International Journal of Recent Research and Review, Special Issues-3 - 2025
ISSN 2277 – 8322

ADVANCING CIRCULARITY IN THE GLASS INDUSTRY: WASTE MANAGEMENT PRACTICES AND ROADMAP FOR INDIA

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Abstract- The glass industry plays a key role in sustainable manufacturing but faces challenges in production scrap management, post-consumer waste, and end-of-life glass products. Soda lime glass, also called soda–lime–silica glass, is the most prevalent type of glass, used for windowpanes and glass containers (bottles and jars) for beverages, food, and some commodity items. Soda–lime glass accounts for about 90% of manufactured glass.

Soda–lime glass is relatively inexpensive, chemically stable, reasonably hard, and extremely workable. Because it can be re-softened and re-melted numerous times, it is ideal for recycling. This paper explores waste management practices and circular economy approaches in the glass sector, with a focus on recycling, resource efficiency, and emission reduction. Glass, being 100% recyclable without loss of quality, offers significant potential for a closed-loop system. However, issues such as contamination (metals, ceramics etc.), different types of cullet mixing, and segregation inefficiencies often hinder large-scale recycling.

The study highlights industrial practices for utilizing cullet in float glass production, along with innovative technologies like optical sorting, remelting, and beneficiation. Case examples from architectural glass manufacturing show that using up to 20–40% internal cullet can reduce energy

consumption by 10–20% and cut CO_2 emissions proportionally. Further, the integration of Extended Producer Responsibility (EPR), take-back systems, and secondary raw material policies within the circular economy framework can help establish sustainable glass value chains.

This paper also reviews environmental and energy benefits of recycling, case examples from Indian and multinational glassmakers, policy and logistical challenges, and a practical roadmap to accelerate circularity in India's flat and container glass sectors.

Keywords: glass waste, cullet recycling, circular economy, flat glass, sustainability, waste management, India, Asahi India Glass.

I. INTRODUCTION

Glass is a vital material for strategies centred around the circular economy: it is chemically stable, inert, and can be re-melted endlessly without losing its properties. In the production of industrial glass, replacing virgin raw materials with cullet decreases the energy needed to melt the batch and reduces CO_2 emissions in the process. Guidance from the international industry and targets set by manufacturers underscore the importance of cullet for the glass sector to achieve its goals for reducing greenhouse gases. In India, the demand for architectural flat glass (used in construction and automotive glazing), container glass (bottles), and specialty glass is increasing due to urbanization and industrial growth. Therefore, enhancing the use of cullet and closing material loops are essential to lessen the sector's environmental impact while ensuring feedstock security and economic benefits.

II. TYPES AND SOURCES OF GLASS WASTE

Glass waste originates from multiple stages of the life cycle:

- **Manufacturing scrap:** Breakage, rejections, off-cuts, and edge trimmings produced during coating, tempering, laminating, and float line processes (internal cullet). Due of its known composition and low contamination, this feedstock has the highest value.
- **Post-consumer flat glass:** automotive glazing, curtain walls, facades and windows that have reached the end of their useful lives. These are frequently noncoated (clear, tinted), coated, laminated, insulated glass units, or affixed to frames. Clear cullet is omniferous and can be used in production of almost all types of float

glass while coated, tinted, laminated and insulated glass units' cullet complicate recycling or reuse from a technological standpoint.

- **Specialty wastes:** Low thermal expansion glass, glass ceramics, tempered, laminated, or coated glass with organic layers, PVB interlayers, or sputtered coatings (e.g., low-e, solar-control) that complicate recycling for particular glass manfacturing.

A key practical limitation is that coatings, adhesives, sealants and mixed materials can make otherwise recyclable glass unsuitable for direct remelting unless pre-processed. Effective separation technologies and pre-treatment are therefore central to circular strategies for flat glass.

III. INNOVATIVE INDUSTRIAL PRACTICES FOR UTILIZING CULLET IN FLOAT GLASS PRODUCTION.

The study highlights industrial practices for utilizing cullet in float glass production, along with innovative technologies like optical sorting, remelting, and beneficiation.

- **Optical sorting:** In this technology cameras and sensors are used to separate unwanted materials from glass cullet by color, shape, and material type (especially metal contamination) for improving purity for recycling. The process involves feeding the cullet onto a conveyor, illuminating it, capturing images with high-resolution cameras and specialized sensors (like NIR for plastics or X-ray for heavy metals), and using a computer to analyze the data in real-time. Based on this analysis, a system of air jets or mechanical ejectors removes unwanted materials.

Figure-1 Schematic of Cullet Optical

- **Remelting:** Remelting cullet (recycled glass) is a standard part of the glass manufacturing process and a key technology for reducing environmental impact. Glass cullet melts at a lower temperature than virgin raw materials, significantly reducing energy consumption and carbon dioxide emissions.

Furnace technologies for cullet remelting

Regenerative furnaces- This is a standard furnace design used in glass manufacturing that is optimized for energy efficiency.

Oxy-fuel furnaces- This technology uses pure oxygen instead of air for combustion, which offers several advantages.

Electric melting furnaces- These furnaces use electricity to heat and melt the glass batch.

Hybrid furnaces- This technology combines different heating methods to maximize efficiency and reduce emissions.

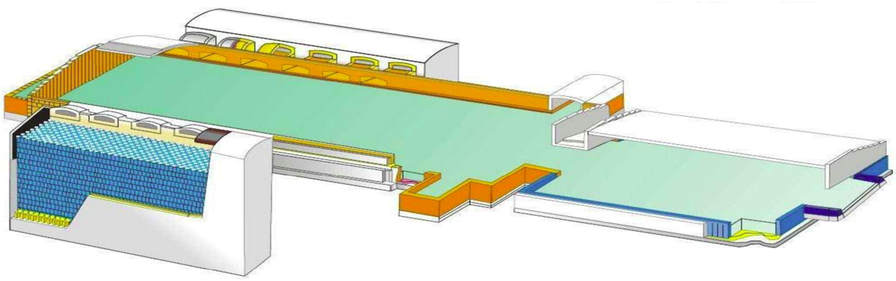

Figure-2 Schematic of Regenerative

- **Beneficiation:** Beneficiation technology for cullet recycling and processing involves a number of steps to prepared recycled cullet for reuse in glass manufacturing by separating(discarding) unwanted materials such as like ceramics, stones, and metals, specialty glass to sort the glass by color and shape to produce a high quality and contaminant free cullet for glass manufacturing.

The key technologies and stages of the beneficiation process include Eddy current technology and Redwave.

Eddy current technology uses a rotating magnetic rotor to separate non-ferrous metals from glass cullet by inducing eddy currents that repel the conductive metals away from the rest of the material stream

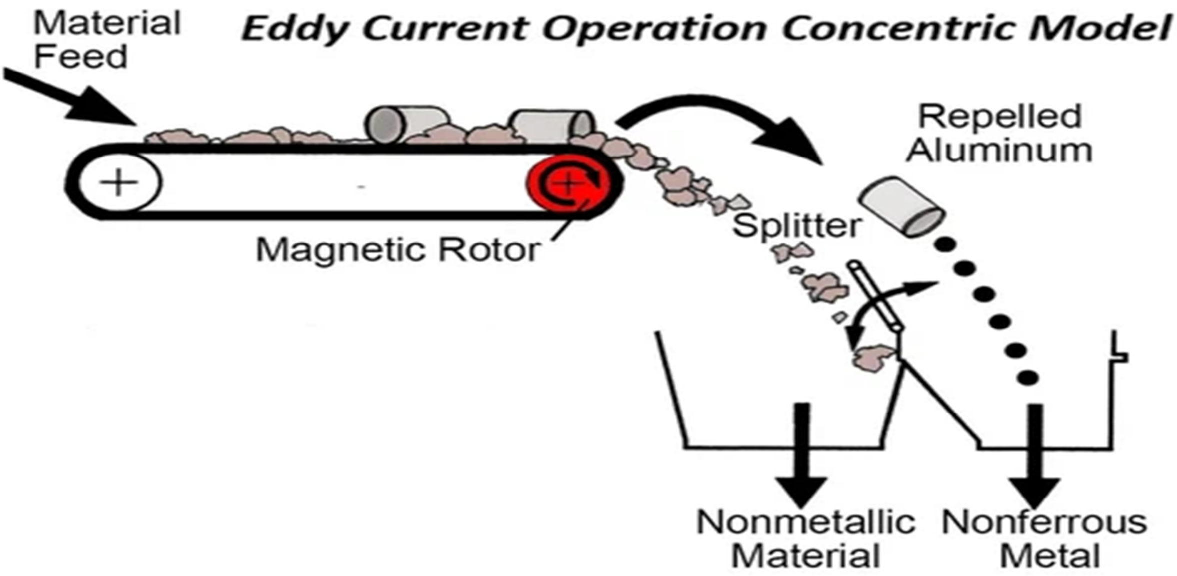

Figure-3 Eddy Current Operation for Cullet

Redwave's technology for cullet processing involves an integrated approach using sensor-based sorting, particularly X-ray fluorescence (XRF) technology, to achieve high purity and high-yield glass recycling. It automates the separation of colors (clear, amber, green), removes contaminants like leaded glass, glass ceramics, and stones, and uses a quality-control system to analyze and verify the final cullet's quality.

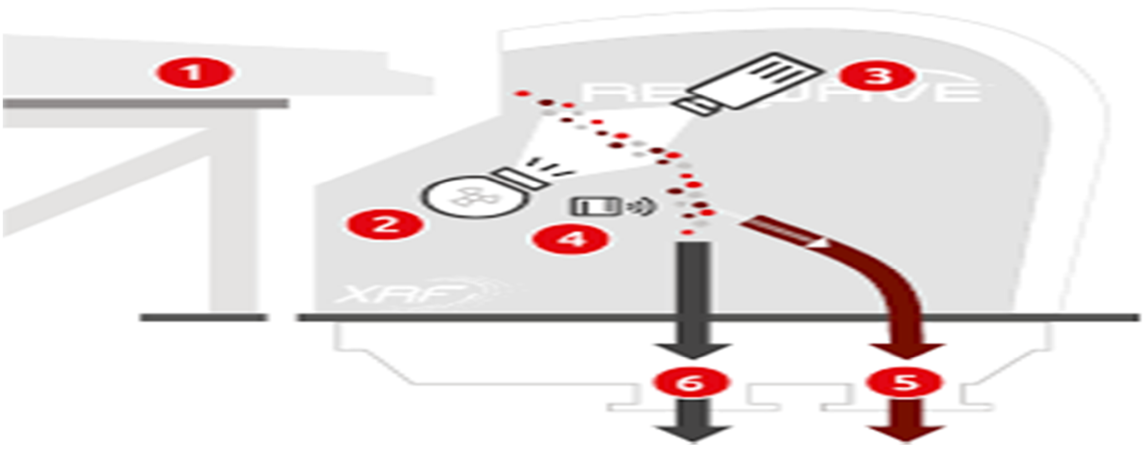

Figure-4 Redwave Operation for Cullet Sorting

IV. ENVIRONMENTAL AND ENERGY BENEFITS OF CULLET USE

Multiple technical studies and industry reports quantify the benefits of replacing virgin raw materials with cullet. A commonly-cited rule of thumb is that every 10% increase in cullet content reduces furnace energy consumption by roughly 2–3% and reduces CO_2 emissions by a larger relative percentage due to avoided raw-material calcination and lower melting temperatures. Several manufacturer and industry sources echo this relationship and set explicit cullet-use targets as part of 2030 sustainability goals.

Using cullet reduces the need for limestone, soda ash, dolomite and other carbon-containing raw materials; this contributes to process emissions reduction beyond mere energy savings. In practice, flat-glass plants often incorporate 10–40% cullet depending on batch chemistry, furnace design, and quality control.

V. COLLECTION, SORTING AND BENEFICIATION TECHNOLOGIES

For cullet to be reliably used in float and container furnaces, its composition must be consistent and free of contaminants. The principal steps are:

- **Collection and source-segregation:** Efficient municipal collection, deposit-return systems for bottles, demolition protocols that separate glazing from frames, and factory segregation of manufacturing scrap.
- **Pre-treatment and mechanical processing:** Crushing, removal of ferrous and non-ferrous metals, washing to eliminate organics, and screening by size.
- **Optical sorting and color separation:** Near-infrared and color-sensing sorters separate clear, green and amber cullet — essential for container glass where color consistency matters. For flat glass, color mixing is less restrictive, but coatings and laminates must still be removed or tolerated.
- **Chemical/thermal beneficiation:** In specific cases, adhesives or organics are thermally decomposed or chemically removed to make cullet furnace ready.

Investment in optical sorters and beneficiation lines is becoming more widespread globally and is a cost-effective lever for improving cullet quality and increasing furnace acceptance rates.

VI. INDUSTRY EXAMPLES — INDIA AND GLOBAL

Asahi India Glass Ltd (AIS)

AIS a major Indian flat and automotive glass producer — highlights sustainability actions in its recent reports, including investments in energy-efficiency, localizing supply and working toward greater resource circularity across product lines. AIS annual disclosures show the company's emphasis on reducing import dependence, improving manufacturing efficiency and aligning product portfolios for energy performance. These steps imply an ongoing focus on material efficiency and cullet integration, particularly for architectural and automotive glass segments.

AGC Group

- **Global Presence:** AGC Inc. is a global leader in glass, chemicals, and high-tech materials, with operations in over 30 countries.
- **Innovation:** The group is focused on innovation and sustainability, with market leadership in both building and automotive glass globally.
- **Indian Entity:** While AIS is the primary brand name for its India operations, the global AGC group has an entity named AGC ASIA PACIFIC (INDIA) PRIVATE LIMITED.

VII. CHALLENGES SPECIFIC TO INDIA

While India has strengths (large glassmakers with manufacturing scale, an active informal recycling sector for container glass, and growing sustainability interest), several barriers impede rapid circularity in flat glass:

- **Fragmented collection infrastructure:** Municipal solid-waste systems vary widely in performance; source segregation is inconsistent, reducing clean cullet availability for external sourcing.
- **Demolition and retrofit practices:** End-of-life flat glass often arrives contaminated (frames, sealants, PVB) and requires pre-processing that is not yet common in India.
- **Lack of centralized cullet hubs:** Many plants rely on their own internal cullet and local sources; the absence of regional processing hubs increases transport costs and reduces economies of scale.
- **Technical limits for coated and laminated glass:** Low-e, sputtered coatings and laminated interlayers require specialized handling or pre-

treatment; otherwise, these wastes must be downcycled.

- **Policy and market signals:** While EPR and waste-management rules for packaging exist, specific regulatory levers for flat-glass circularity (e.g., minimum recycled-content rules, demolition protocols) are less developed.

Addressing these gaps requires coordinated policy, investment in processing infrastructure, and manufacturer–municipality collaboration.

VIII. ECONOMIC AND LOGISTICAL CONSIDERATIONS

From an economics perspective, cullet delivers both cost and carbon advantages, but the value proposition depends on quality, proximity and steady supply. The energy and raw-material savings from cullet translate into operating savings for furnaces, yet capital is required for sorting and beneficiation; these investments pay back faster when a steady external supply of post-consumer cullet is available. Transport is a significant cost because glass is heavy; therefore, regional cullet hubs near clusters of glassmaking furnaces or urban centers are advantageous.

Market mechanisms such as supplier agreements, aggregated take-back contracts, and deposit-return systems for consumer glass can create predictable streams. Public–private partnerships (PPP) to establish regional cullet processing facilities can reduce barriers for smaller manufacturers.

IX. ROADMAP & RECOMMENDATIONS FOR INDIA

To accelerate circularity and convert the full potential of cullet into operational reality, the following actionable roadmap is proposed:

- **Strengthen source segregation and collection:** Municipalities and industry should coordinate pilots for separate glass collection in urban districts and promote deposit-return schemes for bottles where feasible. This increases clean cullet fraction and reduces downstream processing costs.
- **Establish regional cullet hubs:** Invest in regional mechanical and optical beneficiation centers located close to major urban centers and furnace clusters to reduce transport emissions and costs. Encourage shared ownership models or PPPs.

- **Mandate demolition best-practices:** Building codes and demolition permits should require separation of glazing from frames and pre-processing of laminated or coated glazing to divert them from landfills.
- **Incentivize furnace-ready cullet usage:** Offer tax credits, reduced electricity tariffs for energy-efficient melters, or low-interest capital for cullet-acceptance retrofits to accelerates adoption.
- **Promote R&D for coated/laminated glass treatment:** Fund pilot programs for PVB removal, coating stripping and thermal/chemical beneficiation to recover higher-value cullet from architectural wastes.
- **Industry takes-back and EPR for glass products:** Extend EPR frameworks to explicitly include flat glass and incentivize manufacturers to set up reverse logistics, in collaboration with recyclers.
- **Transparency and traceability:** Implement digital traceability (barcoding, circularity passports) for large projects to route high-quality end-of-life glass to recycling streams.
- **Awareness and demand creation:** Encourage architects, specifiers and developers to prefer products with high recycled content and promote market recognition (labels/standards) for cullet-content glass.

These steps will improve both environmental outcomes and economic viability.

X. CONCLUSION

Glass presents a rare opportunity for a high-value circular material flow: it is infinitely recyclable, the benefits of cullet are well quantified, and established manufacturers in India and globally already incorporate circularity targets. To fully realize this potential in India, however, requires investments in collection, beneficiation, regional processing hubs, demolition best-practices, and regulatory incentives that make cullet a steady, high-quality feedstock for both container and flat-glass furnaces. With coordinated action across industry, government and waste-management stakeholders, India's glass sector can significantly reduce energy use and process emissions while building resilient domestic supply chains.

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