiency measures

The list of resource efficiency measures in the glass sector identified via the literature review and interviews can be found in Table 1. Appendix D contains a list of resource efficiency indicators that were discarded from the study.

Table 1: List of resource efficiency measures for the glass sector

#	Lifecycle stage	Strategy	Sub-sectors the measure applies to*	Measure name	Measure indicator
1	Design	Light - weighting	CG: Applicable FG (construction): Limited applicability GW: Applicable	Lightweighting in consumer products	Percentage reduction in weight of consumer products, relative to current (2023) levels
2	Design	Material substitution	CG: Applicable FG (construction): Applicable GW: Applicable	Substitute raw materials with lower embodied carbon alternatives	- Indicator 2a: Percentage change in dry weight substitution of the traditional raw material for the alternative raw material, relative to current (2023) levels - Indicator 2b: Percentage reduction in CO_2e associated with UK glass production

#	Lifecycle stage	Strategy	Sub-sectors the measure applies to*	Measure name	Measure indicator
					achieved through substitution with alternative raw materials, relative to current (2023) levels
3	Design	Material substitution	CG: Applicable GW: Applicable	Substitute glass products with non-glass products (excluding raw material substitution)	Percentage reduction in whole-life CO2e from substitution with products made from alternative materials, relative to current (2023) levels
4	Design	Recycled content	CG: Applicable FG (construction): Applicable GW: Applicable	Reincorporate glass waste back into glass manufacturing	- Indicator 4a: Percentage of internal glass cullet in primary glass manufacture - Indicator 4b: Percentage of external glass cullet in primary glass manufacture - Indicator 4c: Percentage of glass cullet in primary glass manufacture (sum of indicators 4a and 4b)
5	Manufacture	Production efficiencies	CG: Applicable FG (construction): Applicable FG (automotive): Applicable GW: Applicable (primary production only)	Implement efficient product manufacturing and installation processes	- Indicator 5a: Percentage reduction in waste generated per tonne of glass output during primary manufacturing,

#	Lifecycle stage	Strategy	Sub-sectors the measure applies to*	Measure name	Measure indicator
					relative to current (2023) levels - Indicator 5b: Percentage reduction in waste generated per tonne of glass output during secondary manufacturing, filling (container glass) and installation (flat glass), relative to current (2023) levels
6	Sale & Use	Life extension	FG (automotive): Applicable	Lifetime extension through repair of products	Percentage reduction in new consumption through repair, relative to current (2023) levels
7	End of life	Reuse	CG: Applicable FG (construction): Limited applicability FG (automotive): Limited applicability GW: Limited applicability	Reuse of glass products	- Indicator 7a: Percentage of glass products reused - Indicator 7b: Average number of times a glass product is reused - Indicator 7c: Percentage reduction in demand of new glass products through reuse, relative to current (2023) levels (calculated from indicators 7a and 7b)

#	Lifecycle stage	Strategy	Sub-sectors the measure applies to*	Measure name	Measure indicator
8	End of life	Recycling	CG: Applicable FG (construction): Applicable FG (automotive): Applicable GW: Applicable	Recycle post-consumer glass waste	Percentage post-consumer container glass, flat glass and glass wool recycling rate

**CG = Container Glass; FG = Flat Glass; GW = Glass Wool*

1.0 Measure 1 – Lightweighting in consumer products

1.1 Glass resource efficiency measure

1.1.1 Description

Reducing the weight of consumer products made from glass

This measure refers to designing and producing a glass product that is lower in weight (i.e., lighter) whilst maintaining the same level of functionality including strength, capacity, durability, and performance.

The literature review and stakeholder interviews have shown that this measure primarily applies to container glass and glass wool. It has limited applicability to construction flat glass and does not apply to automotive flat glass.

Lightweighting can be achieved by using new manufacturing techniques and using coatings to make glass stronger. In the case of container glass, it involves changing the shape and removing embossing and decorations, whilst in glass wool it involves the use of new manufacturing techniques that results in a product with the same level of insulation whilst using less glass.

Table 2 shows which of the four glass products in scope of this project are applicable to this measure.

Table 2: List of sub-sectors applicable to Measure 1

Container Glass	Flat Glass - Construction	Flat Glass - Automotive	Glass Wool
Applicable	Limited applicability	Not applicable	Limited applicability

It is important to note the interaction between this measure and Measure 7 (the reuse of glass products). When considered independently, both of these measures are designed to increase resource efficiency. However, when considered together, there is a trade-off between the two measures – the increase in the level of efficiency of one of them is likely to have the effect of decreasing the level of efficiency of the other. This is discussed further the "*Interdependencies*" section of this report.

1.1.2 Measure indicator

The indicator selected for this measure was **'percentage reduction in weight of consumer products**, **relative to current (2023) levels'**. The percentage reduction is defined as the average reduction in the weight (in g or kg) of a consumer product divided by the total weight (in g or kg) of that same consumer product. This measure aims to look at the impact of lightweighting whilst maintaining the same level of functionality including strength, capacity, durability, and performance. For example, if a 330ml beer bottle historically weighed 200g, and its weight has been reduced by 20g (whilst maintaining the same 330ml capacity), then this would represent a 10% reduction in the weight of the container (20g/200g).

This indicator is reported in percentage terms as it is consistent with the other indicators that are reported in the literature and interviews.

1.1.3 Examples in practice

Container Glass

Lightweighting is a measure that has historically been used by the container glass industry. Glass bottles have become lighter by as much as 30% in the last 20 years[17] with glass bottle manufacturers and drink brands having reduced the weight of their products by between 13-20% in recent years.[18, 19]

One trade association interviewed indicated that there had been a 20-25% weight reduction of container glass products in the last 10 years. They estimated that beer bottles, which represent 30% of the market, have reduced their weight by ~50% in 25 years. This was supported by another stakeholder who estimated that a 25% reduction through lightweighting had already happened.

There are specific industry examples of lightweighting to draw from. For example, multinational drinks and brewing company AB InBev designed a 150g 330ml beer bottle in 2021, a 17% reduction from their previous design.[20] International beer company Coors Brewers launched a lightweight version of its 300ml bottle achieving a 13% weight reduction.[21] Echovai by Vetropack Group claim to have made the first returnable bottle made of tempered lightweight glass, claiming a weight reduction of up to 30%, greater stability and significantly less scuffing than a standard returnable bottle at the same time.[22] Technologies such as new super coating technologies are being developed which are lighter and as strong as conventional coating.[23]

Flat Glass

No quantitative data was found for the lightweighting of flat glass from the literature review. Instead, the consensus from the interviews conducted was that the historic trend has been for the same amount of glass to be used, but for its insulation properties to be improved through the use of new manufacturing techniques and coatings. Lightweighting has limited applicability to construction flat glass because there are strict safety regulations in place which require a

[17] Friends of Glass (no date) What are the benefits of glass in a circular economy? Available at: link
[18] Glass International (2009) Collaborative UK project enlightens glass industry. Available at: link
[19] Zero Waste Europe & Eunomia (2022) How circular is glass. Available at: link
[20] Ibid
[21] Glass International (2009) Collaborative UK project enlightens glass industry. Available at: link
[22] Vetropack (no date) The next generation of returnable bottles. Available at: link
[23] Glass Worldwide (2023) The key to uber lightweighting of glass containers. Available at: link

certain glass thickness, and this presents a barrier to lightweighting. There is also a drive to improve energy efficiency by installing triple glazing in new builds, increasing the amount of flat glass required in glazing units in order to increase the thermal insulation value (U value).

Despite its limited applicability, some examples of lightweighting were found from the literature and interviews for some specific applications. One source indicated that thin thermal glass technologies with the same or superior heat insulation (Ug value), total energy transmittance (g value) and light transmission values as conventional triple glazing are being introduced to reduce the weight of products.[24] One manufacturer of construction flat glass interviewed indicated that although the industry is moving from double glazing to triple glazing for new builds, the potential for thinner glass panes is being researched, however, these are still in the early research phase, and there are significant barriers to overcome.

Glass Wool

No literature was found on the potential lightweighting of glass wool, and an interview with a glass wool manufacturer was not secured for this study either, therefore the degree to which lightweighting applies to glass wool is highly uncertain. One stakeholder mentioned that there is research underway to improve the insulation performance of glass wool i.e., provide improved insulation performance for the same volume of insulation – this wouldn't make glass wool lighter but would result in the insulation property to weight increase.

1.2 Available sources

1.2.1 Literature review

The literature review found 19 sources that identified lightweighting as a resource efficiency measure (either in terms of providing evidence on levels of efficiency, or by providing commentary on drivers and barriers). These comprise:

- Three academic papers;[25] [26] [27]
- Four industry reports; [28] [29] [30] [31] ,
- Two technical studies[32] [33], and

[24] Buildingtalk (2014) Lightweight, energy efficient glazing units for modern architecture. Available at: link
[25] Furszyfer Del Rio, D. et al (2022) Decarbonizing the glass industry: A critical and systematic review of developments, sociotechnical systems and policy options. Available at: link
[26] Spence (2020) Wine psychology: basic & applied. Available at: link
[27] Wang et al. (2022) Effects of Vehicle Load on Emissions of Heavy-Duty Diesel Trucks: A Study Based on Real-World Data. Available at: link
[28] Glass International (2009) Collaborative UK project enlightens glass industry.
[29] Saint-Gobain (2023) Standards and building regulations. Available at: link
[30] Zero Waste Europe, University of Utrecht, Reloop (2020) Reusable vs Single-use packaging. Available at: link
[31] Zero Waste Europe & Eunomia (2022) How circular is glass. Available at: link
[32] JSC “Stronglasas” (2023) Environmental Product Declaration of Laminated glass from JSC “Stronglasas”. Available at: link
[33] Pilkington Group Limited (2023) Environmental Product Declaration for: Offline Coated Float Glass from Pilkington Group Limited. Available at: link

- Ten website articles.[34] [35] [36] [37] [38] [39] [40] [41] [42] [43]

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 4.0 (out of 5), with all sources exhibiting a score of 3 or above. Eleven of the sources were UK-specific and seventeen sources were from 2014 or later. Overall, the literature was deemed to be highly applicable to the UK market today. Nevertheless, there was a lack of information found on the glass wool sector, and limited information found on the applicability of this measure to the flat glass sector. In many cases quantitative data was not available, however, levels of efficiency were estimated and subsequently evaluated as part of the workshop.

1.2.2 Interviews

Eight of the stakeholders interviewed commented on lightweighting as a measure in the glass sector, commenting on lightweighting in different glass applications depending on their area of expertise. Some interviewees felt that lightweighting is a measure most applicable to container glass. Several stakeholders interviewed discussed how lightweighting of container glass had already happened historically but that there were further gains to be made, and that this was an important resource efficiency measure. For flat glass, stakeholders did not see lightweighting as being very applicable, given the reasons already discussed. For glass wool, some interviewees suggested lightweighting could occur (i.e. gaining the same thermal U-value level from the use of less glass) but could not provide specific evidence to support this.

1.2.3 Workshop

Six stakeholders were active on the mural board and four stakeholders contributed to the discussion verbally. A main point of discussion was the non-linear relationship between flat glass thickness and the emissions impacts of production, with one manufacturer stating that the way production emissions are reported in environmental product declarations can suggest that thinner glass is more energy saving than in reality.

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[34] Buildingtalk (2014) Lightweight, energy efficient glazing units for modern architecture. Available at: link
[35] Glass Worldwide (No date) The key to uber lightweighting of glass containers. Available at: link
[36] Chamaeleon (2023) Vacuum double glazing — Vacuum insulation glass (VIG). Available at: link
[37] Friends of glass (No date) What are the benefits of glass in a circular economy? Available at: link
[38] Glass Hallmark (No date). How is the glass industry delivering on lighter weight glass packaging? Available at: link
[39] The Grocer (2023) Is paper really better for the Earth than plastic? Available at: link
[40] AEGG (2023) Glass Lightweighting. Available at: link
[41] Vetropack (No date) The next generation of returnable bottles. Available at: link
[42] Packaging Insights (2021) Cracking the glass code: Lightweighting tech for Diageo's Johnny Walker bottle uncovered. Available at: link
[43] FEVE The European Container Glass Federation (No date) The EU Packaging and Packaging Waste Regulation (PPWR): How glass can support the EU's circular economy ambition. Available at: link

1.3 Drivers & Barriers

The drivers and barriers influencing this measure were identified through a combination of the literature review, stakeholder interviews and sector workshop. Drivers and barriers which specify a sub-sector in brackets means the driver only applies to that specific sub-sector.

1.3.1 Drivers

Table 3 below shows the main drivers for Measure 1. The most significant drivers are shown in bold as voted for by stakeholders in the workshop.

Table 3: Drivers for glass measure 1

Description	PESTLE	COM-B
Demand for products with a lower material and environmental footprint	**Environmental**	**Motivation – reflective**
Cost savings through reduced transportation weight	**Economic**	**Opportunity – physical**
Competition from other packaging materials (container glass)	**Economic**	**Opportunity – physical**
Cost savings through the use of fewer materials	Economic	Opportunity – physical

Demand for products with a lower material and environmental footprint

According to stakeholders, lightweighting has historically been seen as a reliable way for packaging producers to reduce the GHG emissions associated with their packaging. Lighter products require fewer raw materials and resources in the manufacturing process, resulting in a lower material footprint and reduction in production emissions. The container glass subsector in particular has seen high levels of lightweighting already[44] and one stakeholder suggested that more progress in this area may be difficult to achieve. Stakeholders suggested that transparency around the environmental benefits of lightweighted products could encourage a positive consumer perception and improve acceptance of changes in product specification, composition or design to accommodate lightweighting.

Cost savings through reduced transportation weight

Lighter glass products require less fuel to transport it, as it reduces the weight of the payload and may also allow for more containers per a unit volume due to being smaller.[45] Stakeholders

[44] Zero Waste Europe & Eunomia (2022) How circular is glass? Available at: link
[45] Wang et al. (2021) Effects of Vehicle Load on Emissions of Heavy-Duty Diesel Trucks: A Study Based on Real-World Data. Available at: link

suggested this leads to significant cost and emission savings in transportation. Where in the supply chain this saving is felt, whether it is the manufacturer, haulage company, filler/installer/secondary manufacturer, or retailer, depends on how much of the cost and at what point the cost is passed on.

Competition from other packaging products (container glass)

Plastic, metal and paper-based packaging can offer lighter weight alternatives to glass packaging. According to one stakeholder in interview, to compete and retain its share of the packaging market in the face of competition from these other material industries, glass manufacturers may feel incentivised to develop lighter weight alternatives to current glass packaging products. The ongoing competition between different material industries in the packaging market would benefit from further research, however, this topic is also explored in Measure 3 where the trend towards using lighter materials could see some glass packaging products be substituted for alternative materials.

Cost savings through the use of fewer materials

The use of fewer raw materials in the manufacturing of a product via lightweighting could reduce production costs for manufacturers. However this needs to be weighed against potential costs of lightweighting such as design costs. Further evidence is needed to determine what the ultimate cost implications would be.

1.3.2 Barriers

Table 4 below shows the main barriers for Measure 1. The most significant barriers are shown in bold as voted for by stakeholders in the workshop.

Table 4: Barriers for glass measure 1

Description	PESTLE	COM-B
Consumer / brand owner perception of lighter weight being inferior (container glass)	**Social**	**Motivation – reflective**
Technical strength requirements and standards	**Technological**	**Capability – physical**
Design for reuse presents a trade-off with lightweighting	**Technological**	**Capability – physical**
Legislation on safety (flat glass)	Legal	Capability – psychological
Capital cost associated with technology required to manufacture lighter products	Economic	Opportunity – physical

High cost and technological availability of coatings (container glass)	Economic	Opportunity – physical
Misleading carbon emissions categorisation standards	Environmental / Legal	Capability – psychological
Legislation on energy efficiency (construction flat glass)	Legal	Capability – psychological

Consumer / brand owner perception of lighter weight being inferior (container glass)

Two stakeholders commented that food and beverage brands may choose not to lightweight because consumers may perceive heavier products to be of a higher quality. A report by Sustainable Wine identifies evidence that customers associate bottle weight with quality of wine and would expect to pay more for a heavier bottle – although whether this influences consumer decisions in reality is debated.[46] Another report identified that budget wine bottles tended to weigh less than 320 grams with high end wine bottles weighing over 360 grams.[47] This research implies that reducing the weight of bottles via lightweighting could have a negative impact on consumer perceptions of quality and sales. Additionally, branding and embossing of glass bottles used to distinguish brands may lead to increases in bottle weight.

Technical strength requirements and standards

There are technical limits to lightweighting due to the need for glass products to meet technical strength requirements and standards. Stakeholders discussed that losses through breakages occur during the production process and commercial consumption, and that at some point lightweight products with reduced thicknesses could be more prone to breakage. Containers need to be able to withstand impacts either from the production line or as they move through the logistics and retail chain. Bottles containing carbonated drinks are subject to higher internal pressure and these bottles may require thicker, heavier glass. Stakeholders suggested that flat glass must be thick enough to meet strength and standard requirements.[48] All of these technical requirements place limitations on the potential for lightweighting. For these reasons, further lightweighting may not be feasible in certain applications as the material efficiencies achieved could result in a product that doesn't meet performance requirements.

Design for reuse presents a trade-off with lightweighting

Glass containers used as part of a reuse system (discussed in Measure 7) typically require thicker walls and coatings to improve their durability – requiring them to be heavier. A stakeholder outlined that a single-use soft drink bottle would weigh less than a thicker bottle for reuse despite having the same capacity. The drive to increase reuse of glass containers could

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[46] Sustainable Wine (2023) Reducing wine bottle weight. Available at: link.
[47] ZWE, Eunomia (2022). How circular is glass? Available at: link.
[48] For example, British Standards BS 6206 and BS EN 12600 on building glazing and glass in buildings.

therefore present a trade-off with lightweighting, however, a lifecycle assessment would be required to evaluate the most effective strategy.

Legislation on safety (flat glass)

There are various standards and building regulations associated with glass to ensure the conservation of energy and safety. Building regulations are numerous and vary by geography and glass application and use, but they often require a minimum thickness in order to ensure the safety of its users or occupants.[49] The required thickness is typically determined by calculation that compare the stress and deflection generated in glass under prescribed loadings, based on circumstance and building occupancy, to allowable limits.[50] One stakeholder noted that if flat glass is made too thin there is a risk it could bend and 'pop out' of window frames. These requirements on glass thickness (whilst necessary for safety and energy efficiency) restrict the potential of a flat glass producer to lightweight.

Capital cost associated with technology required to manufacture lighter products

One stakeholder noted that the forming process and lightweighting are interrelated, because a change in the forming process can accommodate changes in glass weight. Therefore, designing lighter products might often require a change in the forming process at the production stage. Changes to the production process can have associated capital costs which can act as a barrier to lightweighting.

High cost and technological availability of coatings (container glass)

One manufacturer interviewed commented that container glass is the lowest cost glass and is sensitive to price increases in alternative packaging (aluminium and plastic mostly). The manufacturer suggested that coatings have been very successfully used in electronic and flat glasses, but the selling prices of these products is several times or even orders of magnitude higher than for container glass. As an approximate rule of thumb, even a very basic coating can double the final cost of the bottle. Another stakeholder stated that while glass can be strengthened by the application of a coating, the technology needs further development. The impact of such coatings on recyclability also needs exploring.

Misleading carbon emissions categorisation standards

Glass products that comply with EU standards for the categorisation of construction products use environmental product declarations (EPDs) to indicate the products' global warming potential (GWP).[51] One stakeholder argued that EPDs assume that energy used in the production of flat glass is linear, i.e., that producing a 2 mm thick glass pane uses half the energy of producing a 4 mm glass pane. This assumption could not be verified with a literature source, however, a number of EPDs found stated that to estimate the GWP of a different thickness of a similar product, the GWP of the product could be multiplied by the pane

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[49] For example, British Standards BS 6206 and BS EN 12600 on building glazing and glass in buildings.
[50] Saint-Gobain (2023) Standards and building regulations. Available at: link
[51] European Standard EN 15804 refers to the assessment method for the sustainability of construction works, using environmental product declarations indicated by the global warming potential expressed in CO_2e.

thickness.[52, 53] The stakeholder argued that in reality, producing a 2 mm pane is less efficient and so uses more than half the energy required to produce a 4mm pane.

One stakeholder also remarked that this assumption could be misleading, since with thinner glass there is an increased risk of breakage and more difficulty transporting it. Therefore, if resource efficiencies are predicted by reducing the thickness (and therefore mass) of glass products, it ought not be assumed that this results in linear emissions reductions.

Legislation on energy efficiency (construction flat glass)

There are various standards and building regulations associated with glass to ensure the conservation of energy and safety.[54] One stakeholder indicated that the construction industry is moving from the use of double glazing to triple glazing for new builds in order to improve energy efficiency. Triple glazing typically requires more glass leading to a heavier product, however it is also important to note the building energy savings that would result from better glazing.

1.4 Levels of efficiency

Table 5: Levels of efficiency for glass measure 1

Indicator: Percentage reduction in weight of consumer products, relative to current (2023) levels*			
Level of efficiency	Current	Maximum in 2035	Business-as-usual in 2035
Value	CG: 0% FG (construction): 0% GW: 0%	CG: 15-25% FG (construction): 0-2% GW: 0-5%	CG: 0-15% FG (construction): 0% GW: 0-2%
Evidence RAG	Not applicable	Red	Red

**CG = Container Glass; FG = Flat Glass; GW = Glass Wool*

[52] JSC “Stronglasas” (2023) Environmental Product Declaration of Laminated glass from JSC “Stronglasas”. Available at: link.
[53] Pilkington Group Limited (2023) Environmental Product Declaration for: Offline Coated Float Glass from Pilkington Group Limited. Available at: link
[54] European Standard EN 15804 refers to the assessment method for the sustainability of construction works, using environmental product declarations indicated by the global warming potential expressed in CO_2e.

1.4.1 Current level of efficiency

Container Glass, Flat Glass and Glass Wool

Historically, container glass is the only sub-sector that has made significant progress on this measure to date. Evidence from the literature and interviews conducted suggests that container glass has become between 10-30% lighter in the last 10-15 years, depending on the specific application in question (see “Examples in practice” section for specific examples).

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

1.4.2 Maximum level of efficiency in 2035

Container Glass

No data was identified in the literature to estimate a maximum efficiency level for this measure. Instead, the maximum efficiency level for this measure relies on insight from the interviews and the workshop conducted.

According to interviews conducted with a trade association and a manufacturer, beer bottles account for roughly 30% of container glass production in the UK (750kt), wine bottles for 30% (750kt), spirits for 20% (500kt) and the remaining 20% (500kt) is accounted for by container glass for soft drinks and food.

Stakeholders indicated that beer bottles have limited opportunity to reduce their weight further as large historical gains have already been made (stakeholders indicated up to 50% reduction in weight in the last 25 years). Spirit bottles have not seen large reductions due to high levels of export which require increased durability for transport.

One manufacturer commented that the weight of wine bottles could potentially reduce by a further 40% on average from their present weight (from the standard current weight of 500g down to 300g). The manufacturer is targeting an average weight of 420g by 2025, but is already manufacturing an even lighter bottle weighing 340g.

One stakeholder estimated that the food and drink container glass could potentially reduce weight by 25% and 40%, depending on the product.

Of the seven workshop participants who voted for the levels of efficiency presented in the workshop, one voted for the range 0-15% (with high confidence), five voted for the range 15-25% (four with medium confidence, one with low confidence), and one voted for the range >25% (with low confidence). One stakeholder noted that to determine the opportunity for lightweighting, a review of current container weight would be required on all glass packaging placed on the UK market. They also noted that the UK has no influence over the weight of imported products.

In the absence of more comprehensive data and based instead on insights from stakeholders, the maximum level of efficiency for container glass is estimated to be 15-25%. It is important to note that the true value will differ depending on product type, with different opportunities available depending on application. The evidence RAG rating for this efficiency level is red, reflecting the lack of supporting literature evidence and limited input on the potential for specific container glass products.

Flat Glass – Construction

As stated in section 1.1.3 (”Examples in practice”) there is limited opportunity for lightweighting in the construction flat glass sector. No literature data was available to estimate a maximum efficiency level for this measure and sub-sector.

The maximum efficiency level for this measure relies on voting at the workshop. Of the five workshop participants who voted for this level of efficiency, two voted for 0% (both with high confidence), two voted for the range 0-5% (one with medium confidence, one with low confidence), and one did not know. One of the participants who voted for 0% agreed that triple glazing will make products heavier. However, this is only a small proportion of the market.

The maximum level of efficiency for construction flat glass has been estimated at 0-2%. The evidence RAG rating for this efficiency level is red, reflecting the lack of supporting literature evidence and limited stakeholder input.

Glass Wool

No data was found in the literature review on glass wool, and no glass wool manufacturers participated in the research. Data was instead collected in the workshop. Of the four workshop participants who voted for this level of efficiency, one voted for <1% (with high confidence), two voted for the range 1-5% (both with low confidence), and one did not know.

Based solely on the data gathered through the workshop, the maximum level of efficiency for glass wool is estimated to be 0-5%. The evidence RAG rating for this efficiency level is red, reflecting the lack of available literature and the limited expertise in glass wool of the participants.

1.4.3 Business-as-usual in 2035

No literature data was available on the BAU efficiency level for this measure, instead the BAU efficiency level for this measure relies on insight from the interviews and the workshop.

Container glass

Of the five workshop participants who voted for this level of efficiency, three voted for the range 0-15% (two with high confidence, one with medium confidence), one voted for the range 15-25% (with medium confidence, one with low confidence), and one voted for the range >25% (with low confidence). One academic interviewed estimated that the business as usual was 15%. This was the figure used as the basis for building the voting ranges for the workshop.

Based on the sector insight gathered through the interviews and workshop voting, the BAU level of efficiency for container glass is estimated to be between 0-15%. The evidence RAG rating for this efficiency level is red, reflecting the lack of literature evidence and somewhat mixed workshop voting.

Flat Glass – Construction

Prior to the workshop, the business-as-usual level of efficiency for construction flat glass was estimated to be 0%, given the insight gathered through the interviews suggesting that lightweighting had very limited applicability to this sub-sector (given the energy efficiency and building regulation drivers mentioned above).

Of the five workshop participants who voted for this level of efficiency, four voted for 0% (all with high confidence) and one did not know.

Therefore, the business-as-usual level of efficiency for flat construction glass is estimated to be 0%. The evidence RAG rating for this efficiency level is red-amber, reflecting the lack of literature evidence but relative consensus in workshop voting.

Glass Wool

Of the four workshop participants who voted for this level of efficiency, three voted for <1% (with high confidence), and one voted for the range >5%. One stakeholder noted that in the development of glass wool products, as the volume increases to increase the U-value (thermal transmittance i.e. insulation level), will reduce the quantity of glass wool required.

The business-as-usual level of efficiency for glass wool is estimated to be 0-2%. The evidence RAG rating for this efficiency level is red, reflecting the limited expertise participants had on this measure and lack of supporting literature.

2.0 Measure 2 – Substitute raw materials with lower embodied carbon alternatives

2.1 Glass resource efficiency measure

2.1.1 Description

Use alternative raw materials in the production of glass that have lower embodied carbon compared to the traditional raw materials used

This measure refers to the substitution of primary raw materials with alternative materials that results in a reduction in the embodied carbon of glass, while providing the same level of performance.

Table 6 shows that this measure is applicable to three of the four glass products in scope of this project. It is not considered relevant to automotive flat glass, as there is no primary manufacturing occurring in the UK, only secondary forming/laminating.

Table 6: List of sub-sectors applicable to measure 2

Container Glass	Flat Glass – Construction	Flat Glass – Automotive	Glass Wool
Applicable	Applicable	Not Applicable	Applicable

2.1.2 Measure indicator

The indicator selected for this measure was the **'percentage reduction in CO_2e associated with UK glass production achieved through substitution with alternative raw materials, relative to current (2023) levels'** which is a defined as 'the average embodied carbon of glass containing alternative raw materials' divided by the 'average embodied carbon of standard glass equivalent'. Embodied carbon is measured by $kgCO_2e$ per kg of material.

This indicator has been split into two contributing sub-indicators:

- **Indicator 2a: 'Percentage change in dry weight substitution of the traditional raw material for the alternative raw material, relative to current (2023) levels'**
- **Indicator 2b: 'Percentage reduction in CO_2e associated with UK glass production achieved through substitution with alternative raw materials, relative to current (2023) levels'**

Whilst these were the indicators chosen, it was not possible to collect adequate information on indicator 2b in order to calculate the level of efficiency. As such, the levels of efficiency are only available for indicator 2a.

2.1.3 Examples in practice

Calumite

Calcium-alumino-silicate (trade name Calumite[55]) is produced from blast furnace slag that has been rapidly quenched to form a homogenous, glassy material. It is used as an alternative raw material replacing sand, limestone and soda ash.

During the Calumite production process, the material is dried, crushed and screened to produce a granular material, of a size consistent with other glass making raw materials.[56] A stakeholder stated that the reduction in blast furnace operations in the UK has decreased the amount of UK based blast furnace slag being generated, and as the UK steel industry moves to manufacturing via Electric Arc Furnaces, its availability in the UK will continue to decrease.

The amount of Calumite that is used in glass production is usually expressed as a percentage of the dry sand weight, and its level of use depends on factors such as glass colour, glass composition and local raw materials.[57] When Calumite is used, adjustments to the batch are needed, depending on the raw materials being used.[58] Typically, the use of Calumite reduces the amount of limestone, dolomite and alumina source, such as nepheline syenite or an alkali feldspar that is used in the batch. In many cases it is possible for Calumite to be the sole alumina source, often simplifying the batch recipe.[59] The use of Calumite reduces both process and combustion CO_2e, resulting in up to 0.7t CO_2e saved per tonne of Calumite used.[60] It also reduces process energy consumption as it requires less energy to melt.

In the interviews, contradictory statements were made by stakeholders in reference to the use of Calumite in flat glass manufacture. A specialist in Calumite manufacturing indicated that Calumite was currently sold into the container glass market, but not in flat glass (although historically it had been). This was corroborated by one of the flat glass manufacturers who mentioned stricter quality standards, with another stating that it was due to availability. However, in a separate interview with a flat glass manufacturer, they indicated they do use Calumite as a substitute in their processes.

Two stakeholders agreed that Calumite is not currently used in glass wool manufacturing due to cost however, according to one source, Calumite can be used to replace 11% of the dry sand weight in glass wool manufacturing.[61]

[55] Calumite is the conventionally used term for Calcium-alumino-silicate
[56] Hanson (no date) Calumite. Available at: link
[57] Hanson (2023) How Calumite is Used. Available at: link
[58] Ibid
[59] Ibid
[60] Calumite Ltd (2021) Calumite, more than just a raw material. Available at: link
[61] Hanson (2023) How Calumite is Used. Available at: link

Biomass ash

Biomass ash is considered a potential alternative raw material for low-carbon glass manufacture. Various trials have occurred in the UK (Enviroglass and Enviroash[62]) that have tested the use of biomass ash to replace sand, limestone and soda ash. Biomass ash has a much lower embodied carbon than the soda ash it replaces, as it reduces the process emissions associated with carbonate decomposition.

A stakeholder stated that its use to replace sand, limestone and soda ash reduces the amount of process energy required to reach the melt temperature. Trials found that a 10% biomass ash inclusion led to a lower melting point and up to 5% reduction in energy.[63]

Large scale commercial trials may take place in the coming years, but challenges such as the variable composition of biomass ash will need to be investigated further. It was also noted that variations in wood types (feedstock) will lead to some chemical variations in the ash.

The interviewee also stated that Calumite and biomass ash could potentially both be used as alternative raw materials in the same mix and, in combination, could increase the overall proportion of alternative raw materials.

Slate tailings

The Enviroash project also looked at slate tailings (waste from slate mining) as raw materials for glass manufacture, and considered its use in containers, glass wool and windows.[64] Using slate to replace limestone and soda ash could reduce CO_2 emissions as it has a lower carbon content than these traditional materials. Whilst laboratory trials showed that it could potentially be used in similar proportions to biomass ash (i.e. up to 10% replacement of primary raw materials) in glass manufacture as an alternative raw material, this hasn't, as of yet, moved beyond a laboratory-based trial.

Others

Carbonate substitution materials (Calcium Oxide and Calcium Silicate)

The chemical reaction that occurs in the glass manufacturing process releases CO_2 as the limestone combines with the sand as follows:

$CaCO_3$ (limestone) $+SiO_2$ (sand) $\longrightarrow CaSiO_3 + CO_2$

There are alternative raw materials such as calcium oxide (CaO) and calcium silicate (Ca_2SiO_4), that can act as substitutes, that do not release CO_2 as part of the glass making chemical reaction, as they do not contain carbon atoms. However, both glass manufacturing

[62] Glass Technology Services (2022) Enviroash investigates the potential for using biomass and other wastes as raw materials across the foundation industries. Available at: link
[63] Ibid
[64] Ibid

and the production of calcium oxide and calcium silicate release the same amount of CO_2, it is just that the generation of that CO_2 is at different stages of the glass manufacturing life cycle.

There may be a shift in the glass sector to use more of these alternatives, as CO_2 generation in calcium oxide and calcium silicate manufacturing has greater potential for carbon capture than in the glass manufacturing process.

Paper and Pulp Mill Fly Ash

The 'Unlocking Resource Efficiency: Phase 2 Paper Report'[65], which is part of the larger research project, discusses the availability of Paper and Pulp Mill Fly Ash (PFFA) which is generated during the combustion process used to produce paper products. This can be recovered, and has been used at a laboratory scale in the manufacture of glass ceramic products.[66] It is unclear however which material the PFFA would offset.

2.2 Available sources

2.2.1 Literature review

Nine literature sources were found which document the use of alternative raw materials as a substitute for primary raw materials:

- One academic paper;[67]
- Four industry reports;[68] [69] [70] [71]and
- Three website articles.[72] [73] [74]
- One technical study[75]

Though there was a relative lack of literature on this measure, particularly for levels of efficiency, the relevant sources that were available 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 average IAS of the sources is 3.8. Seven of the sources scored IAS 4 or higher, eight were UK-specific and all

[65] Unlocking Resource Efficiency: Phase 2 Paper Report.
[66] Cherian. C, Siddiqua. S. (2019) Pulp and Paper Mill Fly Ash: A Review. Available at: link
[67] Deng. W. et al. (2019) Exploratory research in alternative raw material sources and reformulation for industrial soda-lime-silica glass batch. Available at: link
[68] British Glass (2020) Glass sector. Net zero strategy 2050. Available at: link
[69] Calumite Ltd (2021) Calumite, more than just a raw material. Available at: link
[70] Chemanalyst (2023) Decode the future of GGBFS. Available at: link
[71] Department for Business, Energy and Industrial Strategy (2017) Fly Ash And Blast Furnace Slag For Cement Manufacturing BEIS Research Paper No. 19. Available at: link
[72] Glass International (April 2023) LionGlass to extend glass manufacturing furnace lifetimes. Available at: link
[73] Glass Technology Services (2022) Enviroash investigates the potential for using biomass and other wastes as raw materials across the foundation industries. Available at: link
[74] Hanson (2023) How Calumite is Used. Available at: link
[75] Hanson (2022) Calumite. Available at: link

sources except one were from 2019 or later. Whilst the sources do discuss the topic of raw material substitution, there are only two which provide quantifiable data points.

2.2.2 Interviews

This measure was engaged with by six stakeholders during interviews. They emphasised the importance of this measure in achieving resource efficiency. However, stakeholders were hesitant to predict how far this measure could go and were unable to provide estimated emission reductions. Stakeholders broadly agreed that the lower embodied carbon of alternatives would drive an increase in their use, and that the technology for using these alternatives was already available. However, the availability and location of these alternative materials were presented as significant barriers, as well as the discolouration in flint container glass and flat glass that are caused by some alternatives.

2.2.3 Workshop

Six stakeholders across the industry were active on the mural board, three stakeholders contributed to the discussion verbally and one stakeholder contributed via MS Teams. At least five votes were submitted for every sub-sector and level of efficiency for this measure. A key barrier discussed for this measure was the high demand for products with lower embodied carbon, meaning that competition between industries may impact the cost or availability of such products.

2.3 Drivers & Barriers

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

2.3.1 Drivers

Table 7 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 7: Drivers for glass measure 2

Description	PESTLE	COM-B
Energy and cost savings	**Economic**	**Opportunity – physical**
UK net zero policy	**Political**	**Motivation – automatic**
Reducing GHG emissions via lower embodied carbon of product	**Environmental**	**Opportunity – physical**

Demand for sustainable products	**Social**	**Opportunity – social**
Substitutes can be used in a wide range of glass applications	Technological	Opportunity – physical

Energy and cost savings

Multiple stakeholders stated that biomass ash and Calumite have lower energy requirements during melting, and this therefore leads to a reduction in energy for manufacturing plants. The literature review also indicated that the glassy nature of Calumite, combined with its chemical composition, leads to faster melting when Calumite is used in the glass batch. As a result, the energy required to melt a Calumite containing batch is lower than a corresponding non-Calumite batch.[76] Depending on the specific requirements of the glassmaker at the time, this can be used to reduce energy consumption, increase furnace pull and/or reduce furnace temperatures.

It was noted that these alternative raw materials also typically reduce raw material costs as they are cheaper than soda ash, limestone and high-grade sand.

UK net zero policy

The UK Government has committed to a target of net zero GHG emissions by 2050. As a key foundation industry in the UK, this has required the glass sector to set out a strategy to achieve net zero by 2050.[77] One stakeholder suggested that reducing GHG emissions would become more important to the glass industry if the cost of carbon credits purchased via the UK Government’s emissions trading scheme were to increase.

Reducing GHG emissions via lower embodied carbon of products

Stakeholders identified that alternative raw materials with lower embodied carbon are a key enabler in reducing the overall carbon footprint of the glass industry. Several stakeholders raised that the use of biomass ash to replace soda ashes and limestone, the two materials with the highest associated production of CO_2 in the glass making process, would contribute to this goal. For every tonne of Calumite used, 400kg of CO_2e could be saved, and Calumite behaves and melts in the same way as cullet.[78]

Demand for sustainable products

One stakeholder stated that, broadly, other sectors’ (such food and drink) drive to improve their sustainability and reduce the carbon footprint should drive an increase in the use of lower embodied carbon alternatives.

[76] Calumite Ltd (2024) Available at: link
[77] British Glass (2020) Glass sector. Net zero strategy 2050. Available at: link
[78] Calumite Ltd (2021) Calumite, more than just a raw material. Available at: link

Substitutes can be used in a wide range of glass applications

The literature review and interviews indicate that the use of substitute raw materials is not just limited to one application or product but can be used across all the different glass products. This is because the replacement of carbonates with alternatives is applicable to all their primary manufacturing.

2.3.2 Barriers

Table 8 below shows the main barriers for Measure 2. The most significant barriers are shown in bold as voted for by stakeholders in the workshop.

Table 8: Barriers for glass measure 2

Description	PESTLE	COM-B
Competition from other industries for raw material	**Economic**	**Opportunity – social**
Availability and cost of alternative materials	**Environmental**	**Opportunity – physical**
Lack of testing and industry experience (biomass ash)	**Technological**	**Capability – physical**
Biomass ash can be inconsistent in its properties (biomass ash)	Technological	Capability – physical
Consumer/brand owner perception on discolouration in flint (clear) glass (e.g., Calumite)	Social	Opportunity – social
Substitute impacts performance of glass	Technological	Capability – physical

Competition from other industries for raw material

Multiple stakeholders stated that Calumite and biomass ash are sought after by many of the UK's foundation industries (e.g., the cement and concrete sectors) in support of reducing their environmental impacts. Whilst some import of Calumite's raw material (ground granulated blast furnace slag) occurs, global supply is practically fully utilised and there is increasing demand from the cement sector. These factors are expected to impact on availability and price of ground granulated blast furnace slag in the long term for the glass industry[79], and potentially reduce its economic viability.

[79] Concrete4change (2022) Barriers to Net-Zero Concrete – Fly Ash and GGBS. Available at: link

Availability and cost of alternative materials

Calumite is a by-product of steel manufactured using blast furnaces. As the UK (and the world) moves to decarbonise steel production, a move towards electric arc furnaces (EAFs) is likely to occur, which will reduce the availability of Calumite. Tata steel and British steal have already announced plans to transition to EAFs.[80,81] Because of this, a number of interviewees expect domestic Calumite availability to reduce in the long term. However, one stakeholder noted that the UK already imports significant quantities of the Calumite raw material, granulated blast furnace slag (GBFS), suggesting that there are other potential sources available to counteract the slowdown in UK production depending on worldwide steel production. If the availability of UK GBFS does continue to reduce, imported GBFS may be required however this will increase carbon emissions and cost associated with transport.

In terms of biomass ash, this would need to be available in sufficient quantity and quality with no interruption in supply for it to be adopted by the glass sector. The interviews and literature suggest that there is significant competition from other industries (e.g., fertilizer, concrete) for supply.[82] Challenges may arise when biomass plants are not in close proximity with glass manufacturing facilities which could add transport costs and emissions making it less attractive.

Lack of testing and industry experience at commercial scale (biomass ash)

At present, biomass ash has demonstrated its benefits in laboratory-based trials.[83] A stakeholder stated that manufacturers are typically risk averse when it comes to raw materials. This is partly driven by the continuous glass melting process, where small levels of contamination can lead to significant product reject rates and produce additional waste and down time, making the manufacturing process less efficient. The stakeholder stated that before its wider adoption, biomass ash will require large scale demonstration to give manufacturers confidence that it will not impact on glass quality, durability or affect the manufacturing process.

Biomass ash can be inconsistent in its properties (biomass ash)

A manufacturer interviewed stated that as glass manufacturing is a continuous process running for several days at a time there is a preference for consistent raw material inputs once a glass recipe is being processed. A stakeholder with experience of biomass trials stated that the composition of biomass ash can be variable, as each type of biomass has different chemical compositions which can impact the quality of the glass produced. In addition, the presence of

[80] Department for Business and Trade (2023) Welsh steel's future secured as UK Government and Tata Steel announce Port Talbot green transition proposal. Available at: Link
[81] British Steel (2023) British Steel today unveils £1.25 billion proposal to decarbonise its operations. Available at: Link
[82] Glass Technology Services, Enviroash investigates the potential for using biomass and other waste materials across foundation industries. Available at: link
[83] Ibid

undesirable compounds (impurities) could also impact manufacturing.[84] New technical solutions are required to address such challenges.

Consumer/brand owner perception on discolouration in flint (clear) glass (e.g. Calumite)

One manufacturer indicated that customers have a preference for glass containers to be clear (transparent) in order to be able to see the product inside. Calumite is a by-product of the steel industry, and contains small amounts of iron which can discolour the glass (e.g., turn it green). The potential for Calumite to discolour glass therefore limits how much can be used.

Substitute impacts performance of glass

The literature and interviews on the Enviroash[85] project identified that there are limits on the proportion of limestone, soda ash and sand that can be replaced by biomass ash. Based on its laboratory trials, it is thought that a maximum inclusion of 15-20% may be achievable before the quality of the glass is impacted, for example the colour or thermal properties of the product. In the laboratory trials, the colour of glass being produced did not impact the proportions of biomass ash that could be incorporated.

2.4 Levels of efficiency

There was limited data to inform this measure, and there are a range of possible material substitution which could be made. Stakeholders were able to provide commentary on the likely dry weight replacement rates of biomass ash and Calumite but were not able to provide any data on the associated material related embodied carbon impacts. As such, the levels of efficiency given below are only for indicator 2a (percentage change in dry weight substitution of the traditional raw material for the alternative raw material, relative to 2023 levels).

[84] Sheffield Hallam University (no date). Paving the way to Net Zero by repurposing waste. Available at: link
[85] Glass Technology Services, Enviroash investigates the potential for using biomass and other waste materials across foundation industries. Available at: link

Table 9: Levels of efficiency for glass measure 2

Indicator 2: Percentage change in dry weight substitution of the traditional raw material for the alternative raw material, relative to current (2023) levels *			
Level of efficiency	Current	Maximum in 2035	Business-as-usual in 2035
Value	Total: 0%	**Biomass Ash:** 5-15% dry weight replacement **Calumite:** 1-5% increase in dry weight replacement in clear container glass only	**Biomass Ash:** 0-10% dry weight replacement **Calumite:** 1-5% increase in dry weight replacement in clear container glass only
Evidence RAG	Not applicable	Red	Red

Indicator 2b: Percentage reduction in CO_2e associated with UK glass production achieved through substitution with alternative raw materials, relative to current (2023) levels'			
Level of efficiency	Current	Maximum in 2035	Business-as-usual in 2035
Value	Total: 0%	Not available	Not available
Evidence RAG	Not applicable	Not applicable	Not applicable

2.4.1 Current level of efficiency

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. However, data on current levels of use of Calumite is shown below.

Calumite

The amount of Calumite currently used in glass production is unclear, with one internet source stating that for container glass, 4% of raw material in clear glass is Calumite and this increases to as high as 30% for amber glass. Calumite also makes up 4-8% of raw material weight in flat glass and 11% in glass wool.[86] However, this was disputed by a Calumite expert interviewed

[86] Calumite Ltd (2024) How Calumite is Used. Available at: link

who stated that for clear container glass, Calumite makes up on average 1-2% of the raw material dry weight, whilst for green and amber it can be on average ~ 6-7% and that Calumite wasn't currently sold into glass wool, due to cost. This is further backed by estimates from two other interviewees, one from academia and one from a trade body, who noted that the current percentage of Calumite going into the glass manufacturing process as a raw material is around this lower range of 2-3%.

2.4.2 Maximum level of efficiency in 2035

Biomass ash replacement for limestone, soda ash and sand

No literature data were available to estimate the maximum efficiency level for dry weight replacement rates of biomass ash. Instead, this relies on insight from the interviews and the workshop conducted.

Stakeholders suggested a replacement rate of between 10-20% in the interviews, however it is noted that the 20% level has only ever been achieved in very controlled laboratory trials. In the workshop one stakeholder voted for 0-5%, two voted for the range 5-10%, and one voted for the range >10%. Most of these votes were cast with low confidence. Others indicated the figure is 10%, likely to be limited by colourants, supply and consistency of composition.

On reflection of this input, the maximum level of efficiency by dry weight has been estimated to be 5-15%. This estimate is given with the caveat that, to reach the higher end of this estimate some colour change may occur, and glass manufacturers and consumers would have to be willing to accept that. The evidence RAG rating for this efficiency level is red, given the lack of literature to support estimates and the fact stakeholders were split in their votes.

Calumite

No literature data was available to estimate the maximum efficiency level for dry weight replacement rates of Calumite. Instead, estimates rely on insight from the interviews and the workshop conducted.

One stakeholder estimated the maximum technical level of Calumite in glass would likely be 6-7% of raw material dry weight and that green and amber container glass are at their maximum level currently (6-7%). They argued that this is capped by the chemistry of the glass product.

Clear container glass currently contains 1-2% Calumite, and consensus from the stakeholders who were able to comment on this was that the maximum technical level could probably reach the same levels as amber and green (6-7%). No literature evidence was identified to support this estimate and it was noted that moving to 6-7% Calumite would require an acceptance by brands and consumers to have a green tint to the glass. The same stakeholder stated that it is unlikely that any further increases will occur for Calumite in flat glass and glass wool, given lack of availability and competition for the material from other sectors.

The above estimate was used as the basis for building the voting ranges for the workshop. in the workshop most stakeholders voted for the range 1-5% with medium-high confidence. One noted the level would be higher than BAU, but still within the 1-5% range, limited by colourants.

The maximum level of efficiency by dry weight is therefore estimated to be 1-5%. The evidence RAG rating for this efficiency level is red given the lack of literature data.

2.4.3 Business-as-usual in 2035

Biomass ash replacement for limestone, soda ash and sand

No literature data were available to estimate this BAU efficiency level. Instead, the BAU efficiency level for dry weight replacement relies on insight from the interviews and the workshop.

Two stakeholders interviewed, estimated the BAU replacement rate to be between 2.5-5% biomass ash (by mass). In the workshops one stakeholder voted for the range 0-5% (with medium confidence, stating a figure of 5% depending on the success of identifying consistent, quality in appropriate volumes), one voted for the range 5-10% (with medium confidence, stating that it was possible to use and accelerate its use), and one for the range >10% (with low confidence, stating that this would be the likely average level, based on demand from other sectors and availability in sufficient quality). Two did not know.

Based on the above evidence, the business-as-usual level of efficiency is estimated to be 0-10%. The evidence RAG rating for this efficiency level is red, reflecting the lack of literature and limited agreement between participants in the workshop.

Calumite

There wasn't any evidence from the literature or interviews that there will be a change in brand and consumers perceptions on clear glass having a tint, or there being a large-scale shift from clear to green or amber glass containers. Without any likely change identified, the business as usual would be a 0% increase of Calumite. This was used as the basis for the voting ranges (0-1%, 1-5% and >5%) in the workshop, with the lowest one matching the provisional estimate of 0%.

Of the six workshop participants who voted for this level of efficiency, none voted for 0-1%, five voted for the range 1-5% (all with high confidence) and one did not know. With the insight provided by the workshop, the business-as-usual level of efficiency was estimated to be 1-5%. The evidence RAG rating for this efficiency level is red given the lack of literature data.

3.0 Measure 3 – Substitute glass products with non-glass products (excluding raw material substitution)

3.1 Glass resource efficiency measure

3.1.1 Description

Substitute glass products for products made from alternative, non-glass materials (i.e. paper, plastic, aluminium or steel)

This measure refers to replacing single-use glass material for alternative materials in the manufacture of products, where this substitution achieves the same level of functionality and reduces the associated whole-life carbon of the product. Typically, a suitable substitution of glass for an alternative material will depend on the associated GHG emissions with production and transport of the finished product, whether it is derived from a renewable resource, the end-of-life destination of the material and whether it can be recycled. A full assessment of environmental impacts (beyond whole-life CO_2e) is beyond the scope of this report, however it is important to note that these are also key considerations when it comes to material substitution.

The measure excludes raw material substitution, which is covered in Measure 2. This measure also excludes reuse of glass, which is covered in Measure 7. It is important to note however that due to its high reuse potential, glass can be a resource efficient material, especially when compared to materials that are less suitable for reuse.

Table 10 shows the products to which Measure 3 is applicable. The reasons for why each one is applicable or not are outlined in the following sections.

Table 10: List of sub-sectors applicable to measure 3

Container Glass	Flat Glass – Construction	Flat Glass – Automotive	Glass Wool
Applicable	Not applicable	Not applicable	Applicable

3.1.2 Measure indicator

The indicator selected for this measure was '**percentage reduction in whole-life CO_2e from substitution with products made from alternative materials, relative to current (2023) levels'**, which is defined as the percentage reduction in CO_2e emissions by substituting glass material with non-glass materials such as paper/card, plastic, aluminium or steel). This indicator is reported in percentage terms as it is consistent with the other indicators that are reported in the literature and interviews.

3.1.3 Examples in practice

Container Glass

The following examples are focused on comparisons of single-use products. It's important to note however that glass has a high reuse potential, which could significantly contribute to its overall resource efficiency as a material should it be used as part of a reuse, rather than single-use, system. Reuse of glass as a resource efficiency measure is discussed further in Measure 7 (reuse of glass products).

There are several examples of single-use glass containers being substituted with non-glass containers, including with plastic, aluminium, and paper-based containers. Evidence in the form of lifecycle assessments (LCAs) and LCA meta-analyses consistently suggest that single-use glass containers perform worse than their alternatives.[87] Glass production is energy-intensive and whilst energy consumption and associated CO_2 emissions can be reduced by using higher levels of recycled content, the melting of recycled material still uses 75% of the energy required to melt an equivalent quantity of virgin material.[88] By comparison, recycled polyethylene terephthalate (PET, commonly used in plastic bottle manufacture) uses just 10% of the energy required to make its virgin counterpart.[89]

PET bottles may be used instead of glass bottles for drinks packaging. PET plastic bottles require less energy to produce than glass (and aluminium) counterparts, and produce significantly fewer GHG emissions.[90] However, the overall impact of PET is highly variable. Fossil-based PET made of virgin material, for example, has a much higher environmental impact than a bio-based PET or bottles with high levels of recycled content, since it relies heavily on non-renewable resources. In general, in GHG emission terms, PET outperforms glass on a single-use basis, even if that glass is recycled.[91] While it is beyond the scope of this report, it's worth noting that environmental impacts should also be taken into account when it comes to material substitution with PET, for example plastic pollution.

Aluminium cans may also be a suitable replacement as they are lightweight, which reduces associated transport emissions, and achieve slightly higher recycling rates than glass.[92,93] Waitrose has replaced glass bottles with aluminium cans for small-format wine ranges, which

[87] UNEP and Life Cycle Initiative (2020) Single-use plastic bottles and their alternatives - Recommendations from Life Cycle Assessments. Available at: link.
[88] Enviros Consulting Ltd (2003) Glass Recycling – Life Cycle Carbon Dioxide Emissions – A Life Cycle Analysis Report. Available at: link.
[89] ZWE, Eunomia (2022). How circular is glass? Available at: link.
[90] Packaging Gateway (2023). PET plastic bottles deemed more sustainable than aluminium or glass. Available at: link.
[91] Brock and Williams (2020). Life cycle assessment of beverage packaging. Available at: link.
[92] UK Government (2023). UK statistics on waste. Available at: link.
[93] Canmakers (2021). The continuing rise of the can. Available at: link.

was expected to save 320 tonnes of packaging as well as halving CO_2 emissions compared to single-use glass bottles.[94]

Drink suppliers have also piloted moves to paper-based bottles in an effort to reduce the emissions impact of glass packaging. Absolut Vodka trialled a paper bottle that was made of 57% paper and 43% plastic barrier lining[95], weighing eight times less than its glass equivalent. According to an LCA by the manufacturer, the paper bottle reduces whole life CO_2e emissions by at least 15% (258 gCO_2e vs average glass bottle 304 gCO_2e)[96] although considerations are needed with regards to recyclability and other end of life impacts. There are other paper formats such as the Tetra Pak carton, which is made from card laminated with plastic and aluminium. Carton takes less energy to manufacture than glass, is lightweight, and easy to transport and store.[97] However, Tetra is much more difficult to recycle and can only be recycled in specialist paper mills in the UK.

Flat Glass

A stakeholder stated that flat glass will always be used in construction and automotive applications due to the technical and functional qualities of glass. Whilst clear plastics could be used for applications requiring transparency, glass does not degrade, warp or weaken with exposure to UV like plastics.[98, 99] Glass also maintains its clarity when exposed to light and heat, it offers better resistance to scratches and superficial damage from the elements and it is often a better insulator than plastic[100, 101]. A stakeholder stated that other safety concerns such as flammability and release of gases or toxins mean that plastic would not comply with safety standards for many flat glass applications.

Glass Wool

For glass wool, there are a number of potential alternatives:

- Rock wool is very similar to glass wool, except it is manufactured principally from volcanic rock, including basalt, dolomite and similar rocks[102] which are heated to a high temperature until molten and then spun. It is used as for residential, commercial and industrial insulation.[103] The literature suggests glass wool and rock wool have similar environmental performances, and each will be better suited to specific applications.[104]
- Polyester insulation has similar applications to glass wool. It can be made from PET and is predominantly sourced from recycled plastic materials. According to one analysis,

[94] Packaging Europe (2023). Waitrose replaces glass bottles with aluminium cans for small format wine ranges. Available at link.
[95] Institute of Materials, Minerals and Mining (2023) Absolut paper based bottle. Available at: link.
[96] Paboco (2023). Industry comparison –LCA of global warming effects. Available at: link.
[97] 50 Shades Greener (2021). Tetra V Glass V Plastic - Which is best?. Available at: link
[98] Todays Homeowner (2023). Plexiglass vs. Glass: Which Is Right for Your Windows?. Available at: link
[99] W Acrylic (2023). Acrylic Vs. Glass: What's The Difference?. Available at: link
[100] Todays Homeowner (2023). Plexiglass vs. Glass: Which Is Right for Your Windows?. Available at: link
[101] W Acrylic (2023). Acrylic Vs. Glass: What's The Difference?. Available at: link
[102] Isover Saint Gobain (no date) What is stone wool. Available at: link
[103] InterNACHI (no date). Rockwool for insulation. Available at: link
[104] Füschel et al. (2022) Life cycle assessment (LCA) of thermal insulation materials: A critical review. Available at: link

hydrocarbon-based insulation materials have comparable global warming impacts to glass wool.[105] However polyester insulation is suited to slightly different applications due to different vapour permeability, water absorption and installation requirements.

3.2 Available sources

3.2.1 Literature review

The literature review identified 32 sources that suggested substitution of glass for alternative materials as a resource efficiency measure. These comprised:

- Nine academic papers;[106] [107] [108] [109] [110] [111] [112] [113] [114]
- Six industry reports; [115] [116] [117] [118] [119] [120]
- One policy document;[121]
- Four technical studies; and [122] [123] [124] [125]

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105 Hill, Norton and Dibdiakova (2018) A comparison of the environmental impacts of different categories of insulation materials. Available at: link
106 Amienyo et al. (2010) Life cycle environmental impacts of carbonated soft drinks. Available at: link
107 Füschel et al. (2022) Life cycle assessment (LCA) of thermal insulation materials: A critical review. Available at: link
108 Furszyfer Del Rio et al (2022). Decarbonising the glass industry: A critical and systematic review of developments, sociotechnical systems and policy options. Available at: link
109 Hill, Norton and Dibdiakova (2018) A comparison of the environmental impacts of different categories of insulation materials. Available at: link.
110 Stefanini et al. (2021) Plastic or glass: a new environmental assessment with a marine litter indicator for the comparison of pasteurized milk bottles. Available at: link
111 Spence (2020). Wine psychology: basic & applied. Available at: link
112 Zimmerman et al. (2021). Plastic products leach chemicals that induce in vitro toxicity under realistic use conditions. Available at: link.
113 Brock and Williams (2020) Life cycle assessment of beverage packaging. Available at: link
114 Joost, W. (2012) Reducing Vehicle Weight and Improving U.S. Energy Efficiency Using Integrated Computational Materials Engineering. Available at: link.
115 Google and AFARA (2022). Closing the Plastics Circularity Gap: Full Report. Available at: link
116 Serac (2021) Returnable packaging - The practical case of organic dairy products in glass bottles and jars. Available at: link
117 UK Chemicals Stakeholder Forum (2010). A guide to substitution. Available at: link.
118 Valpak (2021) Written evidence submitted by Valpak Limited: Available at: link.
119 ZWE, Eunomia (2022). How circular is glass? Available at: link.
120 Saint Gobain (2021) Circular Economy – Eco-design for sustainable construction. Available at: link
121 European Parliament (2023) Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on packaging and packaging waste, amending Regulation (EU) 2019/1020 and Directive (EU) 2019/904, and repealing Directive 94/62/EC. Available at: link
122 Paboco (2023) Industry comparison - LCA of global warming effects. Available at: link.
123 UK Government (2023). UK statistics on waste. Available at: link
124 Enviros Consulting Ltd (2003) Glass Recycling - Life Cycle Carbon Dioxide Emissions - A Life Cycle Analysis Report. Available at: link
125 UNEP and Life Cycle Initiative (2020) Single-use plastic bottles and their alternatives – Recommendations from Life Cycle Assessments. Available at: link

- Twelve website articles. [126] [127] [128] [129] [130] [131] [132] [133] [134] [135] [136] [137]

Though there was a lack of literature on levels of efficiency, the sources available were considered of relatively 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 4.0 (out of 5). Nineteen sources exhibited a score of 4 or above, nineteen were UK-specific and 25 were from 2014 or later. Overall, the literature was deemed to be highly applicable to the UK market today. However, there was a lack of information on the extent to which different material substitutions were happening, as this is very hard to measure.

3.2.2 Interviews and workshop

This measure was engaged with by five stakeholders in the interviews and workshop. They agreed that this measure predominantly applies to container glass but differed in opinion on whether there is likely to be a significant trend away from the use of glass towards other materials. One stakeholder stated that glass containers consistently performed worse than alternative materials from an emissions perspective and that the most promising alternative material for container glass is aluminium – however, considerations would have to be made for the recycling potential and cost of other materials since glass can technically be recycled infinitely, unlike plastics, and the cost of aluminium is higher than glass.

3.3 Drivers & Barriers

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

3.3.1 Drivers

Table 11 below shows the main drivers for Measure 3. The most significant drivers are shown in bold as voted for by stakeholders in the workshop.

[126] 50 Shades Greener (2021) Tetra V Glass V Plastic - Which is best?. Available at: link.
[127] Arc Building Solutions (2022) Rock Mineral Wool vs Glass Mineral Wool. Available at: link.
[128] Beverage Daily (2023) Can wine and spirits really move away from glass? Available at: link.
[129] Packaging Europe (2023) Waitrose replaces glass bottles with aluminium cans for small format wine ranges. Available at: link.
[130] Packaging Gateway (2023) PET plastic bottles deemed more sustainable than aluminium or glass. Available at: link.
[131] Packaging News (2021) NielsenIQ data shows record value growth for cans. Available at: link.
[132] Packaging World (2006) Survey: Perception huge in beverage packaging. Available at: link.
[133] Pricewise Insulation (2021) Glasswool vs Polyester Insulation - Which one is right for you?. Available at: link.
[134] The Guardian (2021) Toxic 'forever chemicals' are contaminating plastic food containers. Available at: link.
[135] Institute of Materials, Minerals and Mining (2023) Absolut paper based bottle. Available at: link.
[136] Insulation Superstore (no date) Glass wool or mineral wool – which is best for insulation?. Available at: link.
[137] Canmakers (2023) The continuing rise of the can. Available at: link

Table 11: Drivers for glass measure 3

Description	PESTLE	COM-B
Convenience of lighter and non-fragile products, e.g., plastic (container glass)	**Social**	**Opportunity – social**
Emissions reduction from lower transport emissions and lower energy requirements in production of alternatives (container glass)	Environmental	Motivation – reflective

Convenience of lighter and non-fragile products, e.g. plastic (container glass)

According to an article that consolidates examples of consumer brands turning to alternatives to glass as packaging materials, making food and drinks products easier to consume on-the-go or in out-of-home settings (e.g., picnics, festivals) is another convenient benefit of not using glass for customers.[138] According to the article, brands and producers may move away from using glass packaging for certain markets as it can be inconvenient for consumers due to its weight and fragility, unlike the alternatives of plastic, aluminium and paper-based packaging.

Emissions reduction from lower transport emissions and lower energy requirements in production of alternatives (container glass)

Using lighter packaging materials and reducing the overall weight of a product shipment reduces the cost and emissions associated with transportation.[139] Glass is the heaviest of common container packaging format, and according to research by Zero Waste Europe and Eunomia, LCA meta analyses of the emissions associated with different packaging materials consistently shows single-use glass to have a higher emissions impact than alternatives including aluminium cans, PET bottles, HDPE bottles and multi-layer beverage cartons.[140] The economic and environmental cost of the transportation of glass packaging may therefore drive brands towards using lighter alternatives such as plastic and aluminium where possible.

3.3.2 Barriers

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

[138] Beverage Daily (2023) Can wine and spirits really move away from glass? Available at: link.
[139] Wang et al. (2021) Effects of Vehicle Load on Emissions of Heavy-Duty Diesel Trucks: A Study Based on Real-World Data. Available at: link
[140] Zero Waste Europe and Eunomia (2022) How circular is glass? Available at: link

Table 12: Barriers for glass measure 3

Description	PESTLE	COM-B
Consumer perception of health hazards associated with chemicals contained in plastic packaging (container glass)	**Social**	**Motivation – reflective**
Consumer perception that glass products are higher quality (container glass)	**Social**	**Motivation – reflective**
Policy encouraging an increase in reusables	Political	Capability – psychological
Pushback from glass industry	Political	Capability – psychological

Consumer perception of health hazards associated with chemicals contained in plastic packaging (container glass)

Research has shown that many of the world's plastic containers and bottles are contaminated with toxic per- and polyfluoroalkyl substances (PFAS), and data suggests that it could leach into food and drinks at potentially high levels.[141] This therefore presents a barrier to the substitution from glass to plastic for applications such as food and drink packaging.

Whilst there are many food and drinks products packaged in plastic, they must meet strict 'food-grade' levels of purity. As demand for recycled plastics steadily increases, this poses a challenge for food and drinks packagers, where any post-consumer recyclate inputs must be strictly non-contaminated and suitable for contact with food. This either limits food packagers to using only a small amount of food grade recyclate and leaving potential to be penalised for below target levels of recycled content, or encourages them to look for ways to improve the quality of non-food grade quality recyclate with all the associated time and financial costs that may bring.[142] There is also research to suggest that humans and wildlife could be exposed to toxic chemicals via plastic products and microplastics, although whether this is at levels high enough to be a public health concern is yet to be established.[143]

Consumer perception that glass products are higher quality (container glass)

One stakeholder commented that some consumers prefer glass containers over other materials for certain products, as they associate it with a higher quality product. One consumer

[141] United States Environmental Protection Agency (2021) EPA's Analytical Chemistry Branch PFAS Testing Rinses from Selected Fluorinated and Non-Fluorinated HDPE Containers. Available at: link
[142] Google and AFARA (2022). Closing the Plastics Circularity Gap: Full Report.
[143] Zimmerman et al. (2021). Plastic products leach chemicals that induce *in vitro* toxicity under realistic use conditions. Available at: link.

survey by Packaging World suggests that consumers believe glass packaging preserves the taste of beer better and keeps it colder for longer than plastic or aluminium.[144]

Policy encouraging an increase in reusables

Stakeholders suggested in the workshop that future policy may encourages the use of certain materials over others. The EU Environment Committee are proposing new regulation on the minimum levels of reuse of packaging materials to encourage consumers to reuse and refill where possible.[145] This could lead to higher use of glass in beverage containers, where glass is a more appropriate refillable option compared with plastic or aluminium.

Pushback from glass industry

Several stakeholders suggested that the glass industry would likely resist shifts away from the use of glass, since a reduction in glass production would have financial impacts. This industry pushback is also discussed as a barrier for Measure 7 (see Section 7.3.2 Barriers) and Measure 8 (see Section 8.3.2 Barriers).

3.4 Levels of efficiency

Table 13: Levels of efficiency for glass measure 3

Indicator: Percentage CO_2e reduction from substitution with alternative materials			
Level of efficiency	Current	Maximum in 2035	Business-as-usual in 2035
Value	Not available	Not available	Not available
Evidence RAG	Not applicable	Not applicable	Not applicable

3.4.1 A note on findings

The levels of efficiency for this measure were not identified. The calculation of a reduction in CO_2e requires an understanding of two factors: (1) the anticipated change in mass of glass placed on the market used along with the corresponding change in mass of each type of material used to replace glass; and (2) the carbon impacts associated with the production of each of these materials on a lifecycle basis (noting that the emissions associated with each material can vary immensely depending on features such as the origin of each material, production method and local waste management methods). The research process did not yield sufficient information for both of these inputs to produce a meaningful level of efficiency for this

[144] Packaging World (2006). Survey: Perception huge in beverage packaging. Available at: link.
[145] European Parliament (2023) Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on packaging and packaging waste, amending Regulation (EU) 2019/1020 and Directive (EU) 2019/904, and repealing Directive 94/62/EC. Available at: link

indicator and measure – attempting to do so would have potentially lead to misleading conclusions. This remains a significant evidence gap.

4.0 Measure 4 – Reincorporate glass waste back into glass manufacturing

4.1 Glass resource efficiency measure

4.1.1 Description

Reintroduce into the production of primary glass any glass waste that occurs across the supply chain (primary manufacturing, secondary manufacturing, filling, installing, etc) as well as the glass waste produced at end-of-life after the glass products have been consumed.

This measure refers to the reintroduction into the glass manufacturing process (as a raw material) of any glass cullet (glass waste) that results from the manufacturing of glass, its filling (in the case of container glass), or installation (in the case of flat glass and glass wool), as well as any glass cullet that results from end-of-life after use (such as when a consumer purchases a glass beer bottle and disposes of it after its use).

It is important to make the following clarification. This measure is seeking to maximise the percentage of glass cullet that is reintroduced as a raw material back into the production of new glass. From a resource efficiency perspective, the amount of glass cullet that is produced also needs to be minimised, which is addressed by Measure 5 specifically (through more efficient manufacturing), but also by Measures 6 (repair) and 7 (reuse). This measure also links with Measure 8, which seeks to increase the amount of post-consumer glass available for recycling so that it can be reintroduced into production.

There is a clear distinction to be made between internal glass cullet, and external cullet (which in turn is split into pre-consumer cullet and post-consumer cullet). This is explained as follows:

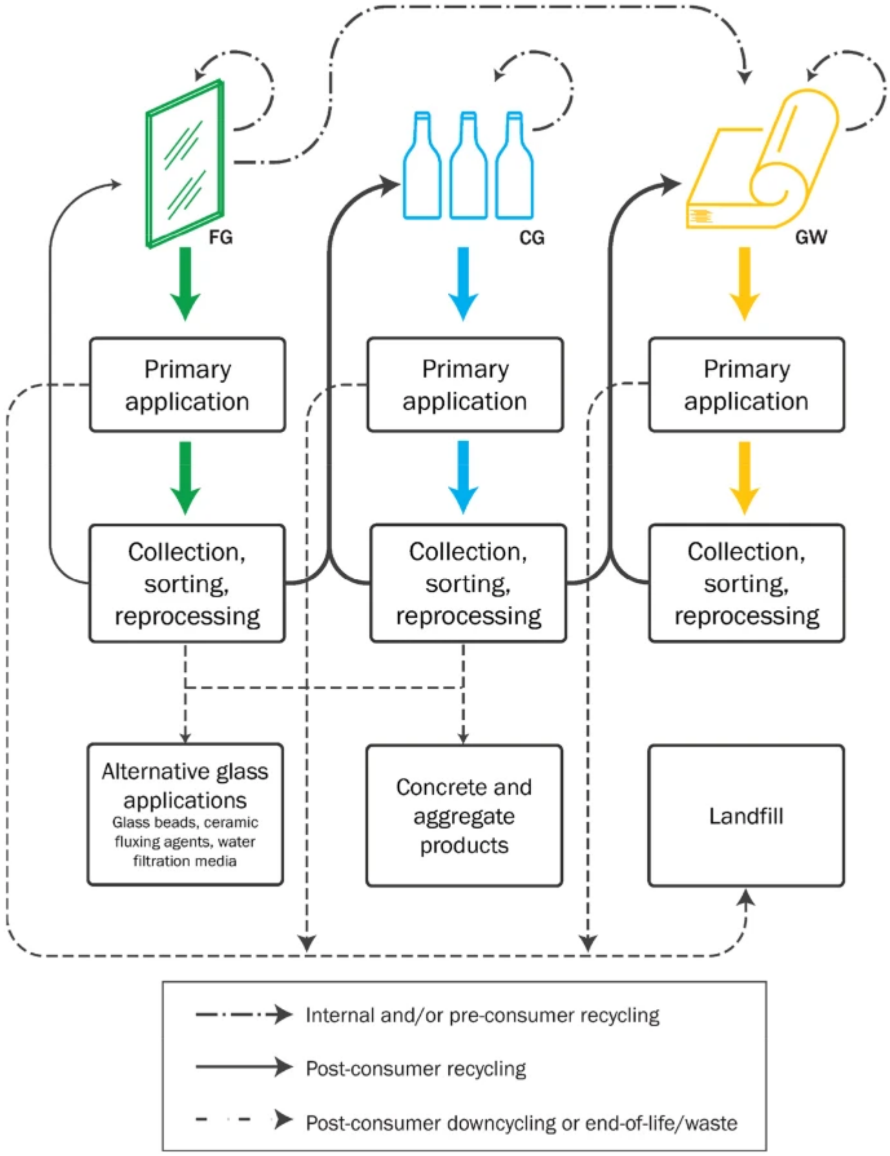
- Internal cullet (also known as process cullet) refers to waste glass that results from the primary manufacturing of glass at the production plant.[146] For example, in the case of flat glass, any offcuts that result from trimming the edges of a flat glass unit, any breakages, or cases where a defect is found and is rejected from the manufacturing process, are classified as internal cullet.
- External cullet refers to:
    - Pre-consumer cullet include offcuts or breakages that result from the secondary (downstream) manufacturing of glass or filling of container glass, during secondary processing by customers of the primary glass producers.
    - Post-consumer glass cullet includes glass that has been retrieved from waste collection services after it has passed through an end consumer and is recycled

[146] Institute for Prospective Technological Studies (2013) Best Available Techniques (BAT) reference Document for the Manufacture of Glass. Available at: link

back into the production of glass. [147] As noted above, the availability of this glass cullet is intrinsically linked to and dependent on Measure 8.

Figure 1 below shows the recycling of glass cullet back into the three primary UK glass products (markets) as well as its use in alternative glass applications and other sectors. In all three product categories, reincorporation of glass waste back into manufacturing (Measure 4) refers to the recycling of internal glass cullet and pre-consumer glass cullet back into the product (as shown by the dotted arrows at the top of Figure 1), and recycling of post-consumer glass cullet (as shown by the bold, non-dotted arrows in the middle of Figure 1).

Figure 1: Recycling of glass cullet (internal, pre-consumer and post-consumer)[148]



The reason it is important to distinguish between the different kinds of cullet is because the availability and use of internal glass cullet is determined by the primary manufacturer, whereas the availability of external cullet is determined by the secondary manufacturer (or installer or

[147] Institute for Prospective Technological Studies (2013) Best Available Techniques (BAT) reference Document for the Manufacture of Glass. Available at: link
[148] Hartwell, Coult, Overend (2022) Mapping the flat glass value-chain: a material flow analysis and energy balance of UK production. Available at: link

filler) in the case of pre-consumer cullet, and by consumers and waste collection services in the case of post-consumer cullet.

Table 14: shows that this measure is applicable to three of the four glass products in scope of this project. It is not considered relevant to automotive flat glass, as there is no primary manufacturing occurring in the UK, only secondary forming/laminating.

Table 14: List of sub-sectors applicable to measure 4

Container Glass	Flat Glass - Construction	Flat Glass - Automotive	Glass Wool
Applicable	Applicable	Not Applicable	Applicable

4.1.2 Measure indicator

The indicator that has been selected to measure the reincorporation of glass waste back into manufacturing is '**percentage of glass cullet in primary glass manufacture**'. This is derived by dividing the mass of glass cullet by the total mass of materials (sand, limestone, soda ash, and others, as well as glass cullet) going into primary glass production.

This indicator has been split into two contributing sub-indicators, both of which are added up to calculate to total percentage of glass cullet in primary glass manufacture:

- **Indicator 4a: 'Percentage of internal glass cullet in primary glass manufacture'**
- **Indicator 4b: 'Percentage of external glass cullet in primary glass manufacture'**
- **Indicator 4c: 'Percentage of glass cullet in primary glass manufacture'**. This indicator is calculated by adding indicator 4a to indicator 4b (i.e. indicator 4c = indicator 4a + indicator 4b)

4.1.3 Examples in practice

The recycling of internal and pre-consumer cullet is an established practice in the glass sector, for all the relevant product applications, with proportions of cullet from different sources varying between the different applications. These proportions are outlined in section 4.4.1 ("Current level of efficiency").

Ardagh Group incorporated an average of 67% glass cullet (internal and external cullet) in their glass bottles produced in the EU in 2020.[149] In 2021, recycled glass accounted for an average of 48% of Encirc's total raw materials.[150] Encirc has also produced a glass bottle using 100%

[149] Ardagh Group (2021) Ardagh Group Sustainability Report 2021. Available at: Link
[150] Vidrala (2021) Sustainability Report. Available at: Link

recycled glass (cullet).[151] Evaluated over multiple years of operation, each tonne of flat glass produced in Guardian Glass' European facilities (EU and UK) contains an average of 20-24% glass cullet (internal and external). This ratio can vary from site to site and over time, depending on cullet availability.[152]

It is worth noting that there is a hierarchy, in terms of the quality of recycled cullet, that dictates which products accept cullet from which other products. These are driven by the technical specifications for each. Flat glass has the highest quality and accepts cullet only from flat glass Flat glass cullet can be used in container glass and glass wool. Container glass cullet, meanwhile, will typically be used in container glass or glass wool, but not into flat glass because using cullet from container glass risks introducing discolouration or impurities that may cause bubbles in the flat glass. In the case of glass wool, cullet from glass wool can go into glass wool but not into flat or container glass (again due to potential impurities). This hierarchy therefore imposes limits and restrictions on the amount of cullet.

4.2 Available sources

4.2.1 Literature review

The literature review identified 21 sources that discussed this resource efficiency measure (either in terms of providing evidence on levels of efficiency, or by providing commentary on drivers and barriers). These comprised:

- Three academic papers;[153] [154] [155]
- Eleven industry reports;[156] [157] [158] [159] [160] [161] [162] [163] [164] [165] [166]

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151 Nick Kirk (2021) Mapping the journey towards intelligent glass bottles. Available at: Link
152 IFT Rosenheim (2021) Environment Product Declaration Available at: Link
153 Forslund H. and Björklund M. (2022) Toward Circular Supply Chains for Flat Glass: Challenges of Transforming to More Energy-Efficient Solutions. Available at: link
154 Geboes E., Galle W., De Temmerman N. (2022) Make or break the loop: a cross-practitioners review of glass circularity. Available at: link
155 Hartwell R., Coult G., Overend M. (2022) Mapping the flat glass value-chain: a material flow analysis and energy balance of UK production. Available at: link
156Ardagh Group (2021) Ardagh Group Sustainability Report 2021. Available at: link
157 ARUP (2018) Re-thinking the life-cycle of architectural glass. Available at: link
158 British Glass (2020) Glass sector. Net zero strategy 2050. Available at: link
159 FEVE (2019) Recycled content and glass packaging - European container glass industry position. Available at: link
160 Glass and Glazing Federation (2000) Cost savings from reducing waste in the glass and glazing industry. Available at: link
161 Green Building Council, Verdextra, British Glass, ARUP (2018). Building glass into the circular economy. Available at: link
162 Saint Gobain (2021) Circular Economy – Eco-design for sustainable construction. Available at: link
163 Vidrala (2021) Sustainability Report. Available at: link
164WRAP (2008) Collection of flat glass for use in flat glass manufacture. Available at: link
165 Xella and URSA (2020) Leading the Change Sustainability Report 2020. Available at: link
166 Zero Waste Europe and Eunomia (2022) How circular is glass. Available at: link

- One policy document;[167]
- Two technical studies;[168] [169] and
- Four website articles.[170] [171] [172] [173]

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 4.0 (out of 5), with 13 of the sources scoring 4 or above. 18 sources are from 2017 or later, and 10 sources were-UK specific.

4.2.2 Interviews

Eight of the stakeholders interviewed provided input on reincorporating glass waste back into glass manufacturing, discussing levels of efficiency, drivers and barriers for the different glass applications, depending on their area of expertise. Interviewees noted that this was a measure the glass sector had already made significant progress on, but further gains were there to be made, in particular with increasing the recycling of post-consumer cullet.

4.2.3 Workshop

Eight stakeholders across the industry were active on the mural board, four stakeholders contributed to the discussion verbally and one on MS teams. There was a high level of engagement from stakeholders for this measure. One key point raised was that with sufficient quality, all industries could use 100% cullet, however the quality of collected material does not allow for this. Stakeholders agreed that many of the enablers or divers for this measure are outside of the control of the glass industry and depend on robust policy and technical infrastructure to drive up the quality of cullet for recycling.

4.3 Drivers & Barriers

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

4.3.1 Drivers

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

Table 15: Drivers for glass measure 4

[167] British Glass and BEIS (2017) Glass Sector Industrial Decarbonisation and Energy Efficiency Roadmap Action Plan. Available at: link
[168] IFT Rosenheim (2021) Environment Product Declaration. Available at: link
[169] Rodriguez Vieitez E. et al. (2011) End-of-Waste Criteria for Glass Cullet: Technical Proposals. Available at: link
[170] Encirc 360 (2021) Mapping the journey towards intelligent glass bottles. Available at: link
[171] Friends of Glass (2023) What are the benefits of glass in a circular economy? Available at: link
[172] Knauf Insulation (2023) Knauf Insulation: Frequently asked questions. Available at: link
[173] The European Container Glass Federation (2023) Reinventing glass? We're already on it! Available at: link

Description	PESTLE	COM-B
Reduced energy consumption and emission charges	**Environmental**	**Opportunity – physical**
Reduced emissions due to decarbonisation of raw material	**Environmental**	**Opportunity – physical**
Lower cost per tonne of input	**Economic**	**Opportunity – physical**
Reduction in indirect environmental impacts (water and air pollution)	Environmental	Opportunity – physical

Reduced energy consumption and emission charges

The use of glass cullet can reduce energy consumption associated with the production of glass. The level of energy reduction is debated but one source claims that each additional 10% of cullet used in melting results in direct energy savings of 3% due to the lower energy required to melt cullet.[174] This assumption suggests that using 100% cullet glass results in a production energy saving of up to 30% compared to 100% virgin glass. However one academic interviewed claimed that energy consumption could be reduced by as much as 75% - although this could include indirect energy savings, for example in the production route of raw materials. A reduction of energy consumption is likely to save glass manufacturers on costs.

Stakeholders also stated the use of cullet could present significant GHG emissions savings of both scope 1 (direct) and scope 3 (indirect) emissions. Research by ARUP found that a reduction in energy consumption subsequently leads to a reduction in emissions which reduces the cost of emission charges (currently called Climate Change Levy in the UK) for glass manufacturers.[175]

Reduced emissions due to decarbonisation of raw material

Limestone decarbonises in the glass manufacturing process, releasing CO_2. Cullet has already been decarbonised, so using this as input material reduces the overall carbon emissions from manufacturing. According to the British Glass Net Zero strategy, each tonne of glass cullet that is recycled/remelted leads to approximately 200kg CO_2 saved in production/process emissions and 580 kg CO_2 saved throughout the supply chain.[176]

Lower cost per tonne of input

[174] Forsulnd. H, Björklund. M (2018) Toward Circular Supply Chains for Flat Glass: Challenges of Transforming to More Energy-Efficient Solutions. Available at: link
[175] ARUP (2018) Re-thinking the life-cycle of architectural glass. Available at: link
[176] British Glass (2020) Glass sector Net zero strategy 2050. Available at: link

Research by ARUP indicated that, in 2018, the cost per tonne of cullet was less than the cost per tonne of raw material. One stakeholder elaborated that for every tonne of cullet utilised, 1.2 tonnes of raw materials are saved, which therefore further increases the financial benefit of increased cullet use.[177] Nevertheless, the costs of materials vary frequently, and it may not always be attractive to use cullet. If competition for cullet from other industries grows (see Section 8.3.2 Barriers), then the cost of cullet may also rise in response to higher demand.

Reduction in indirect environmental impacts (water and air pollution)

Stakeholders pointed out that reducing the mining of batch raw materials should also have a positive impact on the environment and systems by reducing water and air pollution that results from mining the primary raw materials. One trade association claimed that each tonne of glass that is recycled/remelted leads to a 20% reduction in air pollution and 50% reduction in water pollution. This data could not, however, be validated by the literature that informs this report. This driver is particularly pertinent to manufacturers who have corporate environmental responsibilities and who are seeking to minimise their environmental impact.

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 glass measure 4

Description	PESTLE	COM-B
Risk of contamination/composition quality of post-consumer flat glass (construction flat glass, container glass)	**Technological**	**Capability – physical**
Inefficient logistics systems including long transport distances and lack of storage space for post-consumer glass products (construction flat glass)	**Technological / Economic**	**Capability – physical**
Cost of labour and transport (in particular for the recycling of flat glass)	Economic	Opportunity – physical
Limited potential for further reincorporation of internal and pre-consumer cullet as practice already well-established	Technological	Opportunity – physical
Landfill tax too low	Political	Capability – psychological

[177] ARUP (2018) Re-thinking the life-cycle of architectural glass. Available at: link

Risk of contamination/composition quality of post-consumer glass (construction flat glass, container glass)

Due to the risk of contamination post-consumer sorting of flat glass must be carefully performed and thus remains labour-intensive and costly.[178] Further research may shed light on the extent to which such sorting processes could benefit from future technology. Stakeholders stated that there are potential issues with mixing different manufacturers' glass in external cullet, as composition can vary and impact the composition and functionality of new glass. Contamination can cause damage, standstills, or production losses in glass production, as well as glass discolouration.[179] Though there are significant financial and carbon benefits for glass manufacturers to using external cullet, stakeholders in interview suggested that the composition and contamination challenges are difficult to overcome and need to be closely monitored to ensure production is viable.

Inefficient logistics systems including long transport distances and lack of storage space for post-consumer glass products (flat glass)

A literature review looking at the challenges of improving the circularity of flat glass supply chains found that inefficient logistics systems are one of the main barriers to closed-loop supply chains (CLSCs).[180] Long transport distances or distant storage spaces equates to higher cost and reduced efficiency. A lack of storage space for cullet to enable consolidation of sufficient volumes pose further barriers to increasing post-consumer cullet use.[181]

Cost of labour and transport (in particular for the recycling of flat glass)

Despite the current cost per tonne of cullet being less than the cost per tonne of raw material, research has also shown that the relatively low material value of flat glass and the high cost of labour and transport to recycle flat glass means the recycling of flat glass may not be economically viable.[182] Stakeholders confirmed this, stating that the collection of construction flat glass for recycling is rare as it is a technically complex process and automated equipment to perform separation of glass from other materials such as a window frame is not widely available.

The point at which it may be economically viable to collect and recycle flat glass is complex and would depend on individual contracts and recycling supply chains, amongst other factors. Further research could highlight how to make the recycling of flat glass more economically viable and give reprocessors access to a high-quality stream of glass cullet.

The costs of labour and transport are also factors in the recycling of container glass. To retrieve high-quality cullet from post-consumer container recycling feedstocks requires labour

[178] British Glass (2020) Glass sector. Net zero strategy 2050. Available at: link
[179] Forsulnd. H, Björklund. M (2018) Toward Circular Supply Chains for Flat Glass: Challenges of Transforming to More Energy-Efficient Solutions. Available at: link
[180] Ibid
[181] Ibid
[182] Ibid

in sorting, bulking and reprocessing facilities, as well as transport. The price of cullet must remain high enough that the sector can continue to run their facilities using recycled cullet.

Limited potential for further reincorporation of internal and pre-consumer cullet as practice already well-established

Stakeholders have suggested in interview that the recycling of manufacturing by-products (internal and pre-consumer cullet) is a practice that is already well established in glass manufacturing, suggesting there may be limited potential for a further increase in the use of these two types of cullet. The literature corroborates this, stating that manufacturers are already maximising use of high-quality cullet and highlighted a shortage of flint and amber container cullet for container glass manufacture, as well as flat glass cullet for flat glass manufacture.[183]

Landfill tax too low

During the workshop, stakeholders identified that glass is currently subject to a lower rate of landfill tax as it is classified as inert and therefore less polluting than materials that decay or contaminate the land over time. The lower rate stands at £3.25 per tonne for inert waste, compared with a standard rate of £102.10 per tonne for all other waste (as of 1 April 2023).[184] According to the stakeholders, such a low landfill cost might not discourage some producers of glass waste from sending waste to landfill rather than to reprocess it.

4.4 Levels of efficiency

As noted previously, this indicator is split into two sub indicators, one measuring internal cullet and the other measuring external cullet. These are then combined to provide the overall indicator of 'Percentage of glass cullet in primary glass manufacture'.

Table 17: Levels of efficiency for glass measure 4

Indicator 4a: Percentage of internal glass cullet in primary glass manufacture*			
Level of efficiency	Current	Maximum in 2035	Business-as-usual in 2035
Value	CG: 11-20% FG (construction): 10-20% GW: 0-10%	CG: 10-18% FG (construction): 9-18% GW: 0-10%	CG: 10-19% FG (construction): 9-19% GW: 0-10%
Evidence RAG	Red-Amber	Red	Red

183 British Glass (2020) Glass sector. Net zero strategy 2050. Available at: link
184 UK Government (2023) Landfill Tax rates. Available at: link.

**CG = Container Glass; FG = Flat Glass; GW = Glass Wool*

Indicator 4b: Percentage of external glass cullet in primary glass manufacture*			
Level of efficiency	Current	Maximum in 2035	Business-as-usual in 2035
Value	CG: 32-52% FG (construction): 16-25% GW: ~80%	CG: 65-70% FG (construction): 40-50% GW: >80%	CG: 50-65% FG (construction): 30-40% GW: >80%
Evidence RAG	Red-Amber	Red	Red

**CG = Container Glass; FG = Flat Glass; GW = Glass Wool*

The total percentage of total glass cullet in primary glass manufacture for each sub-sector is calculated by adding indicators 4a and 4b.

Indicator 4c: Percentage of glass cullet in primary glass manufacture*			
Level of efficiency	Current	Maximum in 2035	Business-as-usual in 2035
Value	CG: 43-72% FG (construction): 26-45% GW: 80-90%	CG: 75-88% FG (construction): 49-68% GW: 80-90%	CG: 60-84% FG (construction): 29-59% GW: 80-90%
Evidence RAG	Red-Amber	Red	Red

**CG = Container Glass; FG = Flat Glass; GW = Glass Wool*

4.4.1 Current level of efficiency

The proportion of internal and external glass cullet in current primary glass manufacture for each product type is as follows.

<u>Container Glass</u>

Percentage of internal glass cullet in primary container glass manufacture

Three of the interviewees indicated that the vast majority of internal cullet that results from primary manufacturing, in the case of both container and flat glass, is fed back into glass furnaces as cullet. Very limited losses result from this process with one indicating 99.9% of it is recycled and another indicating 100%. The 0.1% loss is due to times when there is contamination in the raw material input that means that a large production run has to be scrapped, and therefore the cullet is not recycled back into the process. This 0.1% waste is instead then sent to produce aggregates. However, cases like this are the exception.

No literature data were available on the percentage of internal glass cullet currently used in primary container glass manufacture. Instead, the current efficiency level relies on insight from the stakeholders.

One manufacturer interviewed indicated that the percentage of internal glass cullet currently used in primary container glass manufacture is on average 15%. This was the figure used as the basis for the voting ranges in the workshop.

In the workshop, six stakeholders voted for the range 11-20% (three with high confidence, one with medium confidence, two with low confidence) and one did not know. One stakeholder noted (with medium confidence) that there is variation from site to site but that an average of 15% seems reasonable. Another stakeholder gave a specific estimate of 10-15%.

Based on the above evidence, the current level of efficiency for the percentage of internal glass cullet used in the primary manufacture of container glass is estimated to be around 11-20%. The evidence RAG rating for this efficiency level is red-amber, reflecting the fact there were data points collected from the interviews and there was agreement at workshop, but there was no supporting evidence from the literature.

Percentage of external glass cullet in primary container glass manufacture

A 2022 report by Eunomia and Zero Waste Europe found that container glass in the UK contains on average ~38% recycled content (recycled content is a term which is used to refer to external cullet but not internal cullet content).[185] A 2019 report by FEVE stated that the average recycled content of glass containers produced in Europe is 52% for containers of unspecified colour (80% for green glass, 50% for brown glass and 40% for flint glass).[186]

Four interviewees commented that external cullet inclusion is dictated by the colour of the new glass container due to the acceptable levels of discolouration caused by cross colour contamination in the cullet. One interviewee explained that for their products, Flint (clear) glass typically includes ~25% external cullet whilst Amber and Green have ~50% and ~65% respectively.

In the workshop, three stakeholders voted for the range 30-40% (one with high confidence, two with medium confidence), two voted for the range >40% (one with high confidence, one with medium confidence) and two did not know.

Based on the above evidence, a range of 32-52% has been selected as the current level of efficiency for the percentage of external glass cullet used in the primary manufacture of container glass. This figure encompasses the literature as well as votes from the workshop.

[185] ZWE, Eunomia (2022) How circular is glass?. Available at: link
[186] FEVE – The European Container Glass Federation (2019) "Recycled content and glass packaging" - European container glass industry position. Available at: link

The evidence RAG rating for this efficiency level is amber, reflecting the fact there is some supporting literature evidence specifically on the percentage of external glass cullet in container glass.

Flat Glass

Percentage of internal glass cullet in primary flat glass manufacture

Three of the interviewees indicated that the vast majority of internal cullet that results from primary manufacturing, in the case of both container and flat glass, is fed back into glass furnaces as cullet. Very limited losses result from this process with one indicating 99.9% of it is recycled and another indicating 100%. The 0.1% loss is due to times when there is contamination in the raw material input that means that a large production run has to be scrapped, and therefore the cullet is not recycled back into the process. This 0.1% waste is instead then sent to produce aggregates. However, cases like this are the exception. No data from the literature was found to support this.

A 2018 Europe-wide report by ARUP states that “internal cullet consists of rejects or offcuts from the float line and typically makes up 20-25% of the volume of raw material mix on average in European float manufacturers”.[187] Hartwell et al state that most of the cullet used in the production of new flat glass is internal or pre-consumer cullet, with an estimate that no more than 1% of post-consumer cullet.[188] The reasons for this are discussed in more detail in the Drivers and Barriers section, but this is principally because the collection infrastructure needed to collect flat glass at post-consumer stage is currently not in place, with the majority of post-consumer flat glass waste currently being sent to landfill or to make aggregates, rather than being recycled back into glass.

One trade association interviewed identified that on average around 10% internal glass cullet was used in flat glass production. One manufacturer interviewed indicated that this percentage was higher, at around 15-20%.

In the workshop, one stakeholder voted for the range 0-10%, and nine for the range 11-20% (four with high confidence, two with medium confidence, two with low confidence, one did not specify the level of confidence). One stakeholder noted that the value is dependent on the product type. Another specified (with medium confidence) that the average seems reasonable, and that it will vary from site to site.

Based on the above evidence, the current level of efficiency for percentage of internal glass cullet used in the primary manufacture of flat glass is 10-20%. The evidence RAG rating for this efficiency level is red-amber, reflecting the fact there were data points collected from the interviews and consensus in the workshop, but there was no supporting evidence from the literature.

[187] ARUP (2018) Re-thinking the life-cycle of architectural glass. Available at: link
[188] Hartwell, Coult, Overend (2022) Mapping the flat glass value-chain: a material flow analysis and energy balance of UK production. Available at: link

Percentage of external glass cullet in primary flat glass manufacture

A 2008 report by WRAP states that "the recycled content of flat glass produced in the UK is between 20%–30%"[189] but does not specify how they define recycled content, i.e. how much of this is external cullet and whether the figure includes internal cullet or not.

One interviewee identified that construction flat glass contains on average ~10% recycled content (external cullet). However, another manufacturer interviewed stated that there are examples of higher levels of cullet use - one of the flat glass manufacturers includes around 30% external cullet (24% pre-consumer, 6% post-consumer) in new flat glass.

One interviewee provided an estimate of the levels of external cullet being incorporated by the three main manufacturers in the UK, which on average was estimated to be ~16-17%. This was the figure used as the basis for deciding the voting ranges for the workshop.

In the workshop, three stakeholders voted for the range 10-20% (all with medium confidence), one voted for the range 20-30% (with medium confidence) and one voted for the range >30%.

Based on the above evidence, the figure of 16-25% has been estimated for the percentage of external glass cullet used in the primary manufacture of flat glass. The evidence RAG rating for this efficiency level is red-amber, given some evidence was gathered from the interviews and literature. The RAG rating is not amber because there was only one data point collected from the literature and it is from an older report, and it does not match the data from the interviews.

Glass Wool

Percentage of internal glass cullet in primary glass wool manufacture

No literature data were available on the current level of efficiency for the percentage of internal glass cullet in primary glass wool manufacture. Instead, the current level of efficiency relies on insight from the workshop conducted.

In the workshop, five stakeholders voted for the range 0-10% (three with medium confidence, two with low confidence), one voted for the range 11-20% (did not specify the level of confidence) and one did not know. One specified that glass wool manufacturers do not remelt processed waste fibres, but rather incorporate it into the glass wool product.

Based on the above evidence, the current level of efficiency for the percentage of internal glass cullet used in the primary manufacture of glass wool is estimated to be around 0-10%. The evidence RAG rating for this efficiency level is red, reflecting the lack of supporting literature evidence specifically on the use of internal glass cullet in glass wool (even though total cullet use is known).

Percentage of external glass cullet in primary glass wool manufacture

[189] WRAP (2008) Collection of flat glass for use in flat glass manufacture. Available at: link

A 2022 report by Hartwell et al states that glass wool production in the EU typically incorporates up to 55% of pre- and post-consumer cullet in new production[190]. This would seem to suggest all of the 55% is external cullet and none is internal cullet. However, this figure is for the EU.

Other literature found suggests that, in the UK, up to 80% total cullet is incorporated into the manufacture of glass wool[191,192], a figure also confirmed by an interview with a trade body. However, neither this literature nor any of the interviewees were able to specify whether any of this 80% total cullet is internal cullet. Furthermore, an interview was not secured with a glass wool manufacturer to be able to comment on this. Based on sector insight from the interviews, it is likely the majority of this 80% total cullet figure is in fact external cullet rather than internal cullet.

One interviewee identified that glass wool, typically contains high levels of recycled content, with up to 40% flat glass cullet and 40% container cullet used in its primary manufacturing. This is because glass wool products can accept high levels of recycled content and still meet the performance specification. The remaining percentage is made up of other chemicals required to form the wool. Knauf Insulation state that glass wool does not include any post-consumer glass wool as it is difficult to reprocess.[193]

In the workshop, four stakeholders voted for the range >80% (all with medium confidence) and none voted for the other ranges.

Based on the above evidence, the figure of ~80% has been used as the current level of efficiency for percentage of external glass cullet used in the primary manufacture of glass wool. The evidence RAG rating for this efficiency level is red-amber given the fact there are two literature sources to support this figure as well as insight from an interview and the votes expressed at the workshop.

4.4.2 Maximum level of efficiency in 2035

As noted earlier, currently nearly 100% of the internal cullet generated in the primary manufacture of glass products is reincorporated into the manufacturing process. Over time, as improvements are made in manufacturing efficiencies (see Measure 5 below), the amount of internal cullet generated is likely to fall, through reduction in offcuts and rejects, according to sector insight. With this likely reduction in cullet generation, the amount of internal cullet available for reincorporation into the manufacturing process is also expected to decrease, according to the insight gathered from the sector through the interview process. Therefore, the percentage of internal glass cullet in primary glass manufactured is expected to fall.

One interviewee indicated that on average Measure 5 could lead to an 8-10% reduction in cullet generation (but did not specify whether this was for a specific sub-sector). This could be

[190] Hartwell R., Coult G., Overend M. (2022) Mapping the flat glass value-chain: a material flow analysis and energy balance of UK production. Available at: link
[191] Knauf Insulation (no date) Sustainability of our insulation products. Available at: link
[192] Saint Gogain (2022) Modernization of Europe’s Largest Glass Wool Plant. Available at: link
[193] Knauf Insulation, Frequently asked questions. Available at: link

a reduction in internal cullet generation through improved primary manufacturing efficiency, or a reduction in pre-consumer cullet generation through improved secondary manufacturing efficiency. This 8-10% reduction has been used to estimate the maximum level of efficiency for the percentage of internal glass cullet in primary glass manufacture across sub-sectors, with the method explained under each sub-sector below.

No literature data were available on the maximum level of efficiency for the percentage of glass cullet in glass manufacture, unless explicitly stated.

Container Glass

Percentage of internal glass cullet in primary container glass manufacture

The maximum efficiency level relies on insight from one interviewee who indicated that on average Measure 5 could lead to an the 8-10% reduction in cullet generation, as well as the workshop conducted.

As currently the percentage of internal cullet used in the production of container glass is 11-20% (see sections above), then an 8-10% reduction in cullet generation (of the 11-20% figure) would equate to an average of 10-18% internal glass cullet incorporated into new container glass. It is important to note the significant limitation and large uncertainty with this figure, which is based on an estimate from one interviewee. However, in the absence of further data from the literature, this was the figure taken forward to the workshops.

In the workshop, four stakeholders voted for the range 0-10% (one with medium confidence, three with low confidence), four voted for the range 11-20% (one high, two medium, one low confidence) and one did not know. One noted (with low confidence) that efficiency increases will reduce availability of internal cullet.

Based on the above evidence, the maximum level of efficiency for percentage of internal glass cullet used in the primary manufacture of container glass is estimated to be around 10-18%. The evidence RAG rating for this efficiency level is red given the lack of evidence from the literature, and the lack of consensus voting at the workshop.

Percentage of external glass cullet in primary container glass manufacture

The maximum amount of external cullet in container glass is limited by discolouration and therefore varies between container colour types. One interviewee suggested that the maximum level for flint (clear) glass would be around 40 to 60%. The interviewee indicated that 60% could be achievable but this would require some perception changes by brands and/or consumers. For green and amber glass, the same interviewee also indicated that a trial was run that produced container glass with 96% cullet (internal and external). If one were to assume that 14% of this total cullet was internal cullet (derived from the 10-18% figure given for the maximum level of efficiency for the percentage of internal glass cullet), then the proportion of external cullet would be around 82% (96%-14%). Based on the amount of container glass produced of each of these three colours (48% clear, 11% amber, 41% green[194]), this would equate to a maximum level of efficiency of ~67%.

In the workshop, four stakeholders voted for the range >40% (three with medium confidence, one with low confidence) and one did not know.

Based on the above evidence, the maximum level of efficiency for percentage of external glass cullet used in the primary manufacture of container glass is estimated to be around 65-70%. The evidence RAG rating for this efficiency level is red given the limited amount of evidence.

<u>Flat Glass</u>

Percentage of internal glass cullet in primary flat glass manufacture

The maximum efficiency level relies on insight from one interviewee who indicated that on average Measure 5 could lead to an 8-10% reduction in cullet generation, as well as the workshop conducted.

An 8-10% reduction in cullet generation (of the current internal cullet figure of 10-20%) would equate to an average of 9-18% internal glass cullet incorporated into new flat glass. It is important to note the large uncertainty with this figure. However, in the absence of further data from the literature, this was the figure taken forward to the workshops.

In the workshop, four stakeholders voted for the range 0-10% (one with medium confidence, three with low confidence) and six voted for the range 11-20% (two high, three medium, one low confidence). One noted (with low confidence) that increased efficiency will reduce availability of internal cullet. Another noted that the flat glass sector does not want to increase internal cullet since this equates to poor yield.

Based on the above evidence, the maximum level of efficiency for percentage of internal glass cullet used in the primary manufacture of flat glass is estimated to more likely be slightly lower than the current level of efficiency of 10-20%, resulting in a range of 9-18%. The evidence RAG rating for this efficiency level is red given the lack of evidence from the literature, and the fact it is based on an estimate from one interviewee and subsequent voting at the workshop.

Percentage of external glass cullet in primary flat glass manufacture

One manufacturer interviewed stated that the maximum level of efficiency for the percentage of external glass cullet in flat glass was likely to be 40-50%.

In the workshop, two stakeholders voted for the range 20-30% (both with medium confidence) and four voted for the range >30% (all with medium confidence). One specified that up to 90% could be used if good quality external cullet was available.

Based on the above evidence, the maximum level of efficiency for percentage of external glass cullet used in the primary manufacture of flat glass is therefore estimated to be around 40-

[194] WRAP (2019) Glass Flow 2025 WRAP Final Report. Available at: link

50%. The evidence RAG rating for this efficiency level is red given the lack of evidence from the literature, and the fact it relies on insight from one interviewee and the workshop voting.

Glass Wool

Percentage of internal glass cullet in primary glass wool manufacture

As with container and flat glass, the maximum efficiency level relies on insight from one interviewee who indicated that on average Measure 5 could lead to an the 8-10% reduction in cullet generation, as well as the workshop conducted.

In the workshop, four stakeholders voted for the range 0-10% (two with medium confidence, two with low confidence) and one did not know.

There is no evidence to suggest whether the maximum level of efficiency would be higher or lower than the current level of efficiency. Based on this, the maximum level of efficiency for the percentage of internal glass cullet used in the primary manufacture of glass wool is therefore estimated to be 0-10%. The evidence RAG rating for this efficiency level is red given the limited amount of evidence.

Percentage of external glass cullet in primary glass wool manufacture

The literature suggested that up to 80%[195, 196] total cullet is currently incorporated into the manufacture of glass wool, but did not specify the proportion that was internal and external cullet. One interviewee stated that, at 80% overall cullet use, the glass wool sub-sector was already at its maximum for the percentage of external cullet in primary glass manufacture, and that the remaining ingredients were required to form the glass wool and therefore could not be replaced with additional cullet.

In the workshop, four stakeholders voted for the range >80% (all with medium confidence). One specified that theoretically the level could be very high, but that the lifespan of wool products is very long, so having the quantities (to recycle back into the process as external cullet) is difficult. It is important to note, however, that though this limits the amount of glass wool that can be recycled back as external cullet into glass wool, cullet from other product types like container and flat glass, could still be used.

Based on the above evidence, the maximum level of efficiency for percentage of external glass cullet used in the primary manufacture of glass wool is therefore estimated to be above 80%. The evidence RAG rating for this efficiency level is red-amber given that there is some but limited evidence from the literature, as well as insight from stakeholders.

[195] Knauf Insulation (no date) Sustainability of our insulation products. Available at: link
[196] Saint Gogain (2022) Modernization of Europe's Largest Glass Wool Plant. Available at: link

4.4.3 Business-as-usual in 2035

No literature data were available to estimate BAU efficiency levels. Instead, the BAU efficiency levels given below rely on insight from the interviews and the workshop conducted.

<u>Container Glass</u>

Percentage of internal glass cullet in primary container glass manufacture

The voting ranges used for the workshop were based on the provisional current and maximum levels of efficiency.

In the workshop, four stakeholders voted for the range 0-10% (one with medium confidence, three with low confidence), five voted for the range 11-20% (one high, three medium, one low confidence) and one did not know. Of those who voted for the range 0-10%, one noted (with low confidence) that in theory internal cullet use should decrease and another argued (with low confidence) that ideally availability would reduce as efficiency is optimised. One stakeholder who voted (with medium confidence) for the 11-20% range said that there was potential for changes and small increases due to lower quality, but that sustainable raw materials could be introduced in the future. Another commented post-workshop that as glass production efficiency improves with technology, the level of internal cullet will reduce, but it is impossible to state what this reduction will be in 2035.

Based on the above evidence, the BAU level of efficiency for the percentage of internal glass cullet used in the primary manufacture of container glass is estimated to be around 10-19%. This range sits in between the current and maximum levels, but the difference is minimal. The evidence RAG rating for this efficiency level is red. This is an approximate estimate based on sector insight rather than quantitative evidence, and therefore the estimate must be taken with a high degree of caution and uncertainty.

Percentage of external glass cullet in primary container glass manufacture

For container glass, one interviewee suggested that the BAU level of efficiency will be close to the maximum level of efficiency.

The voting ranges used for the workshop were based on the provisional current and maximum levels of efficiency. In the workshop, five stakeholders voted for the range >40% (one with high confidence, three with medium confidence and one with low confidence) and one did not know. One specified (with low confidence) that the level would be 50%. One stakeholder post-workshop commented that both the BAU and maximum levels will be dependent on the colour split of UK production and the colour split of what is placed on the market in the UK. They went on to say that the UK currently manufactures more clear glass than is placed on the market in the UK, due to the export of spirit bottles that are predominantly clear glass. Additionally, the UK has sufficient green cullet to achieve maximum cullet levels.

Despite one stakeholder interviewed suggesting that the BAU level of efficiency will be close to the maximum level of efficiency (which has been estimated as 65-70%), in the workshop one participant specified the level would be around 50%. Additionally, there is still the significant barriers of the risk of contamination, and the impact on composition quality and container glass colour, that need to be overcome. Based on the above evidence, the BAU level of efficiency for the percentage of external glass cullet used in the primary manufacture of container glass is therefore estimated to be around 50-65%, which sits in between the current and maximum levels of efficiency. The evidence RAG rating for this efficiency level is red, given the lack of literature evidence.

Flat Glass

Percentage of internal glass cullet in primary flat glass manufacture

The voting ranges used for the workshop were based on the provisional current and maximum levels of efficiency.

In the workshop, two stakeholders voted for the range 0-10% (both with low confidence) and five voted for the range 11-20% (two high, two medium, one low confidence).

Based on the above evidence, the BAU level of efficiency for percentage of internal glass cullet used in the primary manufacture of flat glass is therefore estimated to be around 9-19%. This range sits in between the current and maximum levels, but the difference is minimal. The evidence RAG rating for this efficiency level is red. This is an approximate estimate based on sector insight rather than quantitative evidence, and therefore the estimate must be taken with a high degree of caution and uncertainty.

Percentage of external glass cullet in primary flat glass manufacture

For flat glass, one interviewee estimated that the BAU level of efficiency was likely to be 40%.

In the workshop, three stakeholders voted for the range 20-30% (all with medium confidence) and two for the range >30% (both with medium confidence).

Based on the above evidence, the BAU level of efficiency for the percentage of external glass cullet used in the primary manufacture of flat glass is therefore estimated to be around 30-40%. The sector insight points to it being below the maximum level but higher than the current level. The range therefore sits in between the current and maximum levels. The evidence RAG rating for this efficiency level is red, given the limited amount of evidence.

Glass Wool

Percentage of internal glass cullet in primary glass wool manufacture

The voting ranges used for the workshop were based on the provisional current and maximum levels of efficiency.

In the workshop, four stakeholders voted for the range 0-10% (two with medium confidence, two with low confidence) and one did not know.

There is no evidence to suggest whether the BAU level of efficiency would be higher or lower than the current level of efficiency. Based on this, the BAU level of efficiency for the percentage of internal glass cullet used in the primary manufacture of glass wool is therefore estimated to be around 0-10%. The evidence RAG rating for this efficiency level is red, given the limited amount of evidence.

Percentage of external glass cullet in primary glass wool manufacture

The voting ranges used for the workshop were based on the provisional current and maximum levels of efficiency.

In the workshop, four stakeholders voted for the range >80% (all with medium confidence).

Based on the above evidence, the BAU level of efficiency for the percentage of external glass cullet used in the primary manufacture of glass wool is therefore estimated to be above 80%. The evidence RAG rating for this efficiency level is red, given the lack of literature evidence.

5.0 Measure 5 – Implement efficient manufacturing and installation processes

5.1 Glass resource efficiency measure

5.1.1 Description

Improve manufacturing and installation processes to reduce glass waste generated.

This measure refers to the implementation of efficient manufacturing and installation processes in order to reduce the amount of glass waste that is generated during these processes. This glass waste, such as offcuts, rejects and damaged glass can typically be recycled back into production as seen in Measure 4. Whilst Measure 4 seeks to maximise the amount of glass waste that is reincorporated back into manufacture (thereby no longer making it waste), Measure 5 seeks to minimise the amount of waste that is generated in the first place, since reprocessing these wastes still has associated economic, time and energy costs. Implementing efficient manufacturing and installation processes should help to both maximise glass yield and minimise the amount of waste generated, thereby reducing the amount of internal and pre-consumer cullet available to be recycled in Measure 4. This important interdependency between Measures 4 and 5 is detailed further in Section 9.0 Interdependencies.

This measure is best understood if split into two distinct stages:

1. Primary manufacture waste

Improving efficiency and practices in the primary manufacturing process will reduce the amount of 'process' waste generated and therefore minimise the amount of internal cullet generated, as well as other wastes. Example of primary manufacturing waste include:

- Container glass: rejects from the forming and quality control stages, dusts produced during processing;
- Flat glass: trims, rejects and damaged glass from the production process; or
- Glass wool: waste wool created during product changeovers, line stoppages or out-of-specification products.

2. Secondary manufacture waste

Improving efficiency and practices in the installation or secondary (downstream) manufacturing process to reduce other 'pre-consumer' waste. This refers to improving the efficiencies of secondary processing by customers of the primary glass producers. Examples of secondary manufacturing wastes include:

- Container glass: breakages that occur at the packing and/or filling stage, or where the already manufactured glass container is filled with the product to be sold.

- Flat glass: breakages that occur in construction or assembly, for example in producing double glazing, or breakage occurring in fitting or installation of window frames, or in the case of the automotive sector, when they are fitted to vehicles.
- Glass wool: Not applicable. Glass wool mats come in standard sizes. Any small offcuts of insulation are typically installed in voids.

Table 18 shows which of the four glass products in scope of this project are applicable to this measure.

Table 18: List of sub-sectors applicable to measure 5

Container Glass	Flat Glass - Construction	Flat Glass - Automotive	Glass Wool
Applicable	Applicable	Applicable	Applicable (primary production only)

5.1.2 Measure indicator

The two indicators selected to measure reduction of waste generated were:

- **Indicator 5a:** '**Percentage reduction in waste generated per tonne of glass output during primary manufacturing, relative to current (2023) levels**'.
- **Indicator 5b:** '**Percentage reduction in waste generated per tonne of glass output during secondary manufacturing, filling (container glass) and installation (flat glass), relative to current (2023) levels**'.

This is focused on increasing material yield, with waste seen as anything that is not used in the sold or installed product. Existing reductions in waste generation have been achieved as manufacturing, filling and installation processes have become more efficient over time.

As the indicator for this measure is a percentage reduction, relative to current levels, the current level of efficiency serves as a baseline for subsequent scenarios.

5.1.3 Examples in practice

The literature review identified only a small number of examples that provided details on the measures taken to reduce waste generation in glass manufacturing, the literature evidence typically focusing on the recycling of internal cullet (Measure 4). A characteristic of the glass industry is that most of the activities produce relatively low levels of solid waste. Most of the processes do not have significant inherent byproduct streams.[197] The process residues consist

[197] European Protection Agency (2008) BAT Guidance Note on Best Available Techniques for the Manufacture of Glass including Glass Fibre. Available at: link

of unused raw materials and waste glass that has not been converted into the product.[198] The interviews were used to supplement the available literature where possible.

Improving process efficiency

A number of manufacturing interviewees commented on the continuous nature of float glass production (raw materials are continually fed into the furnace) and large batch runs between product change over. This typically reduces wastes when compared to smaller more frequent batch run type manufacturing.

The Best Available Techniques (BAT) reference document for the manufacture of glass[199] identifies the best techniques used to control the main process residues encountered in the glass industry. This focuses on reducing waste batch material, through material storage techniques and avoiding dust and windborne losses of fine raw materials, and volatile materials. For example, where materials are transported by above ground conveyors the use of enclosures can prevent material loss.

Digitalisation

Several stakeholders during the interviews described how increasing automation and the deployment of AI, machine learning and improved gathering of real-time production data may drive improved process efficiency and quality control in glass production, and therefore reduce the amount of waste generated.

Continuous improvement

Several stakeholder stated that the implementation of process improvement measures within the glass sector had been occurring for many years and that further gains through these types of measures could be limited due to the historic investments already been made. One container glass manufacturer however was of the opinion that the container glass sector could make further gains.

Some specific examples in practice include:

Container Glass

Encirc, a glass container manufacturer, built an Industry 4.0 ready glass production line with technology digitally linking the hot end (bottle production) to the cold end (inspection/quality assurance).[200] In-built intelligent swabbing, laser identification marking and state-of-the-art inspection machines, were fully integrated to work alongside human operators, improving line efficiency. By improving data gathering and automated learning, variations in temperature and conditions are detected faster. This allows contingencies to be put into place to reduce the

[198] European Protection Agency (2008) BAT Guidance Note on Best Available Techniques for the Manufacture of Glass including Glass Fibre. Available at: link

[199] Joint Research Centre, Institute for Prospective Technological Studies, Sissa, A., Delgado Sancho, L., Roudier, S. et al. (2013) Best available techniques (BAT) reference document for the manufacture of glass – Industrial emissions Directive 2010/75/EU: integrated pollution prevention and control. Available at: link

[200] Zenoot (no date) Encirc to invest in Industry 4.0-ready glass production line. Available at: Link.

impact on the production line and any negative impacts, such as waste created due to products not passing quality checks.

Flat Glass

Abc Glass Processing have invested in sophisticated flat glass cutting machines. These assess the planned production run and calculate the most efficient use of glass by digitally laying out separate glass orders across each 4-metre sheet of glass. This maximises the amount of glass used on every sheet, minimising offcut waste.[201] Jotika provide software solutions to the glass manufacturing sector to reduce waste and maximise output. Optimiser X is an optimisation module that helps glass manufacturers find the balance between achieving a good optimising yield with minimised waste and limited disruption to workflow, maximising the utilisation of raw materials and helping to reduce rejects and offcut waste.[202]

One of the most common causes of waste in window installation is inaccurate measurements, leading to the ordering of the wrong size of window.[203] Precise measurement systems and procedures for double checking measurements and that these are correctly added to orders are therefore important in addressing this.

5.2 Available sources

5.2.1 Literature review

The literature review identified six sources that discussed this resource efficiency measure (either in terms of providing evidence on levels of efficiency, or by providing commentary on drivers and barriers). These comprised:

- One industry report;[204]
- One technical report;[205] and
- Four websites.[206] [207] [208] [209]

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 3.8 7 (out of 5). One of the sources scored 5 and three scored 4. Four of the sources were from 2019 or later, and five of the sources were UK-specific. Though the literature available on this

201 abc Glass Processing Ltd (2021) How We've Reduced Glass Waste by Investing in Technology. Available at: Link
202 Jokita (no date). Glass Optimisation. Available at: link
203 Kingswood Trade Frames (2023) How to minimise waste when installing windows. Available at: Link.
204 Glass and Glazing Federation (2000). Cost savings from reducing waste in the glass and glazing industry. Available at: link
205 Institute for Prospective Technological Studies (Joint Research Centre) (2013). Best Available Techniques (BAT) Reference Document for the Manufacture of Glass. Available at: link
206 Abc Glass Processing (2021) How We've Reduced Glass Waste by Investing in Technology. Available at: link.
207 Kingswood Trade Frames (2023) How to minimise waste when installing windows. Available at: link.
208 UKRI (2020). UKRI invests £15m in the future of glass production. Available at: link.
209 Zenoot (2019) Encirc to invest in Industry 4.0-ready glass production line. Available at: link

measure was limited, the literature that was available was deemed to be highly applicable to the UK. There was only one data point on the current level of efficiency and no data points on future levels of efficiency (BAU or maximum technical).

5.2.2 Interviews

This measure was engaged with by five stakeholders during interviews. The stakeholders differed in opinion on whether progress was needed in manufacturing efficiency; some suggested that there was little room for improvement and that the impact of recycling process cullet was not enough of a problem to warrant much change. Others suggested that there was further opportunities, especially since any improvements in manufacturing would likely bring waste, energy use and costs down. These stakeholder were also encouraged by digitisation trials, stating that systems that could monitor environmental conditions and autocorrect the course of the manufacturing line would improve quality control and reduce the reject level of manufactured glass.

5.2.3 Workshop

Seven stakeholders across the industry were active on the mural board and four stakeholders contributed to the discussion verbally. Barriers for this measure were discussed by a number of stakeholders. One manufacturer stated that a number of factors affect the efficiency of glass production, including the impacts of changing product specification which means a not-insignificant amount of product must be discarded, for example between colour changes. Another example was that ‘on-line’ coating of glass produces more wastage that ‘off-line’ coated glass, impacting the overall carbon footprint of the coated glass product. Another key barrier raised was the feasibility of automating production lines to improve efficiency, since different manufacturers are likely to have proprietary software associated with it. This could hinder the connectivity between different sections of the production process.

5.3 Drivers & Barriers

The drivers and barriers influencing this measure were identified through a combination of the literature review, stakeholder interviews and sector workshop. Drivers and barriers that apply to specific applications or sub-sectors will be labelled as such.

5.3.1 Drivers

Table 19 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 19: Drivers for glass measure 5

Description	PESTLE	COM-B
Reduction in energy consumption and GHG emissions	**Environmental**	**Motivation – automatic**

Cost savings in raw materials	**Economic**	**Opportunity – physical**
Prevention of extracting natural resources through improved yield	Environmental	Opportunity – physical

Reduction in energy consumption and GHG emissions

By improving the yield of glass production processes, the energy consumption and associated GHG emissions of production per unit output/installed may be reduced, since less waste is produced and subsequently recycled through the manufacturing process. One stakeholder in interview described the progress already made in this measure as the glass industry moving from 'craft to science', and that new technologies (described in Section 5.1.3 Examples in practice) could result in many more savings for manufacturing businesses.

Cost savings in raw materials

Manufacturers are driven to reduce waste to minimise economic losses. Improved optimisation technologies and processes aim to reduce waste and improve raw material resource efficiency, which in turn reduces raw material and waste management costs for businesses. For example, reducing edge trims to a minimum width will reduce this type of waste. According to stakeholders interviewed, edge trim waste is often recycled (reprocessed) back through the manufacturing line in many facilities, and so there are labour and energy costs associated with this. Minimising glass waste reduces the financial implications of reprocessing/recycling.[210] One stakeholder suggested that even if not using the waste in their own processes, facilities could save on waste management costs if they reduce this waste. A guidance document produced by the Glass and Glazing Federation (GGF) stated that waste minimisation efforts could save as much as 1% business turnover.[211]

Prevention of extracting natural resources through improved yield

Stakeholders highlighted in interview that by reducing waste and improving yield, the amount of raw material required per unit is also reduced. This driver is relevant for both glass manufacturers who aim to reduce their process waste and may therefore reduce their spend on raw materials, and for producers of the final flat glass product, for example glazers or glass wool makers, who benefit from reduced waste per product installed. Reducing waste in this way is likely to reduce their waste management costs.

[210] Institute for Prospective Technological Studies (Joint Research Centre) (2013). Best Available Techniques (BAT) Reference Document for the Manufacture of Glass. Available at: link.
[211] Glass and Glazing Federation (2000). Cost savings from reducing waste in the glass and glazing industry. Available at: link.

5.3.2 Barriers

Table 20 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 20: Barriers for glass measure 5

Description	PESTLE	COM-B
Capital costs of introducing leaner manufacturing methods affect return on investment	**Economic**	**Opportunity – physical**
Lack of testing / industry experience in new and innovative manufacturing technologies (e.g., Industry 4.0)	**Technological**	**Capability – physical**
Lack of standardisation of window sizes leads to higher manufacturing losses in secondary manufacturing (flat glass)	**Legal**	**Capability – physical**
Connectivity of production machinery with proprietary software	Technological	Opportunity – physical
Efficiency nearly maximised	Technological	Capability – physical

Capital costs of introducing leaner manufacturing methods affect return on investment

Optimisation requires upgrade and/or development of current processes and machinery or technology. Stakeholders suggested in interview that this can require significant research investment and capital investment from manufacturers. For some manufacturers, these upfront costs could outweigh the relative process cost savings the improvements could deliver. Industry research funds provided by UK Research and Innovation (UKRI) are enabling manufacturers to test and adapt new technologies without the need to interrupt regular production,[212] however until such time as these technologies become more widely available, some manufacturers may struggle to achieve a good return on investment for new technologies.

Lack of testing / industry experience in new and innovative manufacturing technologies (e.g. Industry 4.0)

Closely related to the above cost barrier, stakeholders noted that the introduction of new and innovative manufacturing technologies, for example Industry 4.0 tech mentioned in section 5.1.3 Examples in practice) can be inhibited by uncertainty in how the new processes may perform. The aforementioned UKRI research funds have enabled some manufacturers to test

[212] UKRI (2020). UKRI invests £15m in the future of glass production. Available at: link.

new technologies.[213] Until results of trials are communicated and technologies are validated, stakeholders suggested manufacturers may not accept the risk of investing in new equipment.

Lack of standardisation of window sizes leads to higher manufacturing losses in secondary manufacturing (flat glass)

According to stakeholders in interview, there is a lack of standardisation in window sizes which means windows are often bespoke. This limits material optimisation because it leads to higher losses when cutting large glass sheets to size. One stakeholder stated that if designers and architects were willing to accept certain standard sizes of windows, significant wastage could be avoided at the window manufacturing phase.

Connectivity of production machinery with proprietary software

One stakeholder indicated in the workshop that a barrier to more efficient manufacturing processes is presented by the use of machinery from different manufacturers for different stages of the production process. It is common for each manufacturer to provide proprietary software for the operation of the machinery that acts as an operational revenue stream, whereby the manufacturer can charge for software updates and developments. With each piece of machinery operating under a different software, achieving connectivity between production sections is challenging.

Efficiency nearly maximised

In many cases, the production of glass is already considered to be highly resource and energy efficient due to the longstanding economic drivers to develop efficient processes. One manufacturer stated that the primary glass manufacturing sector had undertaken a lot of work in this area and that there was minimal room for further improvement. As a result it may be difficult to make further improvements from a technical perspective unless a fundamental change in processing practices were to a occur.

5.4 Levels of efficiency

Statement on evidence strength for maximum and BAU levels of efficiency

The literature review was unable to identify data to estimate levels of efficiency and estimates have been based solely on stakeholder input, which in some cases was relatively limited. There is a need for further research to identify better estimates for these levels, particular for secondary manufacturing.

The current level of efficiency (the baseline) is taken to be zero, so will not include any historic waste reductions that have occurred before the baseline year, 2023. The BAU and maximum level of efficiencies are represented as a further % reduction in waste from the baseline based on prediction of the future improvements in process efficiencies. This does not represent a lack

[213] UKRI (2020). UKRI invests £15m in the future of glass production. Available at: link

of current industry action, as previously discussed many stakeholders indicated that much of the industry has taken significant action to improve manufacturing efficiency.

Table 21: Levels of efficiency for glass measure 5

Indicator 5a: Percentage reduction in waste generated per tonne of glass output during primary manufacturing, relative to current (2023) levels*			
Level of efficiency	Current	Maximum in 2035	Business-as-usual in 2035
Value	CG: 0% FG (construction): 0% GW: 0%	CG: 5-10% FG (construction): 2-5% GW: 5-10%	CG: 0-5% FG (construction): 0-5% GW: 0-2%
Evidence RAG	Not applicable	Red	Red

**CG = Container Glass; FG = Flat Glass; GW = Glass Wool*

Indicator 5b: Percentage reduction in waste generated per tonne of glass output during secondary manufacturing, filling (container glass) and installation (flat glass), relative to current (2023) levels*			
Level of efficiency	Current	Maximum in 2035	Business-as-usual in 2035
Value	CG: 0% FG (construction): 0% FG (automotive): 0% GW: Not applicable	CG: Not available FG (construction): Not available FG (automotive): Not available GW: Not applicable	CG: Not available FG (construction): Not available FG (automotive): Not available GW: Not applicable
Evidence RAG	Not applicable	Not applicable	Not applicable

**CG = Container Glass; FG = Flat Glass; GW = Glass Wool*

5.4.1 Current level of efficiency

There was only one data point on historic levels of efficiency, with the Glass and Glazing Federation in their 2000 report stating that, at that point, glass optimisation at the cutting stage of production was 94%. However, stakeholders noted that there has been significant action to improve manufacturing efficiency as part of continuous improvement due to strong economic drivers to do so.

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.

5.4.2 Maximum level of efficiency in 2035

Stakeholders across the board, including academics and manufacturers, agreed that that there is some room for improvement for this measure. There is a desire to reduce the amount of residual waste from glass manufacturing, filling and installation.

No quantitative data from the literature review was available to estimate maximum efficiency levels for this measure. Instead, the maximum efficiency level for this measure relies on insight from the workshop conducted.

Primary manufacturing

Container Glass

For container glass, one manufacturer estimated that the introduction of Industry 4.0 technology was hoped to reduce primary bottle manufacturing waste levels by a maximum level of 8-10%. In the workshop, one stakeholder voted for the range 0-5% (with low confidence) and four voted for the range 5-10% (all with low confidence).

The maximum level of efficiency is therefore estimated to be 5-10%. This estimate has a red RAG, reflecting the lack of supporting evidence and low confidence of stakeholder input.

Construction Flat Glass

In the workshop, one stakeholder voted for the range 0-2% (with low confidence), three voted for the range 2-5% (all with low confidence), and two voted for the range >5% (but did not specify a figure). This echoes input from one stakeholder who noted that there was limited room for further improvements for flat glass manufacturing.

The maximum level of efficiency is estimated to be around 2-5. This estimate has a red RAG, reflecting the lack of supporting evidence and low confidence of stakeholder input.

Glass Wool

In the workshop, one stakeholder voted for the range 0-2% (with low confidence) and three voted for the range 5-10% (all with low confidence).

The maximum level for the percentage reduction in waste generated per tonne of glass output during primary manufacturing of glass wool, relative to current (2023) levels, is estimated to be around 5-10%. The evidence RAG rating for this efficiency level is red, reflecting the lack of supporting evidence and limited glass wool expertise by those who voted.

Secondary manufacturing

Container Glass

In the workshop, one stakeholder voted for the range 0-5% (with low confidence), one voted for the range 5-10% (with low confidence) and two did not know.

Based on the low levels of workshop voting, the maximum level of efficiency for this indicator was not estimated .

Construction Flat Glass

In the workshop, one stakeholder voted for the range 2-5% (with low confidence) and three did not know. Based on the low levels of workshop voting, the maximum level of efficiency for this indicator was not estimated.

Automotive Flat Glass

In the workshop, one stakeholder voted for the range 2-5% (with low confidence) and three did not know. Based on the low levels of workshop voting, the maximum level of efficiency for this indicator was not estimated.

5.4.3 Business-as-usual in 2035

No quantitative data from the literature review was available to estimate a BAU efficiency level for this indicator. Instead, the BAU efficiency level for this indicator relies on insight from the workshop conducted.

Primary manufacturing

Container Glass

In the workshop, five stakeholders voted for the range 0-5% (with low confidence). Based on this voting, the BAU level of efficiency is estimated to be 0-5%. Despite consensus from the workshop, the evidence RAG rating for this efficiency level is red, reflecting the lack of supporting evidence.

Construction Flat Glass

In the workshop, two stakeholders voted for the range 0-2% (with low confidence) and two voted for the range 2-5% (with low confidence). One who voted for the range >5% commented that there are transition losses due to colour and coating changes for flat glass.

Based on the workshop voting, the BAU level of efficiency is estimated to be 0-5%. The evidence RAG rating for this efficiency level is red, reflecting the lack of supporting evidence.

Glass Wool

In the workshop, three stakeholders voted for the range 0-2% (with low confidence) and one did not know. Based on this, the BAU level of efficiency is estimated to be 0-2%. The evidence RAG rating for this efficiency level is red, reflecting the lack of supporting evidence.

Secondary manufacturing

Container Glass

In the workshop, two stakeholders voted for the range 0-5% (with low confidence) and two did not know. Based on the low levels of workshop voting, the maximum level of efficiency for this indicator was not estimated.

Construction Flat Glass

In the workshop, one stakeholder voted for the range 0-2% (with low confidence) and three did not know. Based on the low levels of workshop voting, the maximum level of efficiency for this indicator was not estimated.

Automotive Flat Glass

In the workshop, one stakeholder voted for the range 0-2% (with low confidence) and three did not know. Based on the low levels of workshop voting, the maximum level of efficiency for this indicator was not estimated.

6.0 Measure 6 – Lifetime extension through repair of products

6.1 Glass resource efficiency measure

6.1.1 Description

Lifetime extension through repair of products

This measure refers to increasing the length of time a glass product can be used before being replaced with a new product, by restoring it to a good condition which enables it to be continued to be used. If a product is damaged, faulty or worn, it is often discarded and replaced with a new product. If the damage or fault with the product can instead be repaired, then the product can be used for longer, negating the need to purchase a new product.

Stakeholders noted in interviews that this measure does not apply to container glass, because once a container cracks, breaks or shatters, it is not technically repairable or else not economically viable to repair.

Multiple stakeholders within the flat glass sector, stated that this measure applies to automotive glass to a limited extent, where chips or small cracks in windscreens can be repaired by filling the area with a clear epoxy resin. Windscreens are constructed of two panes of curved glass which sandwich a layer of strong plastic that bonds them.[214] This structure is a safety feature used so that in the event of a crash, the windscreen does not shatter into dangerous shards. Small cracks usually only impact one pane of glass. Debris that hits a windscreen will likely only crack the outside pane allowing for easier repair. [215] The interviews revealed that small cracks in building windowpanes can technically be repaired however, the repair of building glazing is extremely rare. They indicated that in most cases, it is too costly, impractical or risky to repair a glass unit.

Multiple stakeholder stated during the interviews that this measure is not applicable to the glass wool sector, as once it has been damaged in the course of its functional life as building insulation (e.g. through water infiltration or fire) it is no longer functional and must be replaced.

This measure therefore only applies to automotive flat glass. It is important to note that primary manufacturing of flat glass for the automotive industry takes places overseas, with only secondary processing occurring in the UK. This means that the impacts of repair efforts are displaced and achieved in the countries that manufacture glass rather than in the UK.

Table 22 shows which of the four glass products in scope of this project are applicable to this measure.

[214] Pilkington (no date) Technology Datasheet – Shaping and Strengthening. Available at: link
[215] Metro Auto Glass (no date) Car Safety Glass Explained. Available at: link

Table 22: List of sub-sectors applicable to measure 6

Container Glass	Flat Glass – Construction	Flat Glass – Automotive	Glass Wool
Not applicable	Not applicable	Applicable	Not applicable

6.1.2 Measure indicator

The indicator chosen to estimate levels of efficiency for this measure is '**percentage reduction in new consumption through repair, relative to current (2023) levels**'.

6.1.3 Examples in practice

Windscreen chip and crack repair for automotive glass is a common service provided. Halfords, for example, offer a chipped windscreen repair service.[216] However, due to regulations, there are rules around what size chip can be repaired, as well as where on the windscreen the damage is. A chip can be repaired by injecting an epoxy or acrylic adhesive into it. This seals the chip, preventing moisture and dirt getting into it. Larger cracks, however, cannot be so easily fixed, and will need more detailed cracked windscreen repair.

6.2 Available sources

6.2.1 Literature review

The literature review identified three sources that discussed this resource efficiency measure (either in terms of providing evidence on levels of efficiency, or by providing commentary on drivers and barriers). These comprised:

- Three website articles. [217] [218] [219]

The sources exhibited an average IAS of 3.3 (out of 5), and were limited to websites indicating relatively low quality of evidence on this measure. All of the sources were UK-specific and all from 2023. Overall, the literature was extremely limited, with only three sources identified. Furthermore, the literature only discussed drivers and examples in practice, rather than levels of efficiency.

6.2.2 Interviews

This measure was engaged with by six stakeholders during interviews. There was a general consensus that this measure would not cover repair of container glass or glass wool since it

[216] Halfords (2023) Windscreen Chip Repair. Available at: link
[217] RAC (2023) How to deal with damaged windscreens. Available at: link.
[218] Halfords (2023) Windscreen Chip Repair. Available at: link.
[219] UK Government (2023) MOT inspection manual: cars and passenger vehicles. Available at: link.

would not be cost effective or even practically feasible in most cases. It was mentioned that the high cost of labour and materials, alongside mostly not being especially safe or effective to repair glass in this way, that make it undesirable to attempt.

Several stakeholders confirmed that automotive windscreen glass can be repaired but that the level of repair is unlikely to rise unless new technologies emerge that allow the safe repair of larger cracks. Currently only small cracks can be repaired as defined by MOT standards and one stakeholder remarked that anything above this would be considered a fatal weakness of the windscreen unit and not safe to repair. Another stakeholder remarked that aside from automotive glass, one area that could potentially be cost effective to repair is solar PVs.

6.2.3 Workshop

This measure had very limited engagement from stakeholders in the workshop, and no votes for barriers, drivers or levels of efficiency were received.

6.3 Drivers & Barriers

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

6.3.1 Drivers

Table 23 below shows the one driver identified for Measure 6.

Table 23: Drivers for glass measure 6

Description	PESTLE	COM-B
Cost savings – low cost of repair compared to purchasing a new replacement (automotive flat glass)	Economic	Opportunity – physical

Cost savings

The main driver for vehicle owners in repairing chips in windscreens is the low cost of repair compared to purchasing a replacement windscreen. Stakeholders agreed with this in interview, caveating that the benefit of a cost saving may not be seen directly by the customer, since damage repair is often covered under vehicle insurance.

6.3.2 Barriers

Table 24 below shows the barriers identified for Measure 6. Given its limited applicability, stakeholders did not vote for the top barriers for this measure during the workshop.

Table 24: Barriers for glass measure 6

Description	PESTLE	COM-B
Safety risk with attempting to repair fatal weaknesses in windscreens (automotive flat glass)	Technological / Legal	Capability – physical
Regulation limits size of chip/crack that can be repaired (automotive flat glass)	Legal	Capability – psychological
Energy efficiency trade-off associated with repairing an old product instead of installing a new, more energy-efficient product (construction flat glass)	Environmental / Technological	Capability – physical
Lack of suitable methods for repair (construction flat glass)	Technological	Capability – physical

Safety risk with attempting to repair fatal weaknesses in windscreens (automotive flat glass)

The literature reported that safety is of the utmost importance when considering whether to repair or replace a damaged windscreen.[220] [221] One interviewee stated that a significantly cracked windscreen equates to a fatal weakness that could compromise driver and passenger safety, and therefore attempting to repair it was not worth the risk.

Regulation limits size of chip/crack that can be repaired (automotive flat glass)

The current acceptable level of damage (e.g., size of crack/location) that can be repaired is defined by the MOT test (Ministry of Transport test).[222] If the damage is deemed too large or is located in specific points of the glass, the regulations will not allow for the unit to be repaired.

Energy efficiency trade-off associated with repairing an old product instead of installing a new, more energy-efficient product (construction flat glass)

In construction, poor energy efficiency of older glazing units necessitates the installation of new glazing units with higher energy efficiency. Any potential resource efficiency benefits from repairing old glazing units appear to be outweighed by the energy efficiency losses that would result from keeping the old glazing unit and not installing a new one.

Lack of suitable methods for repair (construction flat glass)

A stakeholder stated that construction glass can technically be repaired like automotive glass, but in practice this is done rarely. Double glazing is compromised when a pane is chipped or cracked, since gas serving as insulation between the panes escapes. One stakeholder noted that when a building window does significantly crack, there is no suitable method to repair.

[220] Halfords (no date) Windscreen Chip Repair. Available at: link
[221] RAC (no date) How to deal with damaged windscreens. Available at: link
[222] UK Government (2023) MOT inspection manual: cars and passenger vehicles. Available at: link.

6.4 Levels of efficiency

Table 25 provides a summary of the current, maximum in 2035 and business-as-usual in 2035 for this measure.

Table 25: Levels of efficiency for glass measure 6

Indicator: Percentage reduction in new consumption through repair, relative to current (2023) levels*			
Level of efficiency	Current	Maximum in 2035	Business-as-usual in 2035
Value	0%	Not Applicable	Not applicable
Evidence RAG	Not applicable	Not applicable	Not applicable

**CG = Container Glass; FG = Flat Glass; GW = Glass Wool*

A note on findings

No evidence was collected to estimate the levels of efficiency for this measure. Repair was found to only be relevant to automotive flat glass, and only appropriate for a subsection of damaged automotive glass. Stakeholders noted that windscreen repair is likely already maximised given strict rules around the size of chips that can be repaired. Additionally, only secondary processing of flat glass (involving shaping, strengthening, toughening and laminating) for the automotive industry takes places in the UK, rather than primary manufacturing. This suggests that there would be very limited potential for further gains from repair of glass products.

7.0 Measure 7 – Reuse of glass products

7.1 Glass resource efficiency measure

7.1.1 Description

The direct reuse of whole glass products, resulting in a reduction in consumption of new products and increasing a functional product's lifetime.

Once products are manufactured, a key method to increase resource efficiency is to maximise their utilisation by increasing the number of times they are used before they reach end-of-life. Identifying reuse markets for these products will minimise waste generation by avoiding the proportion of material that goes to recycling (Measure 8) or landfill, both of which are lower on the waste hierarchy. This measure is highly applicable to container glass, focusing on commercial refill (i.e. where businesses take back containers), but only has limited applicability to flat glass (construction and automotive) and glass wool.

Table 26 shows which of the four glass products in scope of this project are applicable to this measure. The reasons for why each one is applicable or not are outlined in the following sections.

Table 26: List of sub-sectors applicable to measure 7

Container Glass	Flat Glass – Construction	Flat Glass - Automotive	Glass Wool
Applicable	Limited applicability	Limited applicability	Limited applicability

7.1.2 Measure indicators

Two indicators have been selected to estimate levels of efficiency for this measure. The first (labelled indicator 7a) is the '**percentage of glass products reused**' – this measures the total percentage of different glass products reused, without considering how many times these products are reused. The second (labelled indicator 7b) is the '**average number of times a glass product is reused**' – this measures how many time a particular glass product is reused on average (i.e. the number of reuses per item).

7.1.3 Examples in practice

Container glass

The company 'Milk and More', provide products in returnable reusable glass bottles. Bottles are collected from the doorstep, sent to a micro-cleaning facility (managed by Again) to be processed before being returned for refilling. They aim to further increase reuse by sourcing more durable bottles and adjusting its machinery to reduce bottle damage.[223]

Sustainable Wine Solutions, meanwhile, offer a Bottle Return Scheme that enables their customers to return, sterilise and reuse their wine bottles.[224] In addition, breweries like BrewDog and Rebellion Beer have introduced returnable beer bottles[225] [226], whilst Miniml and Molton Brown offer refillable glass containers for personal care products, supported by a refill pouch system where the pouches are returned for reuse.[227] [228]

Flat Glass – Construction

Case studies like the renovation of the Empire State Building, Lloyd's building and One Triton Square illustrate that with tailor-made infrastructure, the disassembly, remanufacturing, and re-assembly of end-of-life insulated glazing is technically feasible, despite complex assembly.[229]

Optima manufactures glass partitions and doors and offers a reuse service that allows for previously installed Optima glass partitions and doors into their new designs, facilitated by a modular design. Optima inspect current glass and how much can be reused, before demounting and reinstalling.[230]

Flat Glass – Automotive

There are a small number of businesses, such as AV Windscreens, that offer second-hand windscreen replacement.[231] Whilst there are some businesses that advertise this service, it was not possible to estimate how common place this practise is.

Glass Wool

Whilst glass wool could technically be collected during refurbishment or demolition activity for reuse, there have been no examples found of this happening. The relatively low value of glass wool, contamination with other materials during demolition, and its high-volume low density are potential contributors to this lack of reuse.

[223] Guardian (2022) Milk & More to increase reuse of bottles by 15% as glass prices soar Article link
[224] Sustainable Wine Solutions. Available at: link
[225] Rebellion Beer (no date) Returnable 1 Litre Bottles. Article link
[226] BrewDog (no date) Waste-free Punk IPA: A new Way to Shop with Loop. Article link
[227] Miniml (no date) Closed loop system. Article link
[228] Molton Brown (no date) hand refill collection. Article link
[229] Geboes. E, Galle. W, De Temmerman. N (2022) Make or break the loop: a cross-practitioners review of glass circularity. Available at: link
[230] Optima (2022) Building sustainability through Optima Reuse Service. Available at: link
[231] AV Windscreens (no date) Second hand Glass Experts. Available at: link

7.2 Available sources

7.2.1 Literature review

The literature review identified 31 sources that discussed this resource efficiency measure (either in terms of providing evidence on levels of efficiency, or by providing commentary on drivers and barriers). These comprised:

- Four academic papers;[232] [233] [234] [235]
- Five industry reports;[236] [237] [238] [239] [240]
- Two policy documents;[241] [242]
- One technical study;[243] and
- Nineteen website articles.[244] [245] [246] [247] [248] [249] [250] [251] [252] [253] [254] [255] [256] [257] [258] [259] [260] [261] [262]

232 Amienyo et al. (2013) Life cycle environmental impacts of carbonated soft drinks. Available at: link
233 Furszyfer Del Rio, D. D., Sovacool, B. K., Foley, A. M., Griffiths, S., Bazilian, M., Kim, J., & Rooney, D. (2022) Decarbonizing the glass industry: A critical and systematic review of developments, sociotechnical systems and policy options. Available at: link
234 Geboes E., Galle W., De Temmerman N. (2022) Make or break the loop: a cross-practitioners review of glass circularity. Available at: link
235 Stefanini et al. (2021) Plastic or glass: a new environmental assessment with a marine litter indicator for the comparison of pasteurized milk bottles. Available at: link
236 Serac (2021) The practical case of organic dairy products in glass bottles and jars. Available at: link
237 Verallia (2023) Reimagining reuse for the circular economy of glass: Stakeholder Perspectives Series. Available at: link
238 Zero Waste Europe and Eunomia (2022) How circular is glass. Available at: link
239 Zero Waste Europe, University of Utrecht, Reloop (2020) Reusable vs Single-use packaging. Available at: link
240 Zero Waste Europe (2022) Making Europe transition to reusable packaging. Available at: link
241 European Parliament (2023) Revision of the Packaging and Packaging Waste Directive. Available at: link
242 UK Government (2023) The Future Homes and Buildings Standards: 2023 consultation. Available at: link.
243 European Commission (1998) Reuse Packaging in Sweden. Available at: link
244 Again (2023) Again: Clean Cells. Available at: link
245 BrewDog (2023) Waste-free Punk IPA: A new Way to Shop with Loop. Available at: link
246 FEVE The European Container Glass Federation (2022) The EU Packaging and Packaging Waste Regulation (PPWR): How glass can support the EU's circular economy ambition. Available at: link
247 Float Mylk (2023) Float Mylk. Available at: link
248 Mc'Nean (2020) Packaging: the truth about glass. Available at: link
249 McKinsey & Company (2022) The next S-curve of growth: Online grocery to 2030. Available at: link
250 Miniml (2023) Closed loop system. Available at: link
251 Molton Brown (2023) Hand refill collection. Available at: link
252 Optima (2022) Building sustainability through Optima Reuse Service. Available at: link
253 Packaging News (2015) Glass bottles: recycling and reuse in the UK | Matthew Kensall. Available at: link
254 Rebellion Beer (2023) Returnable 1 Litre Bottles. Available at: link
255 Somm TV Magazine (2022) These Reusable Glass Bottle Programs Help Solidify a Circular Eco-Solution. Available at: link
256 Sustainable Wine Solutions (2022) Zero Waste Solutions. Available at: link
257 The Guardian (2023) Milk & More to increase reuse of bottles by 15% as glass prices soar. Available at: link
258 Tom Parker Creamery (2023) Our glass bottles are now returnable. Available at: link
259 Upstream (2023) Beverage Refill & The New Reuse Economy. Available at: link
260 UUWD (2023) Supplying you with affordable second-hand windows and doors. Available at: link
261 Zero Waste Europe (2022) Reuse before recycling - ensuring true circularity in beverage packaging. Available at: link
262 Zero Waste Europe (2021) Creating Effective Systes for Reuse. Available at: link

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 3.7 (out of 5), with all sources except for one exhibiting a score of 3 or above. Half (15) of the sources were UK-specific, and 27 of the 30 sources are from 2020 onwards.

7.2.2 Interviews

Eight of the stakeholders interviewed provided input on the reuse of glass products for the different glass applications, depending on their area of expertise. Overall, interviewees believed this measure had lots of potential in the container glass sub-sector but had limited applicability elsewhere in the other sub-sectors. It was argued that an increase in consumer demand for reusable products should drive this measure, and this would particularly be the case for high-end applications. It was noted that this measure would have limited applicability to construction flat glass due to strict building regulations and potential impact of reuse on window integrity. It was noted that there could be industry pushback for reuse as this could lead to a loss in revenue as fewer units manufactured would be sold.

7.2.3 Workshop

Seven stakeholders across the industry were active on the mural board and four stakeholders contributed to the discussion verbally. Stakeholders in the workshop discussed the fact that brand owners, retailers or policy makers were most likely to drive reuse of glass, rather than glass manufacturers who must make products to their customer specifications. One stakeholder suggested that a standardisation of sizing could encourage reuse in the window industry. Without a standardisation of sizing so windows could be refurbished and refitted easily, the likely cost of deconstructing and recutting would be prohibitive to reuse.

7.3 Drivers & Barriers

The drivers and barriers influencing this measure were identified through a combination of the literature review, stakeholder interviews and sector workshop. Drivers and barriers that apply to specific applications or subsectors will be noted in brackets.

7.3.1 Drivers

Table 27 below shows the main drivers for Measure 7. The most significant drivers are shown in bold as voted for by stakeholders in the workshop.

Table 27: Drivers for glass measure 7

Description	PESTLE	COM-B
Perceived environmental benefits of reuse drive consumer behaviour	**Environmental / Social**	**Motivation – reflective**

Potential to incorporate reuse into grocery deliveries providing convenience to households (container glass)	Social	Opportunity – social
Potential cost savings associated with reusing a second-hand windscreen rather than purchasing a new one (automotive flat glass)	Economic	Opportunity – physical
Reuse regulations (container glass)	Legal / Political	Opportunity – physical

Perceived environmental benefits of reuse drive consumer behaviour

Stakeholders suggested in interview that the perceived environmental benefit of reusable packaging compared with single-use packaging means environmentally-minded consumers may choose products that use reusable glass. According to stakeholders, some brands have recognised this and have started planning for a future where reuse of glass forms part of their product offering.

Assessing the environmental impact of different materials requires robust LCA analysis. The literature reviewed suggests that there is significant potential to achieve environmental benefits such as GHG emissions reductions by reusing glass products. One LCA found that if a glass bottle is reused once rather than being recycled, the whole-life emissions associated with the bottle drops by 40% however gains level off after the eight reuse due to emissions associated with transport and washing.[263] Another study on reuse schemes in some European countries found that a returnable glass bottle reused 3 times has the equivalent emissions footprint of a single-use aluminium can, and with 30 reuses the footprint is similar to a single-use PET bottle. Whether 30 reuses are achievable is questionable. Furthermore a glass bottle reused 30 times still performs worse than a single-use PET bottle in categories such as ozone depletion or toxicity to humans but does have a lower impact on marine pollution.[264]

In general, LCAs that assess the comparative impact of certain packaging materials or systems are highly specific to the chosen scenarios of study and more widely applicable conclusions cannot be drawn from single studies. In the literature assessed as part of this research, reusable glass appears to have a significantly reduced emissions footprint when compared to single-use glass, but it is inconclusive whether reusable glass offers an improved environmental performance when compared with other materials. Nevertheless, the perceived benefit to consumers could drive change in habits from single-use glass to reusable glass that, in turn, results in a net reduction in production of glass.

Potential to incorporate reuse into grocery deliveries providing convenience to households (container glass)

[263] Amienyo et al. (2013) Life cycle environmental impacts of carbonated soft drinks. Available at: link
[264] Stefanini et al. (2021) Plastic or glass: a new environmental assessment with a marine litter indicator for the comparison of pasteurized milk bottles. Available at: link

Online grocery deliveries increased significantly in the UK during the COVID-19 pandemic and are expected to continue to be in demand into the future.[265] Reuse systems could take advantage of this to facilitate the easy return of reusable packaging. Packaging delivered by the retailer could be used by the consumer and collected by the retailer in subsequent deliveries. Such a system would reduce or eliminate the inconvenience of returning packaging to collection points and ensure reusable packaging gets returned and is available for reuse.

Potential cost savings associated with reusing a second-hand windscreen rather than purchasing a new one (automotive flat glass)

One stakeholder stated that if vehicles at end-of-life were dismantled considerately, second-hand windscreens should be suitable for reuse and could offer a significant cost saving when compared with replacing damaged windscreens with brand-new ones. The stakeholder suggested that cost alone could be a driver for increased reuse of windscreens, with the benefit realised by individual customers or insurance companies, depending on where responsibility of replacement lies. However, further research would be required to understand the costs associated with reuse that could outweigh the savings of using a second-hand windscreen.

Reuse regulations (container glass)

One stakeholder noted that incoming regulation on the reuse of packaging material via the European Council's Packaging and Packaging Waste Regulation (PPWR) could impact the reuse of glass packaging in the UK.[266] The impact of a mandated level of reuse in the EU on the UK requires further research, and whether the UK Government would adopt similar reuse targets is yet to be seen.

7.3.2 Barriers

Table 28 below shows the main barriers for Measure 7. The most significant barriers are shown in bold as voted for by stakeholders in the workshop.

Table 28: Barriers for glass measure 7

Description	PESTLE	COM-B
Complex collection, cleaning, redistribution and refilling infrastructure required, and additional cost associated (container glass)	**Technological / Economic**	**Capability – physical**
Quality of secondary flat glass (flat glass)	**Technological**	**Capability – physical**

[265] McKinsey & Company (2022) The next S-curve of growth: Online grocery to 2030. Available at: link
[266] FEVE The European Container Glass Federation (No date) The EU Packaging and Packaging Waste Regulation (PPWR): How glass can support the EU's circular economy ambition. Available at: link

Difference in energy efficiency between old and new building glazing (construction flat glass)	**Technological**	**Opportunity – physical**
Lack of agency within glass sector	**Political**	**Opportunity – social**
Lack of standardisation of window dimensions (construction flat glass)	**Technological**	**Capability – psychological**
Reuse systems will generate lower revenue for glass manufacturers (container glass)	Economic	Motivation – automatic
Lack of product passports (flat glass)	Legal	Capability – psychological
Collection for reuse not financially viable (glass wool)	Economic	Opportunity – physical
Thicker glass containers required leading to higher costs (container glass)	Economic	Opportunity – physical

Complex collection, cleaning, redistribution and refilling infrastructure required, and additional cost associated (container glass)

Stakeholders argued that to drive an increase in the reuse of glass containers, new collection, cleaning, refilling and redistribution infrastructure is needed to support this. If the industry would like to see a growth in reuse systems for fresh products like milk and juice, the infrastructure to support this simply does not exist and implementation would be challenging enough to deter investment in such a system. Another stakeholder agreed that the logistics of such a system are a barrier and that only widescale implementation of, for example, a deposit return scheme could facilitate reuse.

Currently the heterogeneity of glass bottles shapes and sizes presents a barrier to reuse systems. This heterogeneity means bottles always need to be returned to one specific bottler, generating further transport distances than a pool system. A stakeholder suggested that for glass packaging to stand as an effective refillable option, it would be necessary to move towards a pool system with a limited number of design options to optimise logistical flows.[267] Such a system would require collaboration across the supply chain.

Stakeholders raised a concern that the costs of a reuse system would place particular pressure on those responsible for the end-of-life management of container glass, and overcoming this barrier would require commitment across the full supply chain. The stakeholders also agreed that without enforced targets for the use of refillable packaging, even with the introduction of an extended producer responsibility (EPR) scheme that places the financial responsibility of end-

[267] Zero Waste Europe and Eunomia (2022) How circular is glass?. Available at: link

of-life treatment of packaging on the producer, the barriers to increasing reuse in the container glass sector are prohibitive.

Quality of secondary flat glass (flat glass)

For flat glass products to be suitable for reuse, they need to meet minimum quality standards. At end of life, flat glass products may be damaged or contaminated. A stakeholder gave an example of this, stating that coatings on glazing units can deteriorate or oxidise over time, and technology does not currently exist to restore such coatings. According to the stakeholder, the glazing unit cannot be reused due to poor quality. Additionally toughened safety glass (which is extensively used) cannot be cut to size. No viable option for reuse limits the proportion of end-of-life glass that is suitable for reuse.

Difference in energy efficiency between old and new building glazing (construction glass)

Older glazing units have lower energy efficiency performances than newer units. Over time, building regulations have become progressively tighter on energy efficiency requirements, meaning mandated U-values cannot be met with older glazing units. [268] In these cases, older units must be replaced with new units with lower U-values, i.e., better energy efficiency ratings. One stakeholder suggested in interview that the average lifetime of a glazing unit currently stands at 15-18 years. After this period, the unit is likely to be inefficient enough to warrant replacement with newer glazing units with lower U-values. Nevertheless, in a future scenario where older units have been replaced and U-values have achieved the maximum level of efficiency (as described in Section 7.3.1 Drivers), other limiting factors must be considered. One such factor is the lack of available technology to ‘re-gas’ glazing units, that is, to reinsulate the airspace between panes of glass in a unit so that they are effective insulators. Sealant is another limiting factor for a glazing product’s lifetime, with organic sealant having a lifetime of 25-30 years before it is likely that moisture can enter the unit and diminish its effectiveness as an insulator.

Lack of agency within glass sector

Several stakeholders raised that the glass sector cannot drive increased reuse, since the agency lies with brand owners to respond to consumer and/or policy pressure to change. Stakeholders suggested in the workshop that for container glass, policy could drive this change, for example, via EU targets being proposed for reuse of packaging.

Lack of standardisation of window dimensions (construction flat glass)

In the workshop, a stakeholder suggested that lack of standardisation of glass windowpanes during design presents a barrier to reuse of flat glass at its end of use. If window sizes were standardised, a viable market for second-hand window units may emerge. As it stands for the majority of cases, to reuse window glass would mean disassembling a unit, removing strong adhesives and cleaning the panes, resizing panes and finally refitting into new units at the

[268] Geboes. E et al (2022) Make or break the loop: a cross-practitioners review of glass circularity. Available at: link

target size. The labour, time and economic costs of this additional processing, as well as the production of cutting wastes, makes reuse unviable. If window sizes were standardised, the potential for reuse increases.

Reuse systems will generate lower revenue for glass manufacturers (container glass)

Stakeholders noted that glass manufacturers could object to a reuse system as it would generate less revenue for their businesses. In theory, a glass bottle reused ten times means nine fewer bottles produced and an equivalent loss in revenue for the manufacturer. A glass manufacturer agreed explicitly with this point in the workshop. One stakeholder suggested that to mitigate this barrier, a financial mechanism may be required to address the lost revenue associated with reuse.

Lack of product passports (flat glass)

One stakeholder raised that in general, the UK construction industry does not currently make consistent digital records of building materials and products during construction. This creates a challenge when identifying products and materials at deconstruction or deinstallation. They suggested that a digital identifier in a glazing unit could help installers to know the performance specification, age and composition of a glazing unit and allow them to assess whether the unit would be suitable for reuse. Even so, using and maintaining such a digital marker or ‘product passport’ would come with its own challenges. The marker would have to be linked to a product database which would require regular monitoring and updating, and data sharing and collaboration amongst stakeholders. In addition, the concept of a barcode or digital trail for a unit would rely heavily on the final stakeholder in the supply chain (likely the installer) ensuring this label is accurate upon reinstallation.

Collection for reuse not financially viable (glass wool)

Issues such as relatively low value of glass wool, contamination with other materials during demolition, and its high-volume low density are potential contributors to its lack of reuse.

Thicker glass containers required leading to higher costs (container glass)

One stakeholder outlined that to increase reuse and recirculation of glass bottles and containers, these bottles and containers would likely require thicker glass walls and coatings, to extend their lifetime. This would require more glass to produce them individually but may reduce overall material consumption if high levels of reuse are achieved. This increased weight presents a trade-off with resource efficiency Measure 1 (lightweighting).

7.4 Levels of efficiency

7.4.1 Indicator 7a: Percentage of glass products reused

Table 29 provides a summary of the current, maximum in 2035 and business-as-usual in 2035 for indicator 7a of this measure.

Table 29: Levels of efficiency for glass measure 7, indicator 7a

Indicator 7a: Percentage of glass products reused*			
Level of efficiency	Current	Maximum in 2035	Business-as-usual in 2035
Value	CG: 0-1% FG (construction): 0-1% FG (automotive): 0-1% GW: 0-1%	CG: 40-80% FG (construction): ~2% FG (automotive): 1-2% GW: 0-10%	CG: 10-20% FG (construction): 0-1% FG (automotive): 0-1% GW: 0-10%
Evidence RAG	Red-Amber	Red	Red

**CG = Container Glass; FG = Flat Glass; GW = Glass Wool*

7.4.1.1 Current level of efficiency

Container Glass

No literature data were available to estimate a current efficiency level for this indicator. Instead, the current efficiency level for this indicator relies on insight from the interviews and the workshop conducted.

One interviewee indicated that currently for container glass, the percentage of glass containers reused was ‘a fraction of a percent’. From this, the estimate of 0.1% has been derived, which was used as the basis for the voting ranges presented in the workshop.

In the workshop, five stakeholders voted for the range 0-1% (four with high confidence, one with medium confidence), and none voted the range 1-3% nor the range >3%.

Based on the above evidence, the current level of efficiency for the percentage of container glass products reused is estimated to be 0-1%. The evidence RAG rating for this efficiency level is red-amber, reflecting the lack of supporting literature evidence but relative consensus in workshop voting.

Construction Flat Glass

No literature data were available on current levels of reuse of construction flat glass and therefore no data was available to estimate a current efficiency level for this indicator. Instead, the current efficiency level for this indicator relies on insight from the interviews and the workshop conducted.

One interviewee indicated that for flat glass for construction, there was a very small level of reuse – mostly some domestic DIY reuse of household glazing. From this, the estimate of less than 1% has been derived. This <1% estimate was used as the basis for the voting ranges presented in the workshop.

In the workshop, five stakeholders voted for the range 0-1% (all with high confidence), and none voted the range 1-5% nor the range >5%. One trade association commented post-workshop that there is no evidence for reuse in construction. The stakeholder noted that it is not possible to cut toughened safety glass, and it is difficult to cut laminated safety glass. Building regulations would also not permit the reuse of glass with a high U-value, and it was probably not cost effective to remove the nano surface coating that provides the thermal properties and recoat. Another stakeholder commented that the upcoming report by Glass For Europe (not published yet) should provide some commentary on potential reuse of construction flat glass.

Based on the above evidence, the current level of efficiency for the percentage of construction flat glass products reused is estimated to be 0-1%. The evidence RAG rating for this efficiency level is red-amber, reflecting the lack of supporting literature evidence, but relative consensus in workshop voting.

Automotive Flat Glass

No data was available from the literature and no data was collected from the interview process on current levels of reuse of automotive flat glass. This is partly because an interview was not secured with a representative of the automotive sector. Therefore no data was available to estimate a current efficiency level for this indicator. Instead, the current efficiency level for this indicator relies on insight from the workshop conducted. The same voting ranges used for the equivalent indicator for construction flat glass was used for automotive flat glass.

In the workshop, four stakeholders voted for the range 0-1% (all with high confidence), and none voted the range 1-5% nor the range >5%. One trade association commented post-workshop that some automotive glass is reused, such as glass from car breakage, but that there is no data on how much, and it would likely be a very small fraction.

Based on the above evidence, the current level of efficiency for the percentage of automotive flat glass products reused is estimated to be 0-1%. The evidence RAG rating for this efficiency level is red-amber, reflecting the lack of supporting literature evidence, but relative consensus in workshop voting.

Glass Wool

No literature data were available on current levels of reuse of glass wool and therefore no data was available to estimate a current efficiency level for this indicator. Instead, the current efficiency level for this indicator relies on insight from the interviews and the workshop conducted.

One interviewee estimated that for glass wool this was likely to be less than 1%. This <1% estimate was used as the basis for deciding the voting ranges for the workshop.

In the workshop, three stakeholders voted for the range 0-1% (two with high confidence, one with medium confidence), and none voted the range 1-5% nor the range >5%. One trade association commented post-workshop that there is no evidence of reuse of glass wool in construction and from what they know, it is not possible to reuse it, the reason for this being that glass wool tends to collapse in volume and would become contaminated during removal. Furthermore, current building regulations would not permit the use of old glass wool with a low volume.

Based on the above evidence, the current level of efficiency for the percentage of glass wool products reused is estimated to be 0-1%. The evidence RAG rating for this efficiency level is red-amber, reflecting the lack of supporting literature evidence, but relative consensus in workshop voting.

7.4.1.2 Maximum level of efficiency in 2035

Container Glass

No literature was identified to estimate the maximum level of efficiency for container glass. In terms of stakeholder input, two stakeholders interviewed indicated that for container glass, there was a lot of potential to increase reuse, but they were not able to give a quantitative figure for the level of efficiency. One interviewee suggested that the theoretical maximum could be around 90% (some applications would still potentially need single use glass containers), but that there were clearly many barriers to this in terms of brand owner and customer demands, and the infrastructure to support reuse. This 90% figure was provisionally used as a maximum level of efficiency for container glass, to feed into the workshop voting.

In the workshop, no stakeholders voted for the range <40%, two voted for the range 40-80% (both with low confidence), one for the range >80% (with medium confidence), and two did not know. One stakeholder commented post-workshop that a maximum of 90% in 2035 was not realistic based on the knowledge they had to date, while the stakeholder who voted for the range >80% said that theoretically very high levels of reuse are possible, with appropriate container design.

Based on the above evidence, the maximum level of efficiency for the percentage of container glass products that could be reused in 2035 is estimated to be around 40-80%.

The evidence RAG rating for this efficiency level is red, reflecting the relatively low levels of literature evidence and lack of consensus in voting.

Construction Flat Glass

No literature data were available on the maximum efficiency level for this sub-sector and indicator. Instead, the maximum efficiency level for this indicator relies on insight from the interviews and the workshop conducted.

Construction flat glass is currently hard to reuse because it is not designed for reuse. For construction flat glass, one interviewee indicated that there is ‘unlikely to be a significant increase’ on the estimated 1% current level of efficiency. From this, a provisional estimate of

2% was derived for the maximum level of efficiency for flat glass (a 1% increase on the current level of efficiency), to take to the workshop for voting. This 2% figure was selected as the research team's interpretation of 'unlikely to be a significant increase on the estimated 1%'. This was used as the basis for building the workshop voting ranges.

In the workshop, one stakeholder voted for the range 0-1% (with high confidence), two voted for the range 1-5% (with low and medium confidence) and one for the range >5% (with medium confidence). The stakeholder who voted for the >5% range said that the level was theoretically reasonably high, but that there are very significant issues on changing legislation over time, window lifespan, and refurbishing (PVC/wood will fail before glass panes). Another commented that in order to remove the glazing from buildings, the building would need to be designed for de-construction with frames that allow the glass to be removed safely and cost efficiently.

Based on the above evidence, the maximum level of efficiency for the percentage of construction flat glass products reused is estimated to more likely be around 2%. One stakeholder did suggest the maximum level could theoretically be reasonably high, but the barriers for this are very large, making the general consensus among interviewees and workshop participants was that the maximum level of efficiency for construction flat glass is quite low. The evidence RAG rating for this efficiency level is red, reflecting the lack of literature evidence and lack of consensus in voting.

Automotive Flat Glass

No data was collected on the current level of efficiency for automotive flat glass through interviews nor through the literature.

The same workshop voting ranges as used for construction flat glass were used for automotive flat glass. In the workshop, three stakeholders voted for the range 0-1% (two with high confidence, one with low confidence) and one voted for the range 1-5% (medium confidence). However it was noted that participants did not have insight into this area.

Based on the above evidence, the maximum level of efficiency for the percentage of automotive flat glass products reused is estimated to be around 1-2%, slightly lower than the maximum for construction flat glass, given the workshop voting (more stakeholders voting for the bottom range 0-1%). The evidence RAG rating for this efficiency level is Red, reflecting the lack of literature evidence and limited insight from stakeholders in the workshop.

Glass Wool

No literature data were available on the maximum efficiency level for this sub-sector and indicator. Instead, the maximum efficiency level for this indicator relies on insight from the interviews and the workshop conducted.

Two interviewees were of the opinion that for glass wool, it was unclear what improvement on the 1% current level could be made, due to issues of contamination when being removed during refurbishment and demolition, and its low density creating a challenge with transport logistics (higher cost). They did indicate that 'potentially very significant gains' could be made as glass wool is technically reusable (U-value is good enough) but that there were many practical issues to overcome (such as issues with contamination and transport logistics). One interviewee estimated up to 25% could be reused if these barriers were overcome. This estimate was used to decide the workshop voting.

In the workshop, three stakeholders voted for the range 0-1% (two with low confidence and one high), and none voted for the range 10-20% nor the range >20%. This voting contradicts the evidence from the two interviewees, particularly the stakeholder who was of the opinion that 25% of glass wool could be reused if all barriers were removed.

Given the conflicting evidence from the interviews (suggesting a level of efficiency of up to 25%) and the workshop (suggesting a level of efficiency of under 1%), the range 0-10% has been selected as the maximum level of efficiency. The evidence RAG rating for this efficiency level is red, reflecting the lack of literature evidence and relatively low voting confidence.

7.4.1.3 Business-as-usual in 2035

Container Glass

Article 26 of the revision of the Packaging and Packaging Waste Directive (PPWD) sets a wide range of reuse and refill targets for different sectors and packaging formats, to be met by 2030 and 2040.[269] Alcoholic beverages (including beer, carbonated alcoholic beverages, fermented beverages other than wine) have a target of 25% of products to be made available in reusable packaging or by enabling refill by 2040, whilst for wine (except sparkling wine) the target is 15% and for non-alcoholic beverages it is 25%. Though these are targets set at the EU level, (not in the UK), apply to all packaging materials (not just glass), and refer to the proportions of packaging that should be able to be reused (not how much they should be reused), they provide a good indication of the direction of travel for the increase in the percentage of glass products that will be reused in 2035. Therefore, the business-as-usual level of efficiency for the percentage of glass containers that will be reused in 2035 was provisionally taken to be in the range of 15-25%, and taken forward as the basis for workshop voting.

Another useful data point to be referred to is the percentage of beverages sold in refillables in Germany, another European nation with similar economic characteristics, which is at 54% (with ~80% of beer sold in refillable bottles).[270] [271]

In the workshop, two stakeholders voted for the range <15% (both with medium confidence), one voted for the range 15-25% (with medium confidence), none voted for the range >25% and two did not know. The stakeholder who voted for the <15% range said that without buy-in from brands and consumers, there will be little change from current levels.

Based on the above evidence, the BAU level of efficiency for the percentage of container glass products reused is estimated to more likely be around 10-20%. This figure reflects a balance

[269] European Parliament (2023) Revision of the Packaging and Packaging Waste Directive. Available at: link
[270] Upstream (2023) Beverage Refill & The New Reuse Economy. Available at: link
[271] Zero Waste Europe (2021) Creating Effective Systems for Reuse. Available at: link

between target reuse levels in Europe (15-25%), and what workshop participants voted for (two voted for the range <15%). The evidence RAG rating for this efficiency level is red, given the relatively low and slightly mixed voting and the fact that the only evidence available from the literature is not from the UK but from Europe.

Construction Flat Glass

No data was collected on this level of efficiency through either the interviews or the literature.

In the workshop, all four stakeholders who voted, voted for the range 0-1% (two with high confidence, two with medium confidence). Given these votes and the limited scope for improvement in reusing construction flat glass without significant changes in policy and window and building design, the BAU level of efficiency for the percentage of automotive flat glass products reused is estimated to be 0-1%. The evidence RAG rating for this efficiency level is red-amber, given the lack of available evidence from the literature but consensus in voting.

Automotive Flat Glass

No data was collected on this level of efficiency through either the interviews or the literature.

In the workshop, all four stakeholders who voted did so for the range 0-1% (three with high confidence, one with medium confidence). Given these votes, the BAU level of efficiency for the percentage of automotive flat glass products reused is estimated to be 0-1%. This also reflects sector insight that the proportion of the automotive glass market which can be reused is low. The evidence RAG rating for this efficiency level is red-amber, given the lack of available evidence from the literature but consensus in voting.

Glass Wool

No data was collected on this level of efficiency through either the interviews or the literature.

In the workshop, all three stakeholders who voted, voted for the range 0-10% (two with high confidence, one with low confidence). Given these votes, the BAU level of efficiency for the percentage of glass wool products reused is estimated to be 0-10%. The evidence RAG rating for this efficiency level is red-amber, given the lack of available evidence from the literature but consensus in voting.

7.4.2 Indicator 7b: Average number of times a glass product is reused

Table 31 provides a summary of the current, maximum in 2035 and business-as-usual in 2035 for indicator 7b of this measure.

Table 30: Levels of efficiency for glass measure 7, indicator 7b

Indicator 7b: Average number of times a glass product is reused*			
Level of efficiency	Current	Maximum in 2035	Business-as-usual in 2035
Value	CG: 20-25 FG (construction): 0-1 FG (automotive): 0-1 GW: 0	CG: 40 FG (construction): 0-2 FG (automotive): 0-1 GW: 1-2	CG: 25-40 FG (construction): 0-2 FG (automotive): 0-1 GW: 0-1
Evidence RAG	Red-Amber	Red	Red

**CG = Container Glass; FG = Flat Glass; GW = Glass Wool*

7.4.2.1 Current level of efficiency

Container Glass

Evidence on the average number of times a container glass product is reused was found from three sources in the literature. A 2020 report by ZWE, explored the benefits of reuse by evaluating the multi-layered environmental impacts of both single-use and reusable types of packaging through an in-depth comparative analysis of 32 Life Cycle Assessment (LCA) studies, including beverage packaging, buckets, bulk dispensers, carrier bags, crates, cups, drums, food containers, jars, kegs and transport packaging. This study suggests that glass beer bottles can undergo 25 to 30 cycles.[272]

A 2022 report by Verallia calculated the reduction in CO2 emissions from a reusable glass bottle versus single-use PET based on 20 cycles of the reusable glass bottle[273]. Though this study did not look at the average number of reuse cycles, the figure of 20 cycles has been interpreted as being indicative of the number of reuses that might be expected from glass bottles.

A report from the European Commission on reusable packaging in Sweden states that the average use of a 33cl return glass bottle is 40 times, according to the Brewers Association.[274]

From these three sources, a current level of efficiency for the average number of times a container glass product is currently reused was provisionally estimated as 20-25, and taken forward to the workshop for stakeholders to vote on.

[272] Zero Waste Europe, University of Utrecht, Reloop (2020) Reusable vs Single-use packaging - A review of environmental impacts. Available at: link
[273] Verallia (2022) Reimagining reuse for the circular economy of glass - Stakeholder Perspectives Series. Available at: link
[274] European Commission (no date) Reuse Packaging in Sweden. Available at: link

In the workshop, two stakeholders voted for the range 0-20x (both with medium confidence), one voted for the range 20-40x (with medium confidence) and one voted for the range >40x (with high confidence).

Based on the above evidence, the current level of efficiency for the average number of times a container glass product is reused is estimated to be 20-25. This figure combines insight from the literature (ranging between 20 and 40 reuses) and results from the workshop voting which, although mixed, are suggestive of the lower end range as two <20 votes were received. The evidence RAG rating for this efficiency level is red-amber, given that there are several literature sources with evidence on the average number of reuses, but they are not UK specific.

Construction Flat Glass

No literature data were available to estimate a current efficiency level for this indicator, and interviewees were not able to comment either. This is because any level of reuse that does exist in construction is extremely low, and no data is available on this.

This measure has limited applicability for construction flat glass but a current level of efficiency for the average number of times a construction flat glass product is reused was sought at the workshop nonetheless. In the workshop, two stakeholders voted for 0x (both with high confidence), three voted for the range 1-2x (two with low confidence, one with high confidence) and none voted for the range >3x.

Based on the fact that all stakeholders voted for 2 or under reuses, the current level of efficiency for the average number of times a construction flat glass product is reused is estimated to be 0-1. The evidence RAG rating for this efficiency level is red-amber, given the lack of available evidence from the literature or interviews but relative consensus in the workshop voting.

Automotive Flat Glass

No literature data were available to estimate a current efficiency level for this indicator, and interviewees were not able to comment either. This is because any level of reuse that does exist in the automotive sector is extremely low, and no data is available on this.

This measure has limited applicability for automotive flat glass but a current level of efficiency for the average number of times an automotive flat glass product is reused was sought at the workshop nonetheless. In the workshop, three stakeholders voted for 0x (two with high confidence, one with low confidence), one voted for the range 1-2x (with low confidence) and none voted for the range >3x.

Based on the fact that all stakeholders voted for 2 or under reuses, the current level of efficiency for the average number of times an automotive flat glass product is reused is estimated to be 0-1. The evidence RAG rating for this efficiency level is red-amber, given the lack of available evidence from the literature or interviews but relative consensus in the workshop voting.

Glass Wool

No literature data were available to estimate a current efficiency level for this indicator, and interviewees were not able to comment either. This is because any level of reuse that does exist in the glass wool sector is very low, and no data is available on this.

This measure has limited applicability for glass wool but a current level of efficiency for the average number of times a glass wool product is reused was sought at the workshop nonetheless. In the workshop, all three stakeholders who voted did so for 0x (two with high confidence, one with low confidence).

Based on the fact that all stakeholders voted for glass wool products not being able to be reused at all, the current level of efficiency for the average number of times a glass wool product is reused is estimated to be 0. The evidence RAG rating for this efficiency level is red-amber, given the lack of available evidence from the literature or interviews.

7.4.2.2 Maximum level of efficiency in 2035

Container Glass

Evidence on the average number of times a container glass product could be reused in 2035 at maximum level of efficiency was estimated from two of the same literature sources that were used for the current levels of efficiency, as no further literature was available. A 2022 report by Verallia states that glass bottles can be reused up to 40 times and still be recycled at the end of their life.[275] A report from the European Commission on reusable packaging in Sweden states that the average use of a 33cl return glass bottle is 40 times, according to the Brewers Association.[276] From these two sources, a maximum level of efficiency for the average number of times a glass product could be reused in 2035 was estimated as 40, and this was the value used as a reference for stakeholders to vote on at the workshop.

In the workshop, no stakeholders voted for the range 0-20x, one voted for the range 20-40x (with medium confidence) and three voted for the range >40x (two with medium confidence, one with high confidence).

Based on the above evidence, and the higher number of votes received by the >40x range, the maximum level of efficiency for the average number of times a container glass product could be reused is estimated to be 40. This is based on the two literature sources that indicate the number of reuses could be up to 40, corroborated by the workshop voting where several voted for the number being even higher than 40. The evidence RAG rating for this efficiency level is red-amber, given that there is some literature evidence, but it is not UK specific.

Construction Flat Glass

No literature data were available to estimate a maximum efficiency level for this indicator, and interviewees were not able to comment either. This measure has limited applicability for

[275] Verallia (2022) Reimagining reuse for the circular economy of glass - Stakeholder Perspectives Series. Available at: link

[276] European Commission (no date) Reuse Packaging in Sweden. Available at: link

construction flat glass but a maximum level of efficiency for the average number of times a construction flat glass product could be reused in 2035 was sought at the workshops nonetheless.

In the workshop, one stakeholder voted for 0x (with high confidence), five voted for the range 1-2x (four with low confidence, one with high confidence) and none voted for the range >3x.

Based on the majority of votes received by the 1-2x range, the maximum level of efficiency for the average number of times a construction flat glass product could be reused would be estimated to be 1-2. However, given the large degree of uncertainty and the lack of consensus, the number of reuses could be 0, therefore the range selected is 0-2. The evidence RAG rating for this efficiency level is red-amber, given the lack of available evidence from the literature or interviews but relative consensus in the workshop voting.

Automotive Flat Glass

No literature data were available to estimate a maximum efficiency level for this indicator, and interviewees were not able to comment either. This measure has limited applicability for automotive flat glass but a maximum level of efficiency for the average number of times an automotive flat glass product could be reused in 2035 was sought at the workshops nonetheless.

In the workshop, two stakeholders voted for 0x (one with high confidence, one with low confidence), one voted for the range 1-2x (with low confidence) and none voted for the range >3x.

Based on the workshop voting, the maximum level of efficiency for the average number of times an automotive flat glass product could be reused is estimated to be 0-1. The evidence RAG rating for this efficiency level is red, given the lack of available evidence from the literature or interviews and the relatively low levels of voting.

Glass Wool

No literature data were available to estimate a maximum efficiency level for this indicator, and interviewees were not able to comment either. This measure has limited applicability for glass wool but a maximum level of efficiency for the average number of times a glass wool product could be reused in 2035 was sought at the workshops nonetheless.

In the workshop, one stakeholder voted for 0x, two voted for the range 1-2x (all with low confidence) and none voted for the range >3x.

Based on a higher number of votes received by the range 1-2x, the maximum level of efficiency for the average number of times a glass wool product could be reused is estimated to be 1-2. The evidence RAG rating for this efficiency level is red, given the lack of available evidence from the literature or interviews and the low confidence level of the voting.

7.4.2.3 Business-as-usual in 2035

Container Glass

No literature data were available to estimate a BAU efficiency level for this indicator, and interviewees were not able to comment either. A BAU level of efficiency for the average number of times a container glass product is likely to be reused in 2035 was based on the evidence found on the current and maximum levels of efficiency, with the provisional estimate for BAU sitting between the current level (20-25) and the maximum level (40-45). In the absence of further insight or evidence as to where the BAU level might lie, the BAU level was selected as 25-40. This was the range used as a reference for stakeholders to vote on at the workshop.

In the workshop, no stakeholders voted for the range 0-20x, two voted for the range 20-40x (both with medium confidence) and two voted for the range >40x (one with medium, the other with high confidence).

There was no consensus from the workshop voting on the number of container glass reuses expected in a BAU scenario, with some voting for 20-40x and some for >40x. This is not surprising given the lack of evidence. However, none voted for the range 0-20x. Based on this workshop voting , the BAU level of efficiency for the average number of times a container glass product is likely to be reused is estimated to be 25-40, which lies in between the current and maximum levels. The evidence RAG rating for this efficiency level is red, given the lack of available evidence from the literature or interviews and slightly mixed voting.

Construction Flat Glass

No literature data were available to estimate a BAU efficiency level for this indicator, and interviewees were not able to comment either. This measure has limited applicability for construction flat glass but a BAU level of efficiency for the average number of times a construction flat glass product is likely to be reused in 2035 was sought at the workshop nonetheless.

In the workshop, one stakeholder voted for the value 0x (with medium confidence), four voted for the range 1-2x (three with low confidence, one with high confidence) and none voted for the range >3x.

Based on the workshop voting, the BAU level of efficiency for the average number of times a construction flat glass product is likely to be reused is estimated to be 0-2, which is the same as the maximum level, given the uncertainty with direction of travel for this indicator. The evidence RAG rating for this efficiency level is red-amber, given the lack of available evidence from the literature or interviews but relative consensus in the workshop voting.

Automotive Flat Glass

No literature data were available to estimate a BAU efficiency level for this indicator, and interviewees were not able to comment either. This measure has limited applicability for automotive flat glass but a BAU level of efficiency for the average number of times an automotive flat glass product is likely to be reused in 2035 was sought at the workshop nonetheless.

In the workshop, three stakeholders voted for the value 0x (two with high confidence, one with low confidence), one voted for the range 1-2x (with low confidence) and none voted for the range >3x.

Based on the workshop voting, the BAU level of efficiency for the average number of times an automotive flat glass product is likely to be reused is estimated to be 0-1, which is the same as the maximum level, given the uncertainty with direction of travel for this indicator. The evidence RAG rating for this efficiency level is red-amber, given the lack of available evidence from the literature or interviews but relative consensus in the workshop voting.

Glass Wool

No literature data were available to estimate a BAU efficiency level for this indicator, and interviewees were not able to comment either. This measure has limited applicability for glass wool but a BAU level of efficiency for the average number of times a glass wool product is likely to be reused in 2035 was sought at the workshop.

In the workshop, two stakeholders voted for the value 0x (one with high confidence, one with low confidence), one voted for the range 1-2x (low confidence), and none voted for the range >3x.

Based on the workshop voting, the BAU level of efficiency for the average number of times a glass wool product is likely to be reused is estimated to be 0-1. The evidence RAG rating for this efficiency level is red, given the lack of available evidence from the literature or interviews.

8.0 Measure 8 – Recycle post-consumer glass waste

8.1 Glass resource efficiency measure

8.1.1 Description

Recycle post-consumer glass waste

This measure concerns increasing the recycling rate of post-consumer glass waste. Post-consumer glass cullet refers to glass that has been retrieved from waste collection services after it has passed through an end consumer and is recycled back into the production of glass. Recycling more post-consumer glass increases resource efficiency by reducing the need for raw materials in glass production. When glass is recycled, it replaces the need for new raw materials like sand, soda ash, and limestone, conserving natural resources, as well as lowering energy consumption in manufacturing as lower melt temperatures are required, and reducing GHG emissions associated with extracting and processing virgin materials. It also decreases the environmental impact of mining and transportation. This measure is different from Measure 4, but there are interdependencies between the two.

This measure covers both closed-loop or open-loop glass recycling. ‘Closed-loop recycling’ is used to describe the production of glass recyclate of similar quality to the input material for use in applications with the same technical demands. ‘Open-loop recycling’, on the other hand, involves repurposing a material into a different product. While open-loop recycling still provides a valuable second life for the material, it is generally considered less resource-efficient than closed-loop recycling since it doesn't directly replace the need for new raw materials in the same product category.

Table 31 shows which of the four glass products in scope of this project are applicable to this measure. The reasons for why each one is applicable or not are outlined in the following sections.

Table 31: List of sub-sectors applicable to measure 8

Container Glass	Flat Glass – Construction	Flat Glass - Automotive	Glass Wool
Applicable	Applicable	Applicable	Applicable

8.1.2 Measure indicator

The indicator selected to measure the recycling of post-consumer glass waste was the **'percentage post-consumer container glass, flat glass and glass wool waste recycling rate'.** This indicator focuses on percentage of each of the glass product sub-sectors that is collected-for-recycling. The real recycling rate (the percentage that is actually recycled) will be slightly lower than the collected-for-recycling rate because losses occur between collection, sorting and where the material enters the recycling process (often referred to as sorting losses), but for the purposes of this report, the two rates are taken to be the same.

8.1.3 Examples in practice

Container Glass

The collection of household container glass in the UK occurs either via a comingled system, or in a single-stream system, where glass is kept separate. According to a stakeholder interviewed, comingled glass collection is less expensive than single-stream recycling for collection authorities, but increases the chance of contamination and therefore reduces the quality of the cullet. In the UK, some 55% of post-consumer container glass is collected via comingled collection.[277] In Germany and France, glass collected co-mingled is less than 1% of the total collected tonnages, with a much higher proportion collected using a separate collection system. This results in more glass returning into glass manufacturing.[278]

Household container glass waste is collected through kerbside recycling, transported to a Materials Recovery Facility, and sorted into clear, brown, and green materials. At some public collection facilities, glass is separated into clear, brown, and green materials at source, which reduces sorting requirements and increases cullet quality. A further challenge to increasing household glass recycling rates is lack of awareness and engagement among consumers.

Construction Flat Glass

End-of-life construction flat glass has often ended up in landfill rather than being recycled. One literature source estimated that in 2018 almost 200,000 tonnes of glass from construction sites in the UK alone were sent to landfill[279], whilst tonnages of building glass arisings from demolition and renovation were estimated at 200,000 for 2013 and projected to be 214,000 for 2025.[280] Separately, British Glass estimated that 750,000 tonnes of end-of-life waste flat glass generated annually in the UK – around 500,000 tonnes of which was landfilled, the rest was primarily recycled for use as aggregates in construction.[281] This compares to an estimated annual production tonnage of 950,000 tonnes of flat glass[282]. As the industry takes a more environmentally conscious approach, recycling and repurposing materials have become a major objective. Whilst the literature review didn't identify any data on the proportion of flat

[277] Eunomia (2022) New report – UK glass recycling lagging behind other major EU countries. Available at: link
[278] Eunomia (2022) New report – UK glass recycling lagging behind other major EU countries. Available at: link
[279] UKGBC (2018) Building Glass into a circular economy – How to guide. Available at: link
[280] Deloitte (2016) Economic study of recycling building glass in Europe. Available at: link
[281] British Glass (2020) Glass sector net zero strategy. Available at: link.
[282] Hartwell, Coult, Overend (2022) Mapping the flat glass value-chain: a material flow analysis and energy balance of UK production. Available at: link

glass that was suitable for recycling, multiple stakeholders stated that a high proportion of it could be if appropriate segregation and collection systems were in place. Glass that is recycled in the UK within the construction sector is often part of an open loop system; when a building is refurbished, end-of-life façade glass is usually crushed and used as aggregates in road construction.[283] Whilst using as aggregates is better than disposal to landfill this means that the material cannot re-enter the glass cycle as its original technical properties will be lost, having been down-cycled.

Within the construction industry, contamination has been identified as the biggest technical challenge to overcome in order to increase the availability of quality cullet. Common contaminants include floor sweepings, and spacer bars from sealed units. For effective recycling, frames and fixes need to be separated, and the glass placed in dedicated skips. Removal of glazing units from the building site to a factory environment for disassembly is a good way of improving quality control and reducing contamination of the glass recyclate.[284] One stakeholder stated that in the domestic sector, some window installers remove old glazing units, return them to their facility and use specialised equipment to crush the unit, recovering the separated glass from the contaminants. This is then sent back to the primary glazing manufacturers for use as post-consumer cullet. One manufacturer noted that the coatings on flat glass don’t have any significant impacts on its recycling into new flat glass.

An example of the recycling of building glazing back into glass is Verde SW1 in London, a major refurbishment project that saw 5,100 m^2 of glass facade being deconstructed, transported off site where it was decontaminated, sorted and crushed, before being recycled into glass bottles. 340 tonnes of glass was recycled, saving 100t CO_2e.[285] Similarly, Lloyds when refurbishing 1 Lime Street reglazed 1,182 floor to ceiling units. It worked with Saint-Gobain Glass to recycle 144 tonnes of the post-consumer glass back into float glass.[286]

Automotive Flat Glass

Automotive glass includes windshields, side windows and rear windows, and can be recycled when cars are scrapped at end of life. In the UK, glass in scrap cars is typically handled in one of two ways; removal from the car prior to being crushed, and crushing of the car with glass still in place. A stakeholder stated that in the latter case, the glass must be sorted from the rest of the crushed materials, and because it is crushed, is not commercially viable to process it into high quality cullet, and typically ends up in an open loop system. Crushed glass is commonly used as a secondary aggregate in the construction industry.

Removal of the glass is also hampered by the fact that glass is typically bonded to a sheet of polyvinyl butyral (PVB) laminate to provide penetration and impact resistance. Specialist technology is available to separate the glass from the PVB. However it was noted that in the majority of cases, glass is not removed from cars, Authorised Treatment Facilities (ATF’s) for cars in the UK have little incentive to do so because of its low value. However, there are a

[283] Ibid
[284] Ibid
[285] Tishman Speyer (2017) Glass from glass Available at: link
[286] Arup (2013) The Arup Journal 2013, Issue 2. Available at: link

number of good examples of windscreen recycling. Auto Windscreens replace vehicle glass, and recycle 100% of the glass removed, which totalled 1,246 tonnes in 2018 and usually goes into drinking glasses and bottles.[287] National Windscreens also recycle 100% of the windscreens replaced.[288]

Glass Wool

Recycling glass wool is not as common or as straightforward as the recycling of container glass or flat glass. When being removed during demolition, glass wool is usually between other layers such as bricks and plaster which means it is complicated and time consuming to separate. Furthermore, its light density makes it difficult to reprocess.[289] The availability of recycling facilities for glass wool can vary by location, and specialized equipment and processes may be needed. In the UK there are no ‘take back’ schemes for glass wool.[290]

8.2 Available sources

8.2.1 Literature review

The literature review identified 37 sources that discussed this resource efficiency measure (either in terms of providing evidence on levels of efficiency, or by providing commentary on drivers and barriers). These comprised:

- Six academic papers[291] [292] [293] [294] [295] [296];

[287] Auto Windscreens (2018) Auto Windscreens recycles over nine blue whales worth of glass a year!. Available at: link
[288] National Windscreens (2023) Embracing the Circular Economy: National Windscreens Recycles 100% of Replaced Glass. Available at: link
[289] Knauf Insulation (2020) New Era of Recycling. Available at: link
[290] Danzay-Smith, G (2022) Rock mineral wool vs Glass mineral wool. Arc. Available at: link
[291] Forslund H. and Björklund M. (2022) Toward Circular Supply Chains for Flat Glass: Challenges of Transforming to More Energy-Efficient Solutions. Available at: link
[292] Furszyfer Del Rio, D. D., Sovacool, B. K., Foley, A. M., Griffiths, S., Bazilian, M., Kim, J., & Rooney, D. (2022) Decarbonizing the glass industry: A critical and systematic review of developments, sociotechnical systems and policy options. Available at: link
[293] Geboes E., Galle W., De Temmerman N. (2022) Make or break the loop: a cross-practitioners review of glass circularity. Available at: link
[294] Hartwell R., Coult G., Overend M. (2022) Mapping the flat glass value-chain: a material flow analysis and energy balance of UK production. Available at: link
[295] Lewis Jones, Rosa Urbano Gutierrez (2023) Circular ceramics: Mapping UK mineral waste. Available at: link
[296] Telesilla Bristogianni & Faidra Oikonomopoulou (2022) Glass up-casting: a review on the current challenges in glass recycling and a novel approach for recycling "as is" glass waste into columetric glass components. Available at: link

- Fifteen industry reports[297] [298] [299] [300] [301] [302] [303] [304] [305] [306] [307] [308] [309] [310] [311];
- One policy document[312];
- One academic report[313];
- Three technical studies[314] [315] [316]; and
- Eleven website articles[317] [318] [319] [320] [321] [322] [323] [324] [325] [326] [327].

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 4.1 (out of 5), with 26 sources exhibiting a score of 4 or above. Over half the sources are from the UK and 34 are from within the past ten years. The vast majority of the levels of efficiency data points found from the literature referred to current levels of efficiency rather than maximum levels, and most referred to container glass rather than flat glass or glass wool.

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297 ARUP (2013) The Arup Journal 2013, Issue 2. Available at: link
298 ARUP (2018) Re-thinking the life-cycle of architectural glass. Available at: link
299 British Glass (2020) Glass sector. Net zero strategy 2050. Available at: link
300 Deloitte (2016) Economic study on recycling of buiding glass in Europe. Available at: link
301 Eunomia (2022) UK glass recycling lagging behind other major EU countries. Available at: link
302 European Environment Agency (2022) Investigating Europe's secondary raw material markets. Available at: link
303 Green Building Council, Verdextra, British Glass, ARUP (2018) Building glass into the circular economy. Available at: link
304 Knauf Insulation (2020) New Era of Recycling. Available at: link
305 Saint Gobain (2021) Circular Economy - Eco-design for sustainable construction. Available at: link
306 WRAP (2008) Collection of flat glass for use in flat glass manufacture. Available at: link
307 WRAP (2019) Glass Flow 2025 WRAP Final Report. Available at: link
308 WRAP (2020) PackFlow Covid19-Phase I: Glass. Available at: link
309 WWF (2021) Packaging unwrapped. Available at: link
310 Zero Waste Europe & Eunomia (2022) How circular is glass. Available at: link
311 Zero Waste Europe, University of Utrecht, Reloop (2020) Reusable vs Single-use packaging. Available at: link
312 British Glass, BEIS (2017) Glass Sector Industrial Decarbonisation and Energy Efficiency Roadmap Action Plan. Available at: link
313 Leeds University Business School (Dr Ursula Balderson, Professor Vera Trappmann, Dr Jo Cutter) (2022) Decarbonising the Foundation Industries and the implications for workers and skills in the UK - The case of steel, glass and cement industries. Available at: link
314 Rodriguez Vieitez E. et al. (2011) End-of-Waste Criteria for Glass Cullet: Technical Proposals. Available at: link
315 Tishman Speyer (2017) Glass from glass. Available at: link
316 Valpak (2017) Packaging Recycling Supply Chain Assessment. Available at: link
317 Arc Building Solutions (2022) Rock Mineral Wool vs Glass Mineral Wool. Available at: link
318 Auto Windscreens (2018) Auto Windscreens recycles over nine blue whales worth of glass in a year!. Available at: link
319 European Commission (2022) Packaging waste - EU rules on packaging and packaging waste, including design and waste management. Available at: link
320 FEVE The European Container Glass Federation (2022) The EU Packaging and Packaging Waste Regulation (PPWR): How glass can support the EU's circular economy ambition. Available at: link
321 Friends of glass (2023) What are the benefits of glass in a circular economy?. Available at: link
322 HMRC (2023) Landfill Tax rates. Available at: link
323 Knauf Insulation (2023) Knauf Insulation: Frequently asked questions. Available at: link
324 National Windscreens (2023) Embracing the Circular Economy: National Windscreens Recycles 100% of Replaced Glass. Available at: link
325 Packaging News (2015) Glass bottles: recycling and reuse in the UK | Matthew Kensall. Available at: link
326 Recycling International (2023) UK glass recyclers want export cut. Available at: link
327 The European Container Glass Federation (2023) Reinventing glass? We're already on it! Our response to Zero Waste Europe/RELOOP policy recommendations on PPWR. Available at: link

8.2.2 Interviews

Eight of the stakeholders interviewed provided input on the recycling of post-consumer glass waste, depending on their area of expertise. Stakeholder generally felt this measure that had potential across all glass sub-sectors with a lot of room for improvement and opportunity particularly with post-consumer flat glass collection and recycling.

8.2.3 Workshop

Eight stakeholders across the industry were active on the mural board, four stakeholders contributed to the discussion verbally and one stakeholder contributed via MS Teams. Stakeholders were clear with the definition of this measure and all agreed on its inclusion as a measure of efficiency for the glass industry. One stakeholder noted that the importance of barriers and drivers would change depending on sub-sectors. Overall, stakeholders agreed that the quality of cullet was key for this measure. One stakeholder suggested that the quality of cullet collected was outside of the control of the glass industry and the collection system of post-consumer waste has the biggest impact on quality. Another suggested that the sorting of glass waste to a high quality was particularly difficult, since it is not just the glass colour or levels of contamination that must be considered but for also the specific chemical composition (such as iron content) of glass that must be considered when incorporating cullet in the highest specification flat glass products.

8.3 Drivers & Barriers

The drivers and barriers influencing this measure were identified through a combination of the literature review, stakeholder interviews and sector workshop. Drivers and barriers that apply to specific applications or subsectors will be noted in brackets.

8.3.1 Drivers

Table 32 below shows the main drivers for Measure 8. The most significant drivers are shown in bold as voted for by stakeholders in the workshop.

Table 32: Drivers for glass measure 8

Description	PESTLE	COM-B
Growing consumer demand for purchasing products made from recycled content	**Social**	**Opportunity – social**
Extended Producer Responsibility and Consistency of Collections regulations (container glass)	**Legal / political**	**Capability – psychological**
Recycling initiatives by individual window companies to promote their activities as green (flat glass)	**Technological / Social**	**Motivation – reflective**

A 'remelt target' for glass packaging (container glass)	Legal / Political	Motivation – automatic
Increased market opportunities (flat glass)	Economic	Opportunity – physical
Financial incentive for cullet use (flat glass)	Economic / Political	Motivation – automatic

Growing consumer demand for products made from recycled content

According to stakeholders, a key driver for companies seeking to improve their recycling process through their own initiatives is a growing consumer awareness and desire to buy 'green' products, such as products made from recycled content. Stakeholders suggested that this increase in consumer demand for products made from recycled content could increase the demand and production of recycled glass. Literature reflects this, suggesting that increased education and growing public awareness of the benefits of recycling, as well as consumer accessibility to products with high recycled content, should increase the recycling of post-consumer waste.[328]

Extended Producer Responsibility and Consistency of Collections regulations (container glass)

This driver is specific to container glass. The proposed changes to Extended Producer Responsibility (EPR) and Simpler Recycling should help drive an increase in post-consumer packaging glass recycling. The container sector has a target of a 90% collected-for-recycling rate by 2030.[329] One interviewee indicated that if the concept of EPR is extended out to a wider range of products including construction products, this should also help drive an increase in collection and recycling infrastructure of post-consumer flat glass. However, there are currently no confirmed plans for EPR for construction products.

Recycling initiatives by individual window companies to promote their activities as green (construction flat glass)

Stakeholders from the flat glass sector highlighted that a number of window companies are actively seeking to improve their recycling process through their own initiatives. Such initiatives have been supported by the Glass and Glazing Federation (GGF) pilot scheme in the North of England whereby glazing and installation businesses can have used window frames collected for free and the GGF can pass on high-quality flat glass to re-processors to be recycled.[330] These businesses promote their recycling activities as “green” or “sustainable” to potential

[328] British Glass (2020) Glass sector. Net zero strategy 2050. Available at: link
[329] British Glass (2020) Glass sector. Net zero strategy 2050. Available at: link
[330] Glass and Glazing Federation (2023). Expansion of the GGF Glass Recycling Scheme. Available at: link

customers as part of their corporate social responsibility initiatives. Whilst this is currently being practised on a small scale, such initiatives have the potential to drive recycling rates higher.[331]

A 'remelt target' for glass packaging (container glass)

This driver is specific to container glass. As part of its recycling targets, the UK has agreed a "remelt target" for glass packaging to improve its circularity (currently at 72% but proposed to be increased to 81% by 2030). [332] This is not a closed-loop target but prioritises remelt applications such as the use of cullet in container glass and insulation applications over the use of glass in aggregates. As glass manufacturers strive to meet this regulatory target, this could help drive an increase in recycling of post-consumer glass waste. Stakeholders did not speak to this specific policy driver during interview but four of the eight voting stakeholders in the workshop voted for this as a top driver for this measure.

Increased market opportunities (construction flat glass)

A report by Zero Waste Europe suggests that there is a growing market for waste management and recycling companies to take framed windows and insulated glazing units away from housing sites to break down into clean and segregated cullet in a factory environment.[333] One stakeholder agreed that this was a big incentive for flat glass installers and contractors who can save money on skips by diverting deinstalled glass to waste companies who will collect it for free. The report cites a drive to increase the amount of recycled content in flat glass production as driving such initiatives. Should such initiatives continue to be successful, this could enable an increase in the proportion of post-consumer glass that is recycled. In the workshop, one stakeholder suggested that an increased availability of such high-quality cullet would mean that manufacturers could eventually attain recycled content of 90-100%.

Financial incentive for cullet use (flat glass)

There is a significant financial incentive for the use of post-consumer cullet in the case of flat glass. One report by Zero Waste Europe with an IAS score of five suggested that the price of cullet paid by float manufacturers indicates sufficient incentive to transport and deconstruct cullet sources, for example, window glazing units, and that the current cost per tonne of cullet is less than the cost per tonne of raw material.[334] In addition to this, two interviewees, both academics, argued that an increase in the use of cullet (rather than raw materials) across product groups reduces energy requirements and therefore costs in the production of glass. As indicated in the driver above, flat glass installers also benefit financially from such drivers as waste collectors can collect their deinstalled units for free. These financial incentives could drive an increase in the recycling of post-consumer glass waste, as manufacturers will want to continue to reduce their costs.

[331] ARUP (2018) Re-thinking the life-cycle of architectural glass. Available at: link
[332] Zero Waste Europe, Eunomia (2022) How circular is glass. Available at: link
[333] Ibid
[334] Ibid

8.3.2 Barriers

Table 33 below shows the main barriers for Measure 8. The most significant barriers are shown in bold as voted for by stakeholders in the workshop.

Table 33: Barriers for glass measure 8

Description	PESTLE	COM-B
Contamination due to recycling collection methods – co-mingled systems lower cullet yield (container glass)	**Technological**	**Capability – physical**
Limitations of mixed-colour collections (container glass)	**Technological**	**Capability – physical**
Cost of collection, reprocessing and transportation higher than other materials	**Economic**	**Opportunity – physical**
Specific glass product compositions (flat glass)	**Technological**	**Capability – physical**
Insufficient landfill tax (flat glass)	**Political**	**Motivation – automatic**
Lack of uptake in the demolition industry (flat glass)	Social	Capability – physical
Barriers to implementing a Deposit Return Scheme (container glass)	Political	Opportunity – social
Low market value for glass waste	Economic	Opportunity – physical
High cost of capital investments in sorting technologies	Economic	Opportunity – physical
Imbalance in demand and availability of different glass colour materials (container glass)	Economic	Opportunity – physical
Inability to mix container glass with other glass for recycling	Technological	Capability – physical
Export of container cullet	Economic	Opportunity – physical
Lack of agency within glass sector	Political	Opportunity – social

Competition for cullet from other industries	Economic	Opportunity – physical
Product composition of glass wool, which is often coated with another material (glass wool)	Technological	Capability – physical

Contamination due to recycling collection methods – co-mingled systems lower cullet yield (container glass)

According to stakeholders, if glass collected was of a high enough quality, glass recyclers could recycle as much as 100% of the material collected but this is currently unachievable due to quality been compromised by contamination and mixing of different recyclable materials.

Co-mingled collections were cited as a key barrier to higher post-consumer recycling rates as it results in a lower yield of cullet suitable for remelt applications than when glass is collected in a separate stream.[335] This is due to the fact that glass collected in co-mingled collections is more likely to be contaminated with other materials and impurities, thereby leading to more rejects and lower yields.

Contamination also contributes to rejection of input material. Glass that is lacquered or has difficult-to-remove labels, for example, can be misidentified in optical sorting lines and therefore be diverted to general waste streams together with cement, stones and porcelain (contaminants).[336]

Also raised by stakeholders in interview was the difficulty that diversity in local authority waste collections can cause for glass recycling. The inconsistency in collection approaches and the accompanying varied guidelines on sorting, contamination levels, and collection methods make it harder for recycling facilities to process glass efficiently as cullet will come from different local authorities with different characteristics, leading to increased costs, and lower quality cullet. One stakeholder also raised that there is a need to collect more post-consumer cullet, requiring higher targets.

Limitations of mixed colour collections (container glass)

Related to the above barrier, glass container recycling can be limited if it is not sorted into different glass types and colours. Separate household glass collections typically collect mixed glass collections that is not separated by colour (typically clear, amber and green). For collections of mixed colour container glass, a positive sort is required on clear glass to generate a cullet fraction suitable for clear glass production. Positive sorting refers to the practice of identifying and removing a desired fraction from the input waste stream, as opposed to negative sorting which focuses instead on identifying and removing a non-desired fraction from the waste stream. Usually, this positive sort does not capture all the clear glass and some

[335] Zero Waste Europe & Eunomia (2022) How circular is glass. Available at: link
[336] Ibid

pieces are left behind in the green and amber cullet, which could lead to an oversupply of amber and green cullet and an undersupply of clear cullet for local manufacturing.[337]

Cost of collection, reprocessing and transportation higher than other materials

Along with issues arising from collection methods, stakeholders indicated that the cost of collecting, transporting and reprocessing post-consumer glass is often higher that the cost for other materials such as paper and plastic, and could deter investment and limit the economic viability of glass recycling. These higher costs are due to its weight, fragility, and the need for specialised processing facilities. Factors that contribute toward exacerbated costs include processing glass that is broken, contaminated, or glass that is not separated into material colours.[338] These factors could make glass recycling less economically viable compared to lighter and less fragile materials like plastic or paper. Whether these factors impact, for example, packaging product specifiers and encourage producers to consider alternative materials to glass for packaging would be an area for further research.

Specific glass product compositions (flat glass)

The specific compositions of different glass products can present a significant barrier to glass recycling. Flat glass products typically include specific additives and coating interfaces with other materials that add to the functionality of the product. For example, clear building glass requires a low iron content for clarity, clear automotive glass has a green tint to reduce glare. One stakeholder noted that even the differences in compositions between different manufacturers of the same product can result in unfavourable differences in a resulting recycled product. Separating these materials to produce cullet free from variations can be technically difficult and costly. Due to glazing methods in automotive flat glass, dismantling this waste stream is complex.[339] One of the key limitations of incorporating higher percentages of post-consumer flat glass, in particular in new production, is the stringent acceptability criteria for cullet which exists to prevent yield losses.[340]

Insufficient landfill tax (flat glass)

Several stakeholders interviewed, confirmed what was argued in a report by Deloitte on the recycling of building glass in Europe,[341] that the current low rate of landfill tax for which glass qualifies is a major barrier to glass recycling. The argument is that, in the case of flat glass, the “inactive” status of glass currently makes the rate of landfill tax in the UK insufficient to promote the uptake of glass recycling. A low landfill tax means that it is relatively inexpensive for businesses and municipalities to dispose of flat glass in landfills, and therefore this becomes the preferred option in some cases.

[337] Zero Waste Europe & Eunomia (2022) How circular is glass. Available at: link
[338] Furszyfer Del Rio et al (2022). Decarbonising the glass industry: A critical and systematic review of developments, sociotechnical systems and policy options. Available at: link
[339] Furszyfer Del Rio et al (2022) Decarbonizing the glass industry: A critical and systematic review of developments, sociotechnical systems and policy options. Available at: link
[340] Hartwell, R., Coult, G., Overend, M. (2022) ‘Mapping the flat glass value-chain: a material flow analysis and energy balance of UK production’ Glass Structures & Engineering. Available at: link
[341] Deloitte (2016) Economic study of recycling building glass in Europe. Available at: link

Lack of uptake in the demolition industry (flat glass)

Demolition contractors tend to be employed for the removal of full façades. One reason for a significant proportion of flat glass ending up in aggregate or landfill is in part due to this sector's lack of awareness of recycling options and economic uncertainty of the recycling processes.[342] One stakeholder suggested there is similarly a lack of awareness of the options for recycling automotive glass, and that it is acceptable in the industry to crush vehicles at the end of life without removing glass, meaning the crushed glass becomes contaminated and unable to be recycled, even by glass wool manufacturers with much lower quality requirements than flat glass manufacturers. Automotive glass, therefore, is often used as a secondary aggregate in the construction industry rather than recycled back into the glass sector.

In addition, moving large sheets of glass can be logistically complex. Adequate transportation infrastructure is needed to handle the movement of glass from collection at the point of demolition to recycling facilities.[343] It could also require specialized handling equipment, like racks, cradles, or suction cups, to ensure it is transported safely without breakage. Transporting glass to landfill sites instead is a logistically easier and less costly endeavour.

Barriers to implementing a Deposit Return Scheme (container glass)

A deposit return scheme (DRS) for glass is a recycling system where consumers pay a small deposit when purchasing products in recyclable packaging, such as glass, plastic or aluminium, which can be retrieved at designated recycling points upon return of the packaging. The deposit is intended to incentivise consumers to return packaging for recycling and thus encourage high recycling rates. Such schemes are run with success in other European countries such as Germany and Estonia. Research by Zero Waste Scotland suggests that a DRS for glass would increase the collection rates of glass and highlighted that many best-practice examples of DRSs in other countries included glass in their schemes.[344] Barriers to a DRS, for example the Scottish Government recently announcing that glass packaging would no longer be captured under its incoming DRS[345], could therefore present barriers to increased collection rates of glass for recycling.

Low market value of glass waste

Glass has a low market value in comparison to other waste materials. Glass is valued at around £6 per tonne in comparison to waste aluminium which has a value of £1,000 per tonne and waste plastic which is worth £200-600 per tonne. As an example, this means that when windows are replaced by glaziers, the glass is often separated from the PVC frame, the PVC which is worth £200 per tonne is recycled, whereas the extracted glass is sent to landfill rather than recycled.[346]

[342] ARUP (2018) Re-thinking the life-cycle of architectural glass. Available at: link
[343] Deloitte (2016) Economic study of recycling building glass in Europe. Available at: link
[344] Zero Waste Scotland (2018) DRS: the case for glass. Available at: link
[345] Scottish Government (2023) Deposit Return: Scottish scheme delayed until October 2025 at the earliest. Available at: link
[346] Leeds University Business School (2022) Decarbonising the Foundation Industries and the implications for workers and skills in the UK – The case of steel, glass and cement industries. Available at: link

High cost of capital investments in sorting technologies

Advanced technologies to improve sorting capacity and reduce contamination, and improve the quality of cullet, require high capital investment. Given the low value of glass, there is a lack of a financial incentive to make this investment.[347] Stakeholders suggested that at best, any adoption of advances in sorting or reprocessing technologies could only be adopted incrementally as equipment reaches its end-of-life and needs to be replaced.

Imbalance in demand and availability of different glass colour materials (container glass)

64% of containers produced in the UK are made from clear glass and exported.[348] However, the largest market share in terms of consumption is green glass, in part due to wine bottle consumption, whilst containers such as clear spirit bottles are primarily exported. In addition, there is strong export demand for clear cullet. This leads to an imbalance in terms of the type of cullet returned to glass manufacturers via recycling (primarily green/brown), and the glass needed by furnaces for their production orders (primarily flint/clear).[349]

Inability to mix container glass with higher-specification glass for recycling

One limitation on recycling rates is that container glass cannot be mixed with higher-specification types of glass, such as windows, ovenware and crystal. This is because such high-specification glass requires specific chemical compositions, coatings and treatments and uses different manufacturing processes, and incorporation of container glass can therefore introduce impurities to these products.[350] Window glass often undergoes additional processes like tempering or lamination, which can make it structurally different from packaging glass. Stakeholders have suggested that this inability to mix container glass with other glass types means that consolidation of glass material to take advantage of economies of scale cannot be done, thereby likely increasing costs overall.

Export of container cullet

One stakeholder in the workshop raised a concern that large amounts of glass cullet are exported from the UK as part of ongoing local authority waste contracts. This, of course, is a barrier to the recycling of post-consumer waste in the UK as it depletes the available feedstock for reprocessors. The export of glass cullet for remelt rose by 79,000 tonnes in 2022, an increase of 31% compared to 2021.[351] It is also important to acknowledge that the current locations and capacities of glass reprocessing facilities mean that it is not feasible to reprocess all the UK's collected glass waste in the UK.

[347] Geboes. E et al (2022). 'Make or break the loop: a cross-practitioners review of glass circularity'. Available at: link
[348] Leeds University Business School (2022) Decarbonising the Foundation Industries and the implications for workers and skills in the UK – The case of steel, glass and cement industries. Available at: link
[349] Leeds University Business School (2022) Decarbonising the Foundation Industries and the implications for workers and skills in the UK – The case of steel, glass and cement industries. Available at: link
[350] European Environment Agency (2022) Investigating Europe's secondary raw material markets. Available at: link
[351] Recycling International (2023) UK glass recyclers want export cut. Available at: link.

Lack of agency within glass sector

One stakeholder remarked that increasing the feedstock of post-consumer glass waste was outside the influence of the glass industry, and that consumers, waste collectors and policy makers are best placed to affect change for this measure.

Competition for cullet from other industries

Glass cullet offers significant savings in energy use when used in place of raw materials in the glassmaking process. Other industries, particularly in construction, use glass cullet with similar energy efficiency savings. For this reason, competition to use cullet materials may drive up its price or limit their availability for use by the glass industry. This barrier was identified by stakeholders during the workshop, however information on the extent or scale on which other industries are taking up use of cullet is not currently available.

Product composition of glass wool, which is often coated with another material (glass wool)

When it comes to recycling, it is difficult to differentiate rock wool from glass wool, and these both require quite different processing. Glass wool is coated once it is manufactured and one interviewee stated that this then makes it difficult to recycle back into glass wool. In addition, any contamination from demolition can potentially cause damage to manufacturing equipment.

8.4 Levels of efficiency

Table 34 provides a summary of the current, maximum in 2035 and business-as-usual in 2035 for this measure.

Table 34: Levels of efficiency for glass measure 8

Indicator: Percentage post-consumer container glass, flat glass and glass wool recycling rate*			
Level of efficiency	Current	Maximum in 2035	Business-as-usual in 2035
Value	CG: 70-75% FG: 25-35% GW: 0-5%	CG: ~90% FG: 60-80% GW: Not available	CG: 75-83% FG: 40-60% GW: 0-10%
Evidence RAG	Amber-Green	Red	Red

**CG = Container Glass; FG = Flat Glass; GW = Glass Wool*

8.4.1 Current level of efficiency

Container Glass

A 2024 report by WRAP found that the UK's glass packaging recycling rate was 76%.[352] A representative from a sector body interviewed estimated the UK closed-loop recycling rate for containers (back into glass) at ~49%, with 22% going into other applications e.g. aggregates.

Based on the literature review and sector insight, the current percentage of post-consumer container glass recycled in the UK is estimated to be 76%.

In the workshop, no stakeholders voted for the range 65-70%, four stakeholders voted for the range 70-75% (all with high confidence), no stakeholders voted for the range >75%, and one did not know. One commented that the precise reported figure was 75%, but wasn't sure how much of that was closed-loop. Another commented that container glass had a recycling rate of 74% in 2021, with 52% of that closed-loop.

Based on the evidence from the literature, the interviews and the workshop voting, the current level of efficiency for the percentage of post-consumer container glass recycled is estimated to be 70-75%. Of this, 49% is estimated to be closed-loop (back into glass), based on insight from the sector body interview. The evidence RAG rating for this efficiency level is amber-green, given that there is evidence from several robust literature sources, supported by stakeholder interviews and consensus in the workshop voting.

Flat Glass

Hartwell et al (2022) report that the collection of flat glass products for recycling at their end-of-life is estimated to be at a rate of 10% of new flat glass production.[353]

British Glass estimate that 750,000 tonnes of end-of-life waste flat glass (e.g. from buildings, vehicles, as well as other applications such as solar panels) is generated annually in the UK. Of this, around 500,000 tonnes is landfilled, the rest (250,000) is primarily recycled for use as aggregates in construction[354]. This equates to a post-consumer recycling rate of ~33-34%, with most or all of this being open-loop recycling (as it is being recycled into aggregates rather than back into glass products).

One interviewee indicated that the percentage of post-consumer flat glass going into aggregates (open-loop recycling) is likely high, but low for flat glass going back into flat glass, container or glass wool (closed-loop recycling). The low closed-loop recycling rate is due to the fact that efficient systems for flat glass closed-loop collection aren't established in the UK.[355]

A number of manufacturer and sector representative organisation interviewees identified that a small amount of recycling back into flat glass does occur and that this was estimated by them to be at 1-2% at present. Given the overall recycling rate (open and closed-loop) is estimated as 33-34% by British Glass, the remaining 32-33% is likely open-loop (e.g. aggregates).

[352] Wrap (2024) A Roadmap to Closed Loop Glass Recycling Available at: link
[353] Hartwell. R, Coult. G, Overend. M (2022) Mapping the flat glass value-chain: a material flow analysis and energy balance of UK production. Available at: link
[354] British Glass (2020) Glass sector. Net zero strategy 2050. Available at: link
[355] Hartwell. R, Coult. G, Overend. M (2022) Mapping the flat glass value-chain: a material flow analysis and energy balance of UK production. Available at: link

In the workshop, four stakeholders voted for the range 25-30% (all with low confidence), one voted for the range 30-35% (with medium confidence) and no stakeholders voted for the range >35%. One commented that data availability is poor, and another commented that they did not know what happened to flat glass at end-of-life.

Based on the above evidence, and despite the lower rate (of 10%) reported by Hartwell et al (2022), the current level of efficiency for the percentage of post-consumer flat glass recycled is estimated to be 30-35%. The evidence RAG rating for this efficiency level is amber, given that there is a reliable data value however there was some uncertainty from workshop participants.

Glass Wool

Whilst glass wool can technically be recycled back into glass wool, it is understood that there is no or very limited recycling of post-consumer glass wool back into glass wool.

No evidence from the literature or the interviews was identified of glass wool being recycled into other glass products (e.g., containers). Therefore, the current efficiency level for this indicator relies on insight from the workshop conducted. In the workshop, three stakeholders voted for the range 0-5% (two with low confidence, one with medium confidence) and one did not know.

Based on the workshop voting , the current level of efficiency for the percentage of post-consumer glass wool recycled is estimated to be 0-5%. The evidence RAG rating for this efficiency level is red, given the lack of available evidence and there were no glass wool experts were present in the workshop.

8.4.2 Maximum level of efficiency in 2035

No literature data were available to estimate a maximum efficiency levels for this measure. Instead, the maximum efficiency level for this indicator relies on voting in the workshop.

Container Glass

Sector interviews suggested that, in theory, a post-consumer recycling rate of container glass of 90-100% could be achieved, given that glass is considered to be infinitely recyclable. However, a number of barriers (outlined in the previous section) would need to be overcome to reach this level. This would need to reduce the losses occurring at the collection phase, potentially shifting to deposit return systems and more effective separate collection systems (rather than co-mingled), supported by consumer education to improve understanding of recycling systems. Technology improvements would also be needed to sort and maximise the quality of the glass recyclate generated.

In the workshop, four stakeholders voted for the range >75% (three with high confidence, one with medium confidence) and one did not know. One commented that the maximum level should be 90-100%.

Based on the above evidence, the maximum level of efficiency for the percentage of post-consumer container glass recycled is estimated to be around 90%, all of which should be closed-loop (back into glass). Though the theoretical potential could be 100%, this is unlikely to be practically feasible, so a level of efficiency of 90% is deemed most appropriate. The evidence RAG rating for this efficiency level is red, given the lack of available evidence from the literature.

Flat Glass

Three interviewees indicated that, in theory, most if not all post-consumer flat glass could be recycled. However, as with container glass, significant logistical, social, economic and political barriers would need to be overcome to achieve the theoretical level of post-consumer 90-100% recycling rate. This would need to see deconstruction of flat glass from vehicles and buildings, rather than breaking or crushing of glass at end of life. This would need to be supported by better separate collection of the glass units, and improvements in the waste management infrastructure to separate the glass from the frames and seals, and create an uncontaminated cullet stream to be fed back into glass manufacture.

In the workshop, one stakeholder voted for the range 30-40% (with medium confidence), one for the range 40-70% (with medium confidence) and three for the range >70% (one with high confidence, one with low confidence, one did not specify). Of those who voted for the range >70%, one commented that the maximum level should be 90-100% and another said flat glass could use maximum amounts if the correct quality is available.

Though the theoretical maximum level of efficiency is 90-100%, given the significant barriers to the post-consumer recycling of flat glass, corroborated by two stakeholders voting for the lower voting ranges (of 30-40% and 40-70%), the maximum level of efficiency for the percentage of post-consumer flat glass recycled is estimated to be 60-80%, all of which should be closed-loop (back into glass). However, this estimate must be taken with a high degree of caution and uncertainty, given the difference in opinion between stakeholders, the significant barriers that remain to achieving this, and the lack of available literature evidence. For these reasons, the evidence RAG rating for this efficiency level is red.

Glass Wool

In the workshop, one stakeholder voted for the range 0-10% (with low confidence), one for the range 11-20% (with low confidence), one for the range >20% (with low confidence) and one did not know. One who voted for the range >20% specified that the maximum level is 80-100%. This is because theoretically good quality cullet should be able to be remelted but that, however, converting glass wool products into good quality cullet is more uncertain than for container or flat glass.

Based on the above evidence, a maximum level of efficiency for the percentage of post-consumer glass wool recycled is not able to be estimated, given the huge range of uncertainty and no consensus in the workshop voting, as well as no clarity on whether the significant barriers to recycling post-consumer glass wool can be overcome. There is no RAG rating for this level of efficiency as no level of efficiency has been estimated.

8.4.3 Business-as-usual in 2035

Container Glass

In 2022, DEFRA proposed a recycling rate for 2030 of 83% and a remelt target of 80%.[356] This provides a good indication of the direction of travel for the increase in the percentage of post-consumer container glass that will be recycled in 2035.

In the workshop, one voted for the range 70-75% (with medium confidence), three voted for the range >75% (two with high confidence, one with medium confidence) and one did not know. The stakeholder who voted for the range 70-75% commented that the BAU figure would be impacted by policies which do not actively promote further recycling.

Based on evidence from the literature and the workshop voting, the BAU level of efficiency for the percentage of post-consumer container glass recycled is estimated to be 75-83%. The evidence RAG rating for this efficiency level is red-amber given the slight difference between the literature and workshop voting.

Flat Glass

In the workshop, two stakeholders voted for the range 30-40% (one with medium confidence, the other with low confidence), two voted for the range 40-70% (one with medium confidence, one with low confidence) and one voted for the range >70% (did not specify level of confidence). One stakeholder who voted for the range 30-40% (with low confidence) specified that the figure would be 35%, and that a lot of work was needed to increase recycling rates, due to quality and logistics issues. One stakeholder who voted for the range 40-70% (with low confidence) said that initiatives are ongoing to increase availability of quality flat glass collection.

There was no consensus from the workshop voting on the BAU level of efficiency, with stakeholders voting for various different ranges. There was also no evidence from the literature and the interviews. With the lack of available evidence, the BAU level of efficiency for the percentage of post-consumer flat glass recycled is estimated to be 40-60%, However, this is a very approximate estimate based on workshop voting, and therefore the estimate must be taken with a high degree of caution and uncertainty. For this reason, the evidence RAG rating for this efficiency level is red.

Glass Wool

In the workshop, three stakeholders voted for the range 0-10% (all with low confidence) and one did not know.

Based on the workshop voting, the BAU level of efficiency for the percentage of post-consumer glass wool recycled is 0-10%. The evidence RAG rating for this efficiency level is red, reflecting

[356] Zero Waste Europe & Eunomia (2022) How circular is glass? Available at: link

the lack of supporting literature evidence and that there were no glass wool experts were present in the workshop.

9.0 Interdependencies

This report has discussed each of the measures identified for the glass 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.

9.1 Interdependencies within the sector

Measures 1 & 7

- Measure 1 – Lightweighting in consumer products
- Measure 7 – Reuse of glass products (resulting in a reduction in consumption of new products and increasing a functional product’s lifetime)

When considered in isolation, both of these measures will increase resource efficiency. However, when considered together, there is a trade-off between the two, i.e. an increase in the level of efficiency of one is likely to decrease the level of efficiency (or reduce the potential) of the other. This is because lightweighting can impact the reusability of glass products (see section 1.3.2). Despite some lightweighting advancements, such as that by Vetropack Group, resulting in bottles that are more stable and scuff proof[357], glass bottles intended for reuse will likely need to be thicker with coatings to extend their lifetime.

Measures 4 & 5

- Measure 4 – Reincorporate glass waste back into glass manufacturing
- Measure 5 – Implement efficient manufacturing and installation processes

Whilst Measure 4 seeks to maximise the amount of glass waste that is reincorporated back into manufacture (thereby no longer making it waste), Measure 5 seeks to minimise the amount of waste that is generated in the first place. Even if the waste generated is recycled through Measure 4, the waste hierarchy dictates that it is still preferable to not generate this

[357] Vetropack (no date) The next generation of returnable bottles. Available at: link

waste in the first place, which is why there is a key role for Measure 5. Implementing efficient manufacturing and installation processes should help both maximise glass yield and minimise the amount of waste generated, thereby reducing the amount of internal and pre-consumer cullet available to be recycled in Measure 4. If Measure 5 is working optimally so that there is no waste in the manufacturing and installation processes, then no glass cullet (both internal and pre-consumer) would be being generated and no cullet from these sources would be available to reincorporate into manufacturing, only post-consumer cullet would be available. This is therefore an important interdependency to consider between Measures 4 and 5.

Measures 4 & 6

- Measure 4 – Reincorporate glass waste back into glass manufacturing
- Measure 6 – Lifetime extension through repair of products

An increase in the level of efficiency of Measure 6 (an increase in the percentage reduction in new consumption through repair) means less glass will be placed on the market, less glass will reach end-of-life, and therefore less post-consumer cullet will potentially be available to be reincorporated back into glass manufacturing (Measure 4).

Measures 4 & 7

- Measure 4 – Reincorporate glass waste back into glass manufacturing
- Measure 7 – Reuse of glass products (resulting in a reduction in consumption of new products and increasing a functional product's lifetime)

An increase in the level of efficiency of Measure 7 (an increase in the percentage of glass products reused) means less glass will be placed on the market, less glass will reach end-of-life, and therefore less post-consumer cullet will potentially be available to be reincorporated back into glass manufacturing (Measure 4).

Measures 4 & 8

- Measure 4 – Reincorporate glass waste back into glass manufacturing
- Measure 8 – Recycle post-consumer glass waste

The ability of post-consumer glass cullet to be reincorporated back into glass manufacturing (in Measure 4) is highly dependent on this post-consumer cullet being available through increasing the collection and recycling rates of post-consumer glass (Measure 8). If the supply of post-consumer glass cullet is not provided by improving efficiency levels (i.e. recycling rates) in Measure 8, then the percentage of post-consumer glass cullet reincorporated into manufacturing (an important part of Measure 4) will not increase either. Measure 4 is therefore very dependent on Measure 8.

Measures 3 & 7

- Measure 3 – Substitute glass products with non-glass products (excluding raw material substitution)

- Measure 7 – Reuse of glass products (resulting in a reduction in consumption of new products and increasing a functional product's lifetime)

The evidence suggests that the material substitution of glass products for products made from other materials (Measure 3) is beneficial from a carbon perspective when considering only single-use products of each type. This is because evidence in the form of LCA analyses consistently suggest that single-use glass containers perform worse than their alternatives, as outlined in section 3.1.3 ("Examples in practice"). However, when the reuse of glass products (Measure 7) is considered, the evidence suggests that glass products have greater reuse potential than products made from other materials (such as paper and plastic products), particularly in the container market, and therefore reusing glass could lead to lower embodied carbon than substituting it with other single-use materials.

9.2 Interdependencies with other sectors

Material Substitution for Other Packaging Sectors (paper, plastic, steel)

The aim of this project is to explore resource efficiency within the glass sector while delivering equivalent utility, rather than a reduction in overall consumption. As such, a reduction in glass use through material substitution (Measure 3) will result in an increase in consumption of those materials being used to replace glass products. This includes materials from other sectors within scope of this project (e.g., plastic, paper, steel) and those outside of scope of this project (e.g., aluminium). Material substitution will also have lifecycle emissions impacts on the products produced as this intervention will impact key features such as weight, lifespan and recyclability of these products, which should also be considered.

Food and Drink

Glass is often utilised as a packaging material for food and drink products. This packaging can have an impact on resource efficiency within the food and drink sector as it offers protection and preservation of perishable products, extending shelf-life and reducing food waste. However, there is often a trade-off in terms of the GHG emissions associated with packaging, due to the carbon embedded in the production of packaging materials, as well as the additional emissions associated with transporting heavier products. Resource efficiency measures within the glass sector may reduce the GHG emissions associated with packaging but may also result in the deterioration of the packaging's ability to preserve food and drink products and a subsequent rise in food and drink waste. For example, reducing the quality of the manufactured glass may make it unsuitable for food and drink contact applications, or lightweighting packaging may increase the risk of breakage. Additionally, packaging that is adapted to improve its chance of reuse is highly likely to require the use of additional glass material.

Sectors that Utilise Glass Products (construction, vehicles, electronics)

Glass products are utilised across many sectors evaluated over the course of the "Unlocking Resource Efficiency" project such as construction (e.g. flat glass for construction, glass wool), vehicles (e.g. automotive windscreens, side glass), and electronics (e.g. flat glass for screens). This results in substantial overlap between the glass material sector and the industries in which these materials are applied.

The potential of resource efficiency measures in the glass sector (such as lightweighting, reuse and repair) are often limited by the regulations set in those other industries. For example, the Government has in place various standards and building regulations associated with glass to ensure the conservation of energy and the health and safety of people in and around buildings. Building regulations are numerous and vary by geography and glass application and use, but they often require a minimum thickness in order to ensure the safety of its users or occupants.[358] This limits the potential of lightweighting for the flat glass sub-sector.

Another example of this interdependency is in vehicles. The current acceptable level of damage of a car window (e.g., size of crack/location) that can be repaired is defined by the MOT (Ministry of Transport test).[359] If the damage is deemed too large or is located in specific points of the glass, the regulations will not allow for the unit to be repaired at all. This limits the number of windscreens that can be repaired, and therefore the overall percentage of automotive flat glass that can be repaired.

Another example of this interdependency is the reuse measure in construction. In the glass sector workshop, a stakeholder suggested that lack of standardisation of glass windowpanes during design presents a barrier to reuse of flat glass at its end of use. If window sizes were standardised in the construction industry, a viable market for second-hand (reused) window units may emerge.

Competition for alternative raw materials

Multiple stakeholders in the glass sector stated during the interviews and the workshop that the improved environmental performance offered by materials such as Calumite and biomass ash is a desirable quality that will be sought after by many of the UK's foundation industries (e.g., the cement and concrete sectors) working towards reducing their environmental impacts. Whilst some import of Calumite (ground granulated blast furnace slag) occurs, global supply is practically fully utilised and there is increasing demand from the cement sector as part of its drive to reduce the carbon impact of cement. These factors are expected to impact on availability and price of ground granulated blast furnace slag in the long term for the glass industry[360], and reduce its economic viability.

[358] For example, British Standards BS 6206 and BS EN 12600 on building glazing and glass in buildings.
[359] UK Government (2023) MOT inspection manual: cars and passenger vehicles. Available at: link.
[360] Concrete4change (2022) Barriers to Net-Zero Concrete – Fly Ash and GGBS. Available at: link

Glossary and abbreviations

AI	Artificial Intelligence
ATF	Authorised Treatment Facility
BAU	Business-as-usual
CG	Container glass
CLSC	Closed-loop supply chains
DIY	Do-it-yourself
DRS	Deposit Return Scheme
EDP	Environmental product declarations
EPR	Extended Producer Responsibility
ETS	Emissions Trading Scheme
FENSA	Fenestration Self-Assessment Scheme
FG	Flat glass

GGF	Glass and Glazing Federation
GHG	Greenhouse Gas
GW	Glass wool
GWP	Global warming potential
IAS	Indicative applicability score
IGU	Insulated glass unit
IIOT	Industrial Internet of Things
LCA	Lifecycle assessment
MOT	Ministry of Transport test
MRF	Materials recovery facility
NPWD	National Packaging Waste Database
NSG	Nippon Sheet Glass
PET	Polyethylene terephthalate
PFAS	Per- and Polyfluorinated Substances
PFFA	Paper and Pulp Mill Fly Ash
PPWR	Packaging and Packaging Waste Regulation
PV	Photovoltaic
PVB	Polyvinyl butyral
PVC	Polyvinyl Chloride
RAG	Red-Amber-Green
RE	Resource efficiency
RMI	Repair, Maintenance and Improvements
SME	Small and medium-sized enterprise
UKRI	UK Research and Innovation
UPVC	Unplasticized Polyvinyl Chloride
UUWD	Used UPVC Windows and Doors

UV	Ultra violet (light)
WRAP	Waste & Resources Action Programme
WWF	World Wide Fund for Nature
ZWE	Zero Waste Europe

Appendix A: IAS Scoring Parameters

Table 35: IAS scoring method

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 36: IAS Scoring Parameters

Criteria	High	Medium
Geography	Specific to UK	Non-UK but applicable to the UK
Date of publication	< 10 years	10 to 20 years
Sector applicability	Sector and measure-specific, discusses RE and circularity	Sector and measure-specific, focus on decarbonisation
Methodology	Research methodology well defined and deemed appropriate	Research methodology well defined but not deemed appropriate / Minor description of research methodology
Peer Review	Explicitly mentioned peer review	Not explicitly mentioned, but assumed to have been peer reviewed

Appendix B: Search strings

- ("uk" OR "united kingdom" OR "great britain") AND (Glass* OR Glass wool* OR Flat Glass* OR container glass* OR glass* OR Packaging glass* OR Construction glass*) AND (circular* OR environment* OR resource efficien* OR sustainab* OR material efficien* OR decarbonis* OR low carbon)
- ("uk" OR "united kingdom" OR "great britain") AND (Glass* OR Glass wool* OR Flat Glass* OR container glass* OR Packaging glass* OR Construction glass*) AND (circular* OR environment* OR resource efficien* OR sustainab*) AND (design* OR "eco-design" OR "eco design" OR "ecodesign")
- ("uk" OR "united kingdom" OR "great britain") AND (Glass* OR Glass wool* OR Flat Glass* OR container glass* OR glass* OR Packaging glass* OR Construction glass*) AND (light weight* OR light-weight* OR lightweight*)
- ("uk" OR "united kingdom" OR "great britain") AND (Glass* OR Glass wool* OR Flat Glass* OR container glass* OR glass* OR Packaging glass* OR Construction glass*) AND thick OR thin
- ("uk" OR "united kingdom" OR "great britain") AND (Glass* OR Glass wool* OR Flat Glass* OR container glass* OR glass* OR Packaging glass* OR Construction glass*) AND material substitution
- ("uk" OR "united kingdom" OR "great britain") AND (Glass* OR Glass wool* OR Flat Glass* OR container glass* OR glass* OR Packaging glass* OR Construction glass*) AND (alternative OR substitute) AND (circular* OR environment* OR resource efficien* OR sustainab*)
- ("uk" OR "united kingdom" OR "great britain") AND (Glass* OR Glass wool* OR Flat Glass* OR container glass* OR glass* OR Packaging glass* OR Construction glass*) AND (calcined OR ash OR slate)
- ("uk" OR "united kingdom" OR "great britain") AND (Glass* OR Glass wool* OR Flat Glass* OR container glass* OR glass* OR Packaging glass* OR Construction glass*) AND plastic substitut*
- ("uk" OR "united kingdom" OR "great britain") AND Cullet* AND (circular design OR resource efficien* OR recycling OR waste management OR decarbonis* OR circular economy)
- ("uk" OR "united kingdom" OR "great britain") AND (Glass* OR Glass wool* OR Flat Glass* OR container glass* OR glass* OR Packaging glass* OR Construction glass*) AND ("recycled content" OR "recycled material" OR "recyclability")
- ("uk" OR "united kingdom" OR "great britain") AND (Glass* OR Glass wool* OR Flat Glass* OR container glass* OR glass* OR Packaging glass* OR Construction glass*) AND reincorporat*

- ("uk" OR "united kingdom" OR "great britain") AND (Glass* OR Glass wool* OR Flat Glass* OR container glass* OR glass* OR Packaging glass* OR Construction glass*) AND production efficien*
- ("uk" OR "united kingdom" OR "great britain") AND (Glass* OR Glass wool* OR Flat Glass* OR container glass* OR glass* OR Packaging glass* OR Construction glass*) AND secondary manufactur* AND production efficien*
- ("uk" OR "united kingdom" OR "great britain") AND (Glass* OR Glass wool* OR Flat Glass* OR container glass* OR glass* OR Packaging glass* OR Construction glass*) AND waste reduction
- ("uk" OR "united kingdom" OR "great britain") AND (Glass* OR Glass wool* OR Flat Glass* OR container glass* OR glass* OR Packaging glass* OR Construction glass*) AND (manufactur* OR process* OR produc*) AND waste
- ("uk" OR "united kingdom" OR "great britain") AND (Glass* OR Glass wool* OR Flat Glass* OR container glass* OR glass* OR Packaging glass* OR Construction glass*) AND (manufactur* OR process* OR production) AND (efficient OR efficiency)
- ("uk" OR "united kingdom" OR "great britain") AND (Glass* OR Glass wool* OR Flat Glass* OR container glass* OR glass* OR Packaging glass* OR Construction glass*) AND repair
- ("uk" OR "united kingdom" OR "great britain") AND (Glass* OR Glass wool* OR Flat Glass* OR container glass* OR glass* OR Packaging glass* OR Construction glass*) AND material recovery
- ("uk" OR "united kingdom" OR "great britain") AND (Glass* OR Glass wool* OR Flat Glass* OR container glass* OR glass* OR Packaging glass* OR Construction glass*) AND install* AND efficien*
- ("uk" OR "united kingdom" OR "great britain") AND (Flat Glass* OR container glass* OR glass* OR Packaging glass* OR Construction glass*) AND (durab* OR repair OR repairing OR repaired OR lifespan OR life-span OR "life span" OR extend OR modular)
- ("uk" OR "united kingdom" OR "great britain") AND (Glass* OR Glass wool* OR Flat Glass* OR container glass* OR glass* OR Packaging glass* OR Construction glass*) AND (reus* OR reprocess* OR re-process OR re-manufactur* OR remanufactur* OR recla*)
- ("uk" OR "united kingdom" OR "great britain") AND (Glass* OR Glass wool* OR Flat Glass* OR container glass* OR glass* OR Packaging glass* OR Construction glass*) AND (recycl* OR waste manag* OR closed-loop recycl* OR open-loop recycl*)
- ("uk" OR "united kingdom" OR "great britain") AND (Glass* OR Glass wool* OR Flat Glass* OR container glass* OR glass* OR Packaging glass* OR Construction glass*) AND (low* OR reduc* OR minim*) AND (manufactur* OR process* OR produc*) AND waste

- (Glass* OR Glass wool* OR Flat Glass* OR container glass* OR glass* OR Packaging glass* OR Construction glass*) AND (circular* OR environment* OR resource efficien* OR sustainab* OR material efficien* OR decarbonis* OR low carbon)
- (Glass* OR Glass wool* OR Flat Glass* OR container glass * OR glass* OR Packaging glass* OR Construction glass*) AND (circular* OR environment* OR resource efficien* OR sustainab*) AND (design* OR "eco-design" OR "eco design" OR "ecodesign")
- (Glass* OR Glass wool* OR Flat Glass* OR container glass* OR glass* OR Packaging glass* OR Construction glass*) AND (light weight* OR light-weight* OR lightweight*)
- (Glass* OR Glass wool* OR Flat Glass* OR container glass* OR glass* OR Packaging glass* OR Construction glass*) AND (thick OR thin)
- (Glass* OR Glass wool* OR Flat Glass* OR container glass* OR glass* OR Packaging glass* OR Construction glass*) AND material substitution
- (Glass* OR Glass wool* OR Flat Glass* OR container glass* OR glass* OR Packaging glass* OR Construction glass*) AND (alternative OR substitute) AND (circular* OR environment* OR resource efficien* OR sustainab*)
- (Glass* OR Glass wool* OR Flat Glass* OR container glass* OR glass* OR Packaging glass* OR Construction glass*) AND (calcined OR ash OR slate)
- (Glass* OR Glass wool* OR Flat Glass* OR container glass* OR glass* OR Packaging glass* OR Construction glass*) AND plastic substitut*
- Cullet* AND (circular design OR resource efficien* OR recycling OR waste management OR decarbonis* OR circular*)
- (Glass* OR Glass wool* OR Flat Glass* OR container glass* OR glass* OR Packaging glass* OR Construction glass*) AND ("recycled content" OR "recycled material" OR "recyclability")
- (Glass* OR Glass wool* OR Flat Glass* OR container glass* OR glass* OR Packaging glass* OR Construction glass*) AND reincorporat*
- (Glass* OR Glass wool* OR Flat Glass* OR container glass* OR glass* OR Packaging glass* OR Construction glass*) AND production efficien*
- (Glass* OR Glass wool* OR Flat Glass* OR container glass* OR glass* OR Packaging glass* OR Construction glass*) AND secondary manufactur* AND production efficien*
- (Glass* OR Glass wool* OR Flat Glass* OR container glass* OR glass* OR Packaging glass* OR Construction glass*) AND waste reduction
- (Glass* OR Glass wool* OR Flat Glass* OR container glass* OR glass* OR Packaging glass* OR Construction glass*) AND (manufactur* OR process* OR produc*) AND waste
- (Glass* OR Glass wool* OR Flat Glass* OR container glass* OR glass* OR Packaging glass* OR Construction glass*) AND (manufactur* OR process* OR production) AND (efficient OR efficiency)

- (Glass* OR Glass wool* OR Flat Glass* OR container glass* OR glass* OR Packaging glass* OR Construction glass*) AND repair
- (Glass* OR Glass wool* OR Flat Glass* OR container glass* OR glass* OR Packaging glass* OR Construction glass*) AND material recovery
- (Glass* OR Glass wool* OR Flat Glass* OR container glass* OR glass* OR Packaging glass* OR Construction glass*) AND install* AND efficien*
- (Flat Glass* OR container glass* OR glass* OR Packaging glass* OR Construction glass*) AND (durab* OR repair OR repairing OR repaired OR lifespan OR life-span OR life span OR extend OR modular)
- (Glass* OR Glass wool* OR Flat Glass* OR container glass* OR glass* OR Packaging glass* OR Construction glass*) AND (reus* OR reprocess* OR re-process OR remanufactur* OR re-manufactur* OR remanufactur* OR re-manufactur* OR recla*)
- (Glass* OR Glass wool* OR Flat Glass* OR container glass* OR glass* OR Packaging glass* OR Construction glass*) AND (recycl* OR waste manag* OR closed-loop recycl* OR open-loop recycl*)
- (Glass* OR Glass wool* OR Flat Glass* OR container glass* OR glass* OR Packaging glass* OR Construction glass*) AND (low* OR reduc* OR minim*) AND (manufactur* OR process* OR produc*) AND waste
- (British Glass OR Saint Gobain OR FGMA) AND (circular* OR environment* OR resource efficien* OR sustainab* OR material efficien* OR decarbonis* OR low carbon OR recycl*)
- UK *Glass* *raw material* *substitution*
- UK flat glass remanufacture reuse
- UK container glass AND *remanufacture OR reuse*
- "lightweighting glass sector UK"
- glass production waste reduction
- % of glass replaced by plastic flat glass report
- UK flat glass circularity *repair* %
- Paper packaging AND reuse*
- glass lightweighting %
- glass manufacturing waste reduction

Appendix C: Literature sources

Table 37 below lists the literature sources for the glass sector.

Table 37: List of literature sources for the glass sector

Title	URL	Author	Year	IAS
Deposit Return: Scottish scheme delayed until October 2025 at the earliest.	link	Scottish Government	2023	**5**
DRS: the case for glass	link	Zero Waste Scotland	2018	**5**
Expansion of the GGF Glass Recycling Scheme	link	Glass and Glazing Federation	2023	**4**
Glass sector. Net zero strategy 2050	link	British Glass	2023	**4**
Mapping the flat glass value-chain: a material flow analysis and energy balance of UK production	link	Hartwell R., Coult G. and Overend M.	2022	**5**
Collection of flat glass for use in flat glass manufacture	link	Wrap	2008	**3**
Economic study on recycling of building glass in Europe	link	Deloitte	2016	**4**
Re-thinking the life-cycle of architectural glass	link	ARUP	2018	**5**
Building glass into the circular economy	link	Green Building Council, Verdextra, British Glass, ARUP	2018	**4**
End-of-Waste Criteria for Glass Cullet: Technical Proposals	link	Rodriguez Vieitez E. et al.	2011	**3**
Glass Sector Industrial Decarbonisation and Energy Efficiency Roadmap Action Plan	link	British Glass, BEIS	2017	**5**
Toward Circular Supply Chains for Flat Glass: Challenges of Transforming to More Energy-Efficient Solutions	link	Forslund H. and Björklund M.	2022	**5**
Leading the Change Sustainability Report 2020	link	Xella/URSA	2020	**3**
Reimagining reuse for the circular economy of glass: Stakeholder Perspectives Series	link	Verallia	2023	**5**

Lightweight, energy efficient glazing units for modern architecture	link	Buildingtalk	2014	**3**
Circular ceramics: Mapping UK mineral waste	link	Lewis Jones, Rosa Urbano Gutierrez	2023	**5**
A guide to substitution	link	UK Chemicals Stakeholder Forum	2010	**2**
Reinventing glass? We're already on it! Our response to Zero Waste Europe/RELOOP policy recommendations on PPWR	link	The European Container Glass Federation	2023	**3**
Exploratory research in alternative raw material sources and reformulation for industrial soda-lime-silica glass batch	link	DENG, Wei, SPATHI, Charikleia, COULBECK, Teig, KILINC, Erhan, BACKHOUSE, Daniel, MARSHALL, Martyn, IRESON, Robert and BINGHAM, Paul	2019	**5**
Decarbonising the Foundation Industries and the implications for workers and skills in the UK - The case of steel, glass and cement industries	link	Leeds University Business School (Dr Ursula Balderson, Professor Vera Trappmann, Dr Jo Cutter)	2022	**4**
Investigating Europe's secondary raw material markets	link	European Environment Agency	2022	**4**
Enviroash investigates the potential for using biomass and other wastes as raw materials across the foundation industries	link	Glass Technology Services	2022	**3**
Decarbonizing the glass industry: A critical and systematic review of developments, sociotechnical systems and policy options	link	Furszyfer Del Rio, D. D., Sovacool, B. K., Foley, A. M., Griffiths, S., Bazilian, M., Kim, J., & Rooney, D.	2022	**5**
Make or break the loop: a cross-practitioners review of glass circularity	link	Geboes E., Galle W., De Temmerman N.	2022	**5**
Glass bottles: recycling and reuse in the UK | Matthew Kensall	link	Packaging News	2015	**4**
Reuse before recycling - ensuring true circularity in beverage packaging	link	Zero Waste Europe	2022	**2**
Making Europe transition to reusable packaging	link	Zero Waste Europe	2022	**4**
THE KEY TO UBER LIGHTWEIGHTING OF GLASS CONTAINERS	link	Glass Worldwide	2023	**3**
Vacuum double glazing — Vacuum insulation glass (VIG)	link	Chamaeleon	2023	**3**

Packaging unwrapped	link	WWF	2021	**4**
Cost savings from reducing waste in the glass and glazing industry	link	Glass and Glazing Federation	2000	**3**
What are the benefits of glass in a circular economy?	link	Friends of glass	2023	**3**
Reusable vs Single-use packaging	link	Zero Waste Europe, University of Utrecht, Reloop	2020	**4**
Glass up-casting: a review on the current challenges in glass recycling and a novel approach for recycling "as is" glass waste into columetric glass components	link	Telesilla Bristogianni & Faidra Oikonomopoulou	2022	**5**
How circular is glass	link	Zero Waste Europe & Eunomia	2022	**5**
Collaborative UK project enlightens glass industry	link	Glass International	2009	**4**
Circular Economy - Eco-design for sustainable construction	link	Saint Gobain	2021	**3**
Is paper really better for the Earth than plastic?	link	The Grocer	2023	**5**
Packaging waste - EU rules on packaging and packaging waste, including design and waste management	link	European Commission	2022	**3**
Glass Flow 2025 WRAP Final Report	link	WRAP	2019	**5**
Glass Lightweighting	link	aegg	2023	**3**
The next generation of returnable bottles	link	vetropack	2023	**4**
Cracking the glass code: Lightweighting tech for Diageo's Johnny Walker bottle uncovered	link	Packaging Insights	2021	**3**
The EU Packaging and Packaging Waste Regulation (PPWR): How glass can support the EU's circular economy ambition	link	FEVE The European Container Glass Federation	2022	**3**
How We’ve Reduced Glass Waste by Investing in Technology	link	abc Glass Processing	2021	**4**
Life cycle environmental impacts of carbonated soft drinks	link	Amienyo et al.	2012	**5**
Life Cycle Assessment (LCA) of thermal insulation materials: A critical review	link	Fuchsl et al.	2022	**5**

A comparison of the environmental impacts of different categories of insulation materials	link	Hill et al.	2018	**5**
Plastic Products Leach Chemicals That Induce In Vitro Toxicity under Realistic Use Conditions	link	Zimmermann et al.	2021	**5**
Closing the Plastics Circularity Gap: Full report	link	Google and AFARA	2022	**5**
The practical case of organic dairy products in glass bottles and jars	link	Serac	2021	**4**
Glass Types	link	Stevenage Glass	2023	**3**
PackFlow Covid19-Phase I: Glass	link	Valpak	2020	**5**
PackFlow Covid19-Phase I: Metals	link	Valpak	2020	**5**
PackFlow Covid19-Phase I: Plastic	link	Valpak	2020	**5**
Written evidence submitted by Valpak Limited	link	Valpak	2021	**5**
UK statistics on waste	link	UK Government	2023	**5**
Tetra V Glass V Plastic - Which is best?	link	50 Shades Greener	2021	**3**
Rock Mineral Wool vs Glass Mineral Wool	link	Arc Building Solutions	2022	**3**
Can wine and spirits really move away from glass?	link	Beverage Daily	2023	**3**
Cans grow market share at the expense of bottles	link	Drinks Retailing	2018	**3**
Waitrose replaces glass bottles with aluminium cans for small format wine ranges	link	Packaging Europe	2023	**3**
PET plastic bottles deemed more sustainable than aluminium or glass	link	Packaging Gateway	2023	**4**
NielsenIQ data shows record value growth for cans	link	Packaging News	2021	**3**
Survey: Perception huge in beverage packaging	link	Packaging World	2006	**3**
Glasswool vs Polyester Insulation - Which one is right for you?	link	Pricewise Insulation	2021	**3**
Glass Products	link	British Glass	2023	**4**
Industrial energy use and decarbonisation in the glass sector: A UK perspective	link	Griffin, Hammond, and McKenna	2021	**5**
Wine Psychology: basic & applied	link	Spence	2020	**5**
Standards and Building regulations	link	Saint Gobain	2023	**5**

Calumite	link	Hanson	2022	**4**
Decode the future of GGBFS	link	Chemanalyst	2023	**2**
How Calumite Is Used	link	Hanson	2023	**4**
Calumite, more than just a raw material	link	Calumite Ltd	2021	**4**
LionGlass to extend glass manufacturing furnace lifetimes	link	Glass International	2023	**4**
Pulp and Paper Mill Fly Ash: A Review	link	Cherian C. and Siddiqua S.	2019	**5**
Life cycle assessment of beverage packaging	link	Brock and Williams	2020	**5**
The continuing rise of the can	link	Canmakers	2023	**3**
Industry comparison - LCA of global warming effects	link	Paboco	2023	**4**
Toxic 'forever chemicals' are contaminating plastic food containers	link	The Guardian	2021	**3**
Recycled content and glass packaging - European container glass industry position	link	FEVE The European Container Glass Federation	2019	**5**
Knauf Insulation: Frequently asked questions	link	Knauf Insulation	2023	**4**
Encirc to invest in Industry 4.0-ready glass production line	link	Zenoot	2019	**3**
How to minimise waste when installing windows	link	Kingswood Trade Frames	2023	**4**
UKRI invests £15m in the future of glass production	link	UKRI	2020	**4**
Best Available Techniques (BAT) reference Document for the Manufacture of Glass	link	Institute for Prospective Technological Studies (Joint Research Centre)	2013	**5**
Windscreen Chip Repair	link	Halfords	2023	**3**
How to deal with damaged windscreens	link	RAC	2023	**4**
MOT Inspection manual: cars and passenger vehicles	link	UK Government	2023	**3**
Again: Clean Cells	link	Again	2023	**3**
Milk & More to increase reuse of bottles by 15% as glass prices soar	link	The Guardian	2022	**3**
Our glass bottles are now returnable	link	Tom Parker Creamery	2023	**3**
Float Mylk	link	Float Mylk	2023	**3**

Zero Waste Solutions	link	Sustainable Wine Solutions	2022	**3**
These Reusable Glass Bottle Programs Help Solidify a Circular Eco-Solution	link	Somm TV Magazine	2022	**3**
Returnable 1 Litre Bottles	link	Rebellion Beer	2023	**3**
Waste-free Punk IPA: A new Way to Shop with Loop	link	BrewDog	2023	**3**
Closed loop system	link	Miniml	2023	**3**
Hand refill collection	link	Molton Brown	2023	**3**
Building sustainability through Optima Reuse Service	link	Optima	2022	**3**
Supplying you with affordable second-hand windows and doors	link	UUWD	2023	**4**
Packaging: the truth about glass	link	Mc'Nean	2020	**3**
Revision of the Packaging and Packaging Waste Directive	link	European Parliament	2023	**5**
Beverage Refill & The New Reuse Economy	link	Upstream	2023	**3**
Creating Effective Systems for Reuse	link	Zero Waste Europe	2021	**4**
Reuse Packaging in Sweden	link	European Commission	1998	**3**
UK glass recycling lagging behind other major EU countries	link	Eunomia	2022	**4**
Glass from glass	link	Tishman Speyer	2017	**5**
The Arup Journal 2013, Issue 2	link	Arup	2013	**5**
Auto Windscreens recycles over nine blue whales worth of glass in a year!	link	Auto Windscreens	2018	**3**
Embracing the Circular Economy: National Windscreens Recycles 100% of Replaced Glass	link	National Windscreens	2023	**3**
New Era of Recycling	link	Knauf Insulation	2020	**4**
Packaging Recycling Supply Chain Assessment	link	Valpak	2017	**5**
Landfill Tax rates	link	HMRC	2023	**4**
Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on packaging and packaging waste, amending Regulation (EU) 2019/1020 and Directive (EU) 2019/904, and repealing Directive 94/62/EC	link	European Parliament	2023	**5**

UK glass recyclers want export cut.	link	Recycling International	2023	**3**
HOW IS THE GLASS INDUSTRY DELIVERING ON LIGHTER WEIGHT GLASS PACKAGING?	link	Glass Hallmark	No date	**3**
Effects of Vehicle Load on Emissions of Heavy-Duty Diesel Trucks: A Study Based on Real-World Data.	link	Wang et al.	2021	**5**
The next S-curve of growth: Online grocery to 2030.	link	McKinsey & Company	2022	**3**
Fly Ash And Blast Furnace Slag For Cement Manufacturing BEIS Research Paper No. 19	link	Department for Business, Energy and Industrial Strategy	2017	**5**
Ardagh Group Sustainability Report 2021	link	Ardagh Group	2021	**5**
Sustainability Report	link	Vidrala	2021	**4**
Mapping the journey towards intelligent glass bottles. Available at: Link	link	Encirc 360	2021	**3**
Environment Product Declaration	link	IFT Rosenheim	2021	**4**
Reducing Vehicle Weight and Improving U.S. Energy Efficiency Using Integrated Computational Materials Engineering	link	Joost, W.	2012	**4**
Environmental Product Declaration of Laminated glass from JSC “Stronglasas”	link	JSC “Stronglasas”	2023	**5**
Environmental Product Declaration for: Offline Coated Float Glass from NSG Group	link	Pilkington Group Limited	2023	**5**
Plastic or glass: a new environmental assessment with a marine litter indicator for the comparison of pasteurized milk bottles	link	Stefanini et al.	2021	**5**
Glass Recycling - Life Cycle Carbon Dioxide Emissions - A Life Cycle Analysis Report	link	Enviros Consulting Ltd	2003	**4**
Single-use plastic bottles and their alternatives - Recommendations from Life Cycle Assessments	link	UNEP and Life Cycle Initiative	2020	**5**
Absolut paper based bottle	link	Institute of Materials, Minerals and Mining	2023	**3**
Glass wool or mineral wool - which is best for insulation?	link	Insulation Superstore	No date	**3**
The Future Homes and Buildings Standards: 2023 consultation	link	UK Government	2023	**5**

Appendix D: List of discarded resource efficiency measures and indicators in the glass sector

No measures were discarded. However, some indicators were – these are shown in Table 38 below. The reasons for discarding indicators were either due to the data not being available, having conducted the research, or in order to align with other sectors and measures within the same sector.

Table 38: List of discarded resource efficiency indicators for the glass sector

Theme	Sub-theme	Measure name	Measure indicator	Reason for De-prioritisation
Sale & Use	Life extension	Measure 6: Lifetime extension through repair of products	% increase in utilised product lifetime through repair	Lack of data.
End of life	Reuse	Measure 7: Reuse of glass products	% increase in utilised product lifetime through reuse	Lack of data. Additionally, not deemed important to calculate the resulting reduction in demand.
End of life	Recycling	Measure 8: Recycle post-consumer glass not suitable for reuse	% post-consumer recycling rate of container glass, flat glass and glass wool	Changed to align with the measure name and exclude reuse from the rate

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