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Reuse, remanufacturing, recycling: the case of glass for buildings

Review of the technical feasibility and sustainability potential of the different end-of-life options for various building glass products

In March 2020, the European Commission (EC) adopted a new Circular Economy Action Plan (CEAP) (COM (2020) 98 final) that promotes greener manufacturing, waste reduction, reuse, remanufacturing, and recycling of construction products. This action plan is part of the EU Green Deal agenda, which aims to support the EU climate neutrality objective and strengthen sustainability practices in Europe.

As expressed in Glass for Europe's 2050 vision document[1], the European flat glass sector is committed to maximizing its contributions to the EU climate neutrality objective and seeking constant sustainability advances in all its activities.

The adequate end-of-life management of building glass products can be key in advancing these two objectives. For this reason, Glass for Europe issues this paper to shed light on the end-of-life management options for the different types of building glass products. The paper outlines how the different concepts of 'reuse' and 'remanufacturing' could apply to flat glass products and explains the technical possibilities and challenges of the different options. It also emphasizes the importance of promoting the closed-loop recycling of flat glass, which has the potential to become the most sustainable end-of-life option for much larger quantities of end-of-life flat glass.

1. What is to be understood as reuse and remanufacturing?

Considering that building glass products are covered by the EU Construction Products Regulation[2], the following definitions are used in this paper:

- **'used product'** means a product that is not waste or has ceased to be waste in accordance with Directive 2008/98/EC, and which has been installed at least once into a construction work, and that:
  - has not undergone a process going beyond checking, cleaning or repairing recovery operations, by which the product or components of products are prepared so that they can be used for construction purposes without any other pre-processing; or
  - has been subject to a transformative process going beyond checking, cleaning and reparing recovery operations which according to the applicable harmonised technical specification is qualified as non-essential to the product's performance;[3]
- **'remanufactured product'** means a product that is not waste or has ceased to be waste in accordance with Directive 2008/98/EC, which has been installed at least once into a construction work, and that has been subject to a transformative process going beyond checking, cleaning

[1] Glass for Europe. (2020). 2050 | Flat Glass in Climate-Neutral Europe. https://glassforeurope.com/2050-flat-glass-in-a-climate-neutral-europe/

[2] Regulation 2024/3110. *Regulation (EU) 2024/3110 of the European Parliament and of the Council of 27 November 2024 laying down harmonised rules for the marketing of construction products*. http://data.europa.eu/eli/reg/2024/3110/oj

[3] Regulation 2024/3110, Article 3 (20).

and repairing recovery operations which according to the applicable harmonised technical specification are qualified as essential to the product's performance;[4]

In addition, **'remanufacturing'** means an industrial process that produces a product from used products where at least one change is made that influences the product's safety, original performance, purpose or type. The product created by the remanufacturing process may be considered a new product when placed on the market.

Considering the definitions given above, **'reusing'** a product would mean using it for its original purpose more than once without further processing. **Preparing for reuse** then means checking, cleaning, or repairing retrieval operations, by which products or components of products are prepared so that they can be reused without any other pre-processing[5].

Glass for Europe recognizes the interest in reusing/remanufacturing flat glass when it is technically achievable and can effectively reduce CO_2 emissions during the whole life cycle. There are, however, considerations to apprehend and technical constraints that can limit the potential for reuse and remanufacturing of flat glass products. These are outlined in the following sections.

2. Potential and recommendation for the reuse of flat glass

Glass products for building and construction applications are generally custom-made. The glass product is selected to satisfy legal requirements and the individual preferences of the building owner, considering the building design, usage, climatic zone, etc. The characteristics of the glass (e.g., size, type) are bespoke, except for certain specific applications like glass doors or roof windows where standard glass sizes exist. As a result, a window or a roof glazing suitable for one building is unlikely to be suitable for another building or another location.

The possibilities for reusing are thus limited, and the legal requirements related to the new application need to be carefully checked and compared with the product requirements. From a technical perspective, the elements to be verified when preparing a product for reuse depend on the glass type:

a) Annealed monolithic glass

Monolithic annealed glass can last several centuries, depending on the product's environmental conditions. However, the glass surface properties may change throughout its life.

Mechanical impacts over a long period of time may result in scratches of randomly distributed length, depth, and orientation that may or may not be visible, depending on the observation conditions. Surface lacerations that may not be disturbing under a certain installation and observation condition may well become obtrusive under other conditions, especially when the glass surfaces are coated.

In case of chemical attacks or deterioration, changes in the surface chemistry will appear. Depending on the type of chemical attack, the surface structure and/or the refractive index at the glass surface may result in colour changes of the reflected light, increased roughness, variations in wettability, haze, or cloudiness.

[4] Regulation 2024/3110, Article 3 (25).
[5] This definition is taken from the initial CPR proposal of the EU Commission (COM (2022) 144 final), Article 3 (30): https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52022PC0144

b) Thermally pre-stressed glass

There are several thermally pre-stressed glass products:

- Thermally toughened safety glass
- Heat soaked thermally toughened safety glass
- Heat strengthened glass

These products have a lifetime that is like the one of monolithic glass.

c) Laminated glass

Laminated glass has a shorter lifetime than monolithic glass as it includes organic interlayers, which, even if not visible, may change the safety and security properties of the products when exposed to UV radiation, moisture or high temperature over a long period.

d) Insulating glass units (IGUs)

The expected lifetime of insulating glass units is 25-30 years. This is because the edges are sealed using organic sealants. Moisture, which permeates through the edge seal, is usually absorbed by desiccants, which are incorporated in the spacer bars, keeping the glass sheets at the desired distance. If the desiccant is saturated, the ingress of additional moisture in the IGU will leach off the inner glass surfaces and possibly attack silver-based coatings. These processes will lead to a deterioration of the product properties and adversely affect the visual appearance of the IGU.

When discussing IGUs, one also needs to ensure that the performance of the product is still adapted for today's needs. An IGU can be considered “high-performance” and thus adequate for incorporation in buildings from an energy efficiency perspective if it has a U-value of about 1,0 to 1.4 W/m²K in case of double glazing and 0,5 to 0.9 W/m²K in case of triple glazing[6]. Up-to-date insulating glass units usually incorporate coated glass and can be filled with gas, mostly with argon and less frequently with krypton. Both operations improve the U-value and the g-value of the IGUs to allow adequate energy efficiency in the buildings where the IGUs are installed. For gas-filled IGUs, a small percentage of the gas will be lost over time due to permeation through the edge seal. The loss is less than 1% per annum but may deteriorate the U-value of about 0,1 W/m²K after 30 years. Considering these points, even if a used product might have a low U-value (< 1,5 W/m²K), it is most likely unsustainable to reuse it since it will limit the energy performance of buildings.

The market penetration of high-performance glazing is not identical everywhere in the EU and depends on local climates, market availability of products, and national legislation requirements[7]To assess whether the remaining expected lifetime of the product meets the customer's needs, it is necessary to know at least the year of production and the place of first installation.

The constraints described in this section mean that glass products often cannot be reused, and other end-of-life processes must be considered.

[6] Glass for Europe, (2023). Choosing ‘High energy performance’ glazing in windows. https://glassforeurope.com/choosing-high-energy-performance-glazing-in-windows/
[7] Op. cit. Glass for Europe (2023)

3. Potential and recommendation for remanufacturing flat glass

Due to the requirements indicated in the previous section, remanufacturing may be more adapted than reusing glass. The following remanufacturing processes can be considered depending on the type and state of glass:

- Edge processing
- Cutting to smaller sizes
- Pre-stressing, including enameling
- Bending
- Laminating
- IGU manufacturing
- Sandblasting
- Acid etching
- Painting

These manufacturing processes can only be applied to certain used glass types; **Annex A provides an overview of processes which can be applied per type of used glass.**

Note that even when one of the above processes can be applied to a used product, the mechanical and chemical properties of the surface of the used product can have changed compared to when it was first installed. Although these changes may not be visible, they can influence the process and the success of the remanufacturing, e.g., due to an increase of surface haze and modification of adhesion properties and on the mechanical resistance.

The following processes are never recommended for remanufacturing:

- Coating: A possible change in surface chemistry will influence the optical properties of the coating and may also compromise the adhesion. Scratches may become more visible after coating.
- Silvering: mirrors are very sensitive to any optical defect
- Chemical strengthening: This process is expensive, and research would be necessary to confirm that it is suitable for used glass.

4. Assessment of flat glass products for reuse/remanufacturing

When assessing if a used product made of flat glass can be reused or remanufactured, the following impacts must be considered:

- Human safety
- Environmental safety and environmental impact
- Product durability
- Excessive costs
- Risks to machinery
- Safety for the building, etc.

Keeping these impacts in mind, a quality protocol should also be prepared for each project and focus on the following actions when relevant:

1. Assessment of relevant product properties/functions (bending strength, safety properties, U-value, light and solar characteristics, etc.), as well as aesthetic expectations

2. Deconstruction processes
3. Disassembly processes
4. Preparation for reuse
5. Preparation for remanufacturing
6. Remanufacturing process
7. Handling (in all stages)
8. Transport (in all stages)

Finally, the quality protocol should be accompanied by proof that reuse/remanufacturing has a significantly lower CO_2 impact compared to the use of a new product. This evaluation should be based on the harmonized methodology outlined in EN 15804:2012+A2:2019+AC:2021 and EN 17074. Considerations going beyond product-related emissions are also needed. If installing reused/remanufactured glass products in a building reduces the efficiency of this building and increases the building's operational emissions, using reused/remanufactured products may cause more CO_2 emissions overall.

When reusing and remanufacturing are not possible, other end-of-life treatment options should be considered, such as recycling, which can reduce CO_2 emissions during the production of new glass. **Annex A provides all end-of-life possibilities for different glass product types.**

5. Closed-loop recycling should become the predominant sustainable end-of-life option for flat glass products

While the reuse and remanufacturing of products offer specific sustainability benefits and stand higher in the waste hierarchy (see Figure 1), recycling is likely to become the predominant end-of-life option for most flat glass products. This is due to the various limitations to the reuse and remanufacturing of flat glass products, which are explained in the previous sections of this paper.

Figure 1 – Waste hierarchy as laid down in the EU Waste Framework Directive[8]

[8] https://environment.ec.europa.eu/topics/waste-and-recycling/waste-framework-directive_en

The closed-loop recycling of flat glass products offers many benefits in terms of CO_2 emissions reduction and saving resources from virgin raw materials. The use of 'cullet', i.e., recycled glass, as raw material is critical for the glass industry. Because it requires less energy to melt, it contributes to reducing energy consumption and 'heat-related CO_2 emissions. It also helps reduce 'process emissions' as using cullet saves 1.2 times the same amount of raw materials.

The share of recycled glass (i.e., cullet) used as raw material has increased over the last decade thanks to collection schemes set in place by the industry with transformers and recyclers. Moving from 20 to 26% of cullet has made possible a further reduction of 6% of CO_2 emissions[9].

The flat glass industry is actively looking for ways to recover more flat glass cullet to produce new flat glass. This requires better dismantling, sorting and cleaning of end-of-life glazing to reach quality levels good enough for remelting into new flat glass products. Glass for Europe is collaborating with EU authorities to that end[10].

To reap all the sustainability benefits of flat glass recycling, Glass for Europe supports 'closed-loop' recycling whereby end-of-life building glass products are recycled into new flat glass products (see Figure 2). Recycling flat glass into other types of glass products or recovering it for use as aggregate are forms of downcycling and should be avoided.

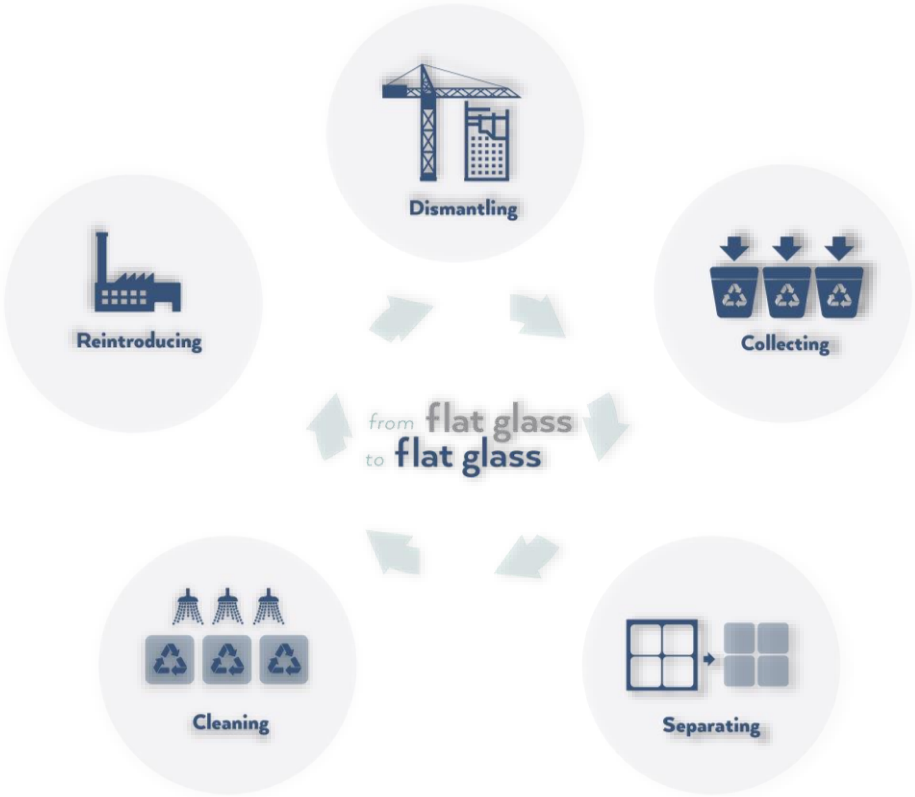

Figure 2 - Closed-loop recycling process for flat glass.

Please read the Glass for Europe paper on closed-loop recycling of flat glass for more information.[11]

[9] Op. cit. Glass for Europe (2020)

[10] Glass for Europe. (2023). Glass for Europe responses to two EU consultations on C&D waste & flat glass recycling. https://glassforeurope.com/glass-for-europe-responses-to-two-eu-consultation-on-cd-waste-flat-glass-recycling/

[11] Glass for Europe. (2024). Recycling of end-of-life building glass - A powerful tool to reduce CO_2 emissions. https://glassforeurope.com/recycling-of-end-of-life-building-glass-2/

6. Conclusions

Glass for Europe recognizes the interest in reusing/remanufacturing flat glass when it is technically achievable and can effectively reduce CO_2 emissions during the whole life cycle. There are, however, many considerations to apprehend and technical constraints that limit the potential for reuse and remanufacturing of flat glass products.

- Technically speaking, choosing whether to reuse, remanufacture, or transform old glazing in cullet to produce new glass panes (recycling) depends on the quality of the used product, which cannot be known upfront when dismantling buildings. Besides, the industry has little practical experience with reuse/remanufacturing practices. For instance, the protocol to follow for reuse has not yet been researched extensively. As of today, used products need to be assessed by flat glass experts with the competence and experience to evaluate what is feasible.
- The industrialization of different processes needed for reuse and remanufacturing may also be difficult or even impossible in some cases.
- From a sustainability point of view, evaluating whether reuse/remanufacturing activities are advantageous must be done for each project, considering the whole life cycle of products and buildings in which the glass will be used and be declared following European standards (EN 15804:2012+A2:2019/AC:2021 and EN 17074).
- Finally, this paper does not address the legal aspects surrounding the reuse/remanufacturing of used products, which is something needed. Various aspects would need to be scrutinized, e.g., the assessment procedures to guarantee the performance of flat glass products, the distribution of responsibilities for the making and usage of dismantled products or the rules regarding their transport among EU member states.

For the reasons explained above, reuse and remanufacturing, although potentially highly sustainable end-of-life treatments are likely to remain niche practices, adapted for very specific end-of-life flat glass products to be used in bespoke applications. The most sustainable option for managing large quantities of end-of-life flat glass rather lies in closed-loop recycling. Glass for Europe calls on EU authorities to work with industry to develop adequate closed-loop recycling infrastructures.

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Please note that this document does not cover the whole portfolio of glass types. Other types of glass products might be adapted for reuse or remanufacturing provided that the needed processes are applicable and that the final product satisfies legislative requirements and customer expectations.

Glass for Europe is the trade association for Europe's flat glass sector. Flat glass is the material that goes into a variety of end products, primarily in windows and facades for buildings, windscreens and windows for automotive and transport as well as solar energy equipment, furniture and appliances. Glass for Europe brings together multinational firms and thousands of SMEs across Europe, to represent the entire building glass value-chain. It is composed of flat glass manufacturers, AGC Glass Europe, Guardian, NSG-Group and Saint-Gobain Glass Industry, and works in association with national partners gathering thousands of building glass processors and transformers all over Europe.

Annex A

End-of-life possibilities and potential for remanufacturing of used flat glass products

The potential for remanufacturing depends on the operations that the used product can withstand. Table 1 informs about the remanufacturing processes that can be used on various glass types and indicates the possible treatment at the end-of-life of glazing products.

Table 1 – End-of-life possibilities per glass type & details on processes that can be considered for remanufacturing

Glass type	Processes that can be considered suitable for remanufacturing	End-of-life possibilities
Annealed glass (float, patterned glass, acid etched glass, sandblasted glass)	cutting, edge processing, lamination, thermal prestressing, chemical strengthening, printing, IGU assembly	Reuse, Remanufacturing, Recycling
Wired glass	cutting, edge processing	Reuse, Remanufacturing, Other waste industry
Annealed painted glass		
Mirrors		
Magnetron coated float (annealed)	not applicable[12]	Recycling
Magnetron coated float (Thermally prestressed)	not applicable	Recycling
Pyrolytic coated float (annealed)	cutting, edge processing, lamination, thermal prestressing, chemical strengthening, printing, IGU assembly	Reuse, Remanufacturing, Recycling
Pyrolytic coated float (Thermally prestressed)	not applicable	Reuse, Recycling
Laminated glass	cutting, edge processing, IGU assembly	Reuse, Remanufacturing, Recycling
Laminated glass made with thermally prestressed glass panes	not applicable	Reuse, Recycling (not all laminated glass can be recycled yet), Other waste industry
Insulating glass units (IGUs)	Disassembled glass components of IGUs shall be processed according to their glass types' possibilities.	Reuse, Other waste industry
Prestressed glass types	not applicable	Reuse, Recycling
Note on the end-of-life possibilities: Reuse: Systems & components may be suitable for reuse. Remanufacturing: Systems & components may be suitable for remanufacturing. Recycling: Scrap material can be of high value and processed in a recycling facility. Other waste industry: Unsorted scrap material that cannot be recovered for glass recycling can be sent to other waste treatment facilities (e.g. landfills).		

[12] Glass with Class A and B coatings according to EN 1096-1 can sometimes be remanufactured.

Bibliography

[1] *Rebecca Hartwell, Sebastian Macmillan, Mauro Overend: Circular economy of façades: Real-world challenges and opportunities*

[2] *Rota, A., Zaccaria, M. & Fiorito, F. Towards a quality protocol for enabling the reuse of post-consumer flat glass. Glass Struct Eng (2023). https://doi.org/10.1007/s40940-023-00233-0*

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