Driving Flat Glass Circularity: A Contribution to Sustainability in the Construction Sector

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Abstract

Flat glass is a critical material in the construction and automotive industries, but its production is resource-intensive and contributes significantly to carbon emissions. AGC Glass Europe is committed to advancing flat glass circularity by increasing the recycling rate of flat glass waste, known as cullet. Recycling cullet reduces landfill waste, preserves natural resources, and mitigates carbon emissions, aligning with circular economy principles. This paper explores the sources of cullet, including internal, pre-consumer, and post-consumer sources, and highlights successful recycling initiatives such as the Oxy Project in Brussels, which saved 210 tons of CO_2 through closed-loop recycling of 300 tons of dismantled glass. Closed-loop recycling is a sustainable approach that ensures materials are continuously reused within the same production cycle, minimizing waste and reducing the need for virgin resources. In the flat glass industry, cullet is collected, cleaned, and reintroduced into the manufacturing process, reducing energy consumption and CO_2 emissions. AGC has established strict guidelines for cullet collection to ensure quality and avoid contamination, with recycling yields varying by cullet type. For example, clear flat glass (Quality A) achieves a recycling yield of 95–100%, while laminated glass (Quality B) requires additional treatment prior to recycling which aim to maximize resource efficiency and minimize waste, emphasizing the importance of designing systems and products that prioritize sustainability. This paper also presents three use case in driving flat glass circularity: an example of post-consumer glass collection, the case of the first-ever hybrid furnace to produce flat glass only by electric green energy and the case of low- carbon glass. Additionally, AGC's decarbonization efforts focus on increasing cullet use, electrification, hybrid melting, hydrogen combustion, and carbon capture, utilization, and storage (CCUS), alongside the development of low-carbon glass products.

Keywords

Closed loop, recycling, Volta, R- Strategies, post- consumer, pre- consumer, recycled content

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1. Introduction

Flat glass is an essential material in the construction but also in the automotive industry. But its production is resource-intensive and contributes significantly to carbon emissions. AGC Glass Europe is committed to advancing flat glass circularity by increasing the recycling rate of flat glass waste, known as cullet. Recycling cullet not only reduces landfill waste but also preserves natural resources and mitigates carbon emissions. This paper explores the sources of cullet, examples of cullet types, and case studies that highlight successful recycling initiatives, demonstrating AGC's role in promoting sustainability in the construction sector.

2. Closed Loop Recycling, Waste Hierarchy Pyramid and the R9 Strategies

2.1. Closed Loop Recycling in the Flat Glass Industry

Closed-loop recycling is a sustainable approach that ensures materials are continuously reused within the same production cycle, minimizing waste and reducing the need for virgin resources. In the flat glass industry, this concept involves collecting and recycling post-consumer or post-industrial glass waste (cullet) to manufacture new flat glass products. Flat glass, commonly used in construction, automotive, and solar applications, is ideal for closed-loop recycling due to its ability to be recycled indefinitely without loss of quality.

The process begins with the collection and sorting of waste glass to remove contaminants. The cullet is then cleaned, crushed, and reintroduced into the glass manufacturing process, where it is melted alongside raw materials like silica sand, soda ash, and limestone. Using cullet reduces energy consumption, as recycled glass melts at lower temperatures compared to virgin materials, and decreases CO_2 emissions, contributing to environmental sustainability.

Closed-loop recycling in flat glass production not only conserves natural resources but also aligns with circular economy principles by keeping materials in continuous use. This approach is increasingly adopted by manufacturers to meet sustainability goals, reduce production costs, and comply with environmental regulations. By prioritizing closed-loop systems, the flat glass industry can significantly reduce its environmental footprint while supporting a more sustainable future.

2.2. Waste Hierarchy Pyramid

The waste hierarchy pyramid is a visual representation of the preferred order of actions to manage waste, emphasizing sustainability and environmental responsibility. It typically consists of the following levels, from most to least preferred:

a. Prevention: Avoiding waste generation in the first place by reducing consumption, designing products to last longer, and using fewer resources.
b. Reduce: Several examples are showing, that we can "make more with less". For example we can achieve a Ug Value from 0.7 W/m²K with a very slim glass configuration and only two panes of glass instead of three. This is possible thanks to vacuum glazing consisting of two sheet of glass with a distance from about 0.5 mm. Which allows glass thicknesses from 6 mm up to 12 mm. Reuse: Extending the life of products by using them again, repairing them, or repurposing them.
c. Recycling: Processing waste materials to create new products, reducing the need for raw materials.This is one of the key actions for closed-loop approach in the flat glass industry and others. It is key to collect and recycle flat glass waste (cullet) as much as possible to increase the circularity also for flat glass.
d. Recovery: Extracting energy or materials from waste, such as through incineration with energy recovery.

e. Disposal: The least preferred option, involving landfill or incineration without energy recovery. This hierarchy helps guide decision-making to minimize environmental impact and promote sustainable waste management practices. Let me know if you'd like a visual representation or further details!

2.3. The R9 strategies

The R9 strategies for a circular economy are a set of principles aimed at minimizing waste and maximizing resource efficiency by keeping materials and products in use for as long as possible. These strategies align with the goals of a circular economy, which seeks to create a sustainable system where resources are continuously reused, repurposed, and recycled. Here's a breakdown of the R9 strategies:

1. Refuse: Avoid unsustainable products and single-use items.
2. Reduce: Minimize resource consumption and waste during production.
3. Reuse: Extend product life by using items multiple times.
4. Repair: Fix damaged items to prevent premature disposal.
5. Refurbish: Restore used products to good condition.
6. Remanufacture: Rebuild products using reused, repaired, and new components.
7. Repurpose: Find new uses for items beyond their original purpose.
8. Recycle: Process waste into new products, e.g., glass recycling.
9. Recover: Extract energy or materials from non-recyclable waste.

These strategies form the backbone of a circular economy, emphasizing the importance of designing systems and products that prioritize resource efficiency, waste reduction, and sustainability.

3. But what are “cullet” and why is it good to use recycled glass?

Cullet, or recycled flat glass, is an important raw material in AGC’s decarbonization journey. It can be defined as “ready-to-use glass waste” that can be directly fed into float furnaces, complementing the traditional batch of raw materials such as sand, soda ash, dolomite, limestone, and alumina.

The use of cullet offers significant environmental benefits: for every ton of cullet used, 1.2 tons of raw materials are preserved, and 0.7 tons of CO2 emissions are avoided. This makes cullet a key component in producing low-carbon glass, for example.

4. Sources of Cullet

4.1. Internal Cullet

Internal cullet is coming from float line rejects, such as glass rejected for quality issues, glass from edge removal operations and glass discarded as a result of changes in thickness and/or colour. The quality of this cullet is well known and there are generally no risks associated with the full and direct reuse of this cullet in flat glass production. Glass with pyrolytic coatings, patterned glass, wired patterned glass, polished wired glass are excluded.

4.2. Pre-Consumer Sources

Pre-consumer cullet originates from industrial processes and includes production yield losses, off- cuts of flat glass processing(mirror production, coating, insulating glass units, laminated glass, etc.) , and defects during the assembly of glazing units. These sources are typically easier to manage due to their controlled environment and predictable quality.

4.3. Post-Consumer Sources

Post-consumer cullet is collected from end-of-life glazing and includes glass waste from residential and commercial renovations, as well as other sources such as automotive glass, refrigerator glass, and photovoltaic panels, which are currently under research and development.

Strict guidelines are in place to ensure the quality of cullet and avoid contamination. For example, prohibited materials in the collection of clear flat glass (Quality A) include colored glass, mirrors, and floor sweeping waste. Similarly, laminated flat glass (Quality B) and ISOMIX/IGU flat glass (Quality C) must exclude pollutants such as mixed glass, colors, mirrors, and floor sweeping waste.

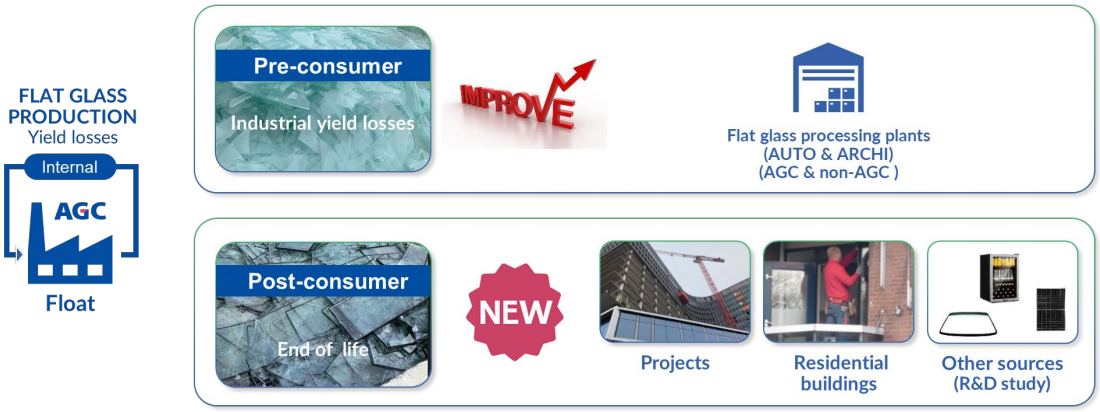

Fig. 1: Cullet Sources.

4.4. Categories of Cullet

Not all glass waste can be recycled into flat glass. AGC has established strict guidelines for cullet collection to ensure quality and avoid contamination. For example, clear flat glass (Quality A) must exclude materials such as colored glass, mirrors, and floor sweeping waste or ISOMIX (old insulating glass units) mixed glass. Laminated flat glass, classified as “Quality B” includes laminated and laminated safety glass, typically with a PVB interlayer. In case of other interlayer types, such as Sentry Glas or EVA, we must check the usability in individual cases. Quality B must also exclude materials such as coloured glass, mirrors, and floor sweeping waste or ISOMIX (old insulating glass units) mixed glass.. Similarly, ISOMIX/IGU (Quality C) must avoid, coloured glass, mirrors, and floor sweeping waste.

4.5. Recycling yield

The recycling yield varies depending on the cullet type. Typically the yield, this is the quantity of cullet which can be used from originally 100 % of gained cullet through the collection process, is

- For cullet according to category A, 95 % to 100 % (Ready to use glass waste which can be put in our float furnace)
- For cullet according category B, 60 % to 80 %, these cullet needs to be treated from a professional glass recycling before it is shipped to our float glass productions
- For cullet according category B, 45 % to 60 %, these cullet needs to be treated from a professional glass recycling before it is shipped to our float glass productions

The yield is varying with the quality of the sorting, the contamination of the original glass waste, the equipment of the glass recycler, the transport and many other influences.

By addressing these yield-related challenges and leveraging validated flat glass recyclers and waste management partners, AGC continues to optimize the recycling process and increase the use of cullet in its float furnaces.

- The EU Regulation 2020/852, clause 3.1, requires regarding the construction of new buildings:
- The use of primary raw materials in building construction must be minimized by prioritizing secondary raw materials.
- For glass (combined with mineral insulation), no more than 70% of the total material can come from primary raw materials.

Secondary raw materials are defined as those prepared for reuse or recycled under Article 3 of the Waste Framework Directive and that have ceased to be classified as waste under Article 6 of the same directive.

Primary raw materials are on the other hand, are natural, unprocessed, materials.

Clause 3.2. of the same regulation, requires for the renovation of existing buildings,

- At least 70% of the non-hazardous construction and demolition waste, measured by mass, must be prepared for reuse or recycling, excluding backfilling and naturally occurring materials classified under category 17 05 04 in the European List of Waste. Naturally occurring materials under category 17 05 04 are clean, non-contaminated soil and stones from construction, excavation, or demolition, classified as non-hazardous waste.
- Additionally, the use of primary raw materials in the renovation must be minimized by prioritizing secondary raw materials. For the combined total of glass and mineral insulation added during the renovation, no more than 85% of the material can come from primary raw materials.

All construction and demolition waste generated during the process must be treated in accordance with Union waste legislation and the EU Construction and Demolition Waste Management Protocol. This includes implementing sorting systems and conducting pre-demolition audits.

For the purposes of collecting cullet, there is an increased need for the recovery of old glass.

Regulation (EU) 2020/852, also known as the EU Taxonomy Regulation, establishes a framework to classify environmentally sustainable economic activities. Its goal is to guide investments toward projects and activities that contribute to the EU's environmental objectives, such as climate change mitigation, adaptation, and the transition to a circular economy.

Green Building certification schemes are in general addressing the need of circular economy, but also the context of re-use or recycling. It is worth to mention that in the context of green building certification schemes, only post- consumer cullet is rated with credit points. But knowing, that collecting industrial losses, pre- consumer cullet, which are then normally not used in the closed loop scenario – flat-to-flat – are having also a positive environmental impact.

4.6. Recycled Content

In the context of glass recycling, it is essential to differentiate between the terms "recycling content" and "recycled material." Glass manufacturers may report the percentage of cullet used to produce glass with reduced CO2 emissions, as well as the "recycling content" of their products. The recycling content is calculated according to ISO 14021, which defines it as the proportion, by mass, of recycled material in a product or packaging. Only pre-consumer and post-consumer materials are considered as recycled content, in line with the definitions provided in the standard.

Recycled material is defined as material that has been reprocessed from recovered or reclaimed material through a manufacturing process and transformed into a final product or a component for incorporation into a product.

5. Practical approach to reduce CO2 emissions

AGC's sustainability approach is centred on achieving carbon neutrality by 2050, as outlined in its medium-term management plan, AGC plus-2023. The company has set interim targets, including a 30% reduction in direct and indirect CO2 emissions by 2030, and is actively working to reduce emissions across its supply chain through energy-saving technologies, renewable energy utilization, and inter-industry collaboration.

Decarbonizing the manufacturing of flat glass, we need to address this topic with an holistic approach. Some of these solutions exist already today or must be further developed. This includes the

Decarbonization in glass production involves a variety of strategies, each with distinct impacts on CO2 emissions across Scope 1, 2, and 3, as well as specific advantages and challenges. Increasing the use of cullet, or recycled glass, is a key approach that reduces energy consumption and avoids emissions by replacing carbonated raw materials. Electrification and electrical boosting offer alternatives to fossil fuels, leveraging electricity to heat molten glass more efficiently. Hybrid melting combines traditional combustion methods with electrical boosting, enabling a gradual transition to lower-carbon production. Hydrogen combustion is a promising alternative fuel, producing water vapor instead of CO2, though it requires significant infrastructure and cost considerations. Carbon Capture Utilisation & Storage (CCUS) captures emissions for storage or reuse, mitigating direct emissions from production processes. Decarbonated raw materials further reduce emissions during production and complement other strategies like cullet recycling. Together, these solutions contribute to sustainability goals by addressing emissions across various scopes while balancing efficiency, cost, and environmental impact

5.1. Organisation of the building site

On- site glass collection

Apart from an appropriate sorting of the glass, the on-site collection of cullet (recycled glass) faces several challenges:

- Quality: The use of cullet from external sources in flat glass furnaces is limited due to significant quality concerns. Contaminants such as metals, stones, ceramics, plastic, and wood can ruin an entire production batch. Ensuring the cullet is free from these pollutants requires a strict treatment process.
- Traceability: Maintaining the traceability of cullet batches is difficult, which can lead to limited care during the dismantling process. This further aggravates quality concerns for flat glass makers
- Logistical Challenges: Effective cullet management requires proper coordination with transport companies to ensure timely collection and avoid mixing different types of cullet.
- Storage and Handling: On-site storage and handling of cullet require dedicated facilities and personnel.
- Economic Viability: The economic benefit of using cullet is limited for all players involved, which can discourage its collection and recycling.
- Dismantling: During the dismantling process the glazing will be removed from the frames either on site or in a specific workshop. All joinery, hardware, gaskets and sealants must be removed properly to limit the breakage of the glass. Broken glass lying on the floor can’t be recovered for recycling as this leads to huge risk of additional pollution (bricks, concrete, etc.).

These challenges highlight the complexities of on-site cullet collection and the need for strict processes, effective coordination, and dedicated infrastructure to ensure its successful integration into glass production.

EU Construction & Demolition Waste Management

The EU Construction & Demolition Waste Management Protocol is a framework designed to improve the management of Construction and Demolition Waste (CDW), which is the largest waste stream in the European Union. It aims to foster trust in recycled materials and reused products while promoting circularity in construction activities. The EU Construction & Demolition Waste Management Protocol is a framework aimed at improving the handling of Construction and Demolition Waste (CDW), the largest waste stream in the European Union. Its primary goal is to build trust in recycled materials and reused products while advancing circularity in construction practices. The key aspects are:

Objectives

- Enhance CDW Management: Improve processes for handling, recycling, and reusing CDW.
- Foster Trust: Build confidence in recycled materials and reused products through quality assurance.
- Promote Circularity: Encourage sustainable practices in construction to reduce waste and maximize resource efficiency.

Key Processes

a. Pre-Demolition Audits:
   Conduct audits to identify hazardous materials and assess the potential for reuse and recycling.
   Ensure proper documentation of materials for effective waste management.
b. Selective Demolition:
   Implement safe and systematic demolition practices to segregate waste materials effectively.
   Focus on separating glass, concrete, metals, wood, and other materials to facilitate recycling.
c. Transparent Waste Logistics:
   Establish clear and traceable systems for waste transportation and storage.
   Ensure compliance with regulations and promote accountability in waste handling.

Use case – The Oxy Project (Brussels, Belgium), Recycle Glass Service

AGC has successfully implemented flat glass recycling initiatives in several large renovation projects, showcasing the practical application of its circularity efforts. The Oxy Project is located in the city centre of Brussels. The building is undergoing a total refurbishment with a strong focus on sustainability. The building will contain in future apartments, offices and a hotel. As mentioned before, the onsite recovery of old glass elements is a challenge for several parties. In total three partners were involved. The waste company De Meuter, which has done the on-site dismantling of the old glass panes from the frames including the container supply and the overall logistic service. As well as the transport and storage including the necessary authorisations and reporting. Minerale was the second partner, doing the flat glass recycling and responsible for the transport of the ready-to-use cullet to AGC. And finally AGC as a glass manufacturer. The new glass is also Low- Carbon Glass.

The Oxy Project involved the dismantling of 2800 panes of glass, in total 300 tonnes of double glazing units and laminated glass were dismantled and brought back to a full closed loop recycling in the float glass production. Thanks to that approach 210 tons of CO_2 have been saved as well.

Use- case Volta Project

The Volta project involves the design of a hybrid mid-sized pilot furnace for flat glass production, developed collaboratively by AGC and Saint-Gobain. This innovative furnace aims to significantly

reduce direct CO2 emissions by combining 50% electrification with 50% firing using a mix of oxygen and gas. This approach represents a technical breakthrough compared to traditional flat glass furnaces that rely solely on natural gas.

The furnace design is part of a broader decarbonization effort in the flat glass industry, supported by the European Union's Innovation Fund. The project is expected to pave the way for industrial flat glass lines to be powered primarily by low-carbon electricity, offering greater efficiency and reduced carbon emissions compared to gas-based solutions. Operational testing of the new furnace technology is planned for the second half of 2024.

AGC's patterned glass production line in Barevka, Czech Republic, will be entirely refurbished into a high-performing, state-of-the-art line to implement this new furnace design. This refurbishment aligns with AGC and Saint-Gobain's shared commitment to carbon neutrality and accelerating decarbonization in the flat glass industry.

The furnace design incorporates innovative processes, including oxygen combustion and an improved electrified ratio, to further enhance energy efficiency and reduce greenhouse gas emissions.

Use- case Low- Carbon Glass

To address environmental concerns, flat glass manufacturers have developed low-carbon products with a significant reduction of the Global Warming Potential (GWP).

To reach low CO2 values, a holistic approach is a useful and reliable approach. AGC for example is focusing on six key areas for scope 1, 2 and 3.

1. Sustainable sourcing of materials
2. Use of highly efficient melting furnaces
3. Increased use of cullet
4. Use of green electricity
5. Optimisation of transport between production lines for finishing processes
6. Optimisation of transport for end products

The scopes of carbon emissions were introduced by the Greenhouse Gas (GHG) Protocol, the internationally recognized standard for corporate carbon footprint calculations. They break down GHG emissions into 3 different categories, facilitating the work of assessing the carbon footprint.

- Scope 1 = direct emissions occurring at the production plants
- Scope 2 = indirect emissions from electricity and steam production
- Scope 3 = indirect emissions from upstream and downstream activities along the value chain

6. Conclusions

The glass industry commitment to flat glass circularity is transforming the construction sector by reducing carbon emissions, preserving natural resources, and minimizing landfill waste. By leveraging pre-consumer and post-consumer cullet sources, implementing strict quality standards, and collaborating with waste recyclers, AGC is driving the transition to low-carbon glass production. Case studies such as the Oxy Project, demonstrate the tangible benefits of flat glass recycling, contributing to a more sustainable future for the planet.