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From Vision to Implementation: Evaluating Readiness for Circular and Climate-Neutral Glass Production

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Abstract

The glass industry is undergoing a profound transformation on its path toward climate neutrality by 2045. Along the value chain of glass and facade products, varying challenges emerge: while environmental considerations can be integrated relatively easily in some segments, others demand fundamental systemic change. Within the CircuClarity initiative, stakeholders from industry and academia collaborate to advance innovations supporting climate neutrality and circularity. This study evaluates the current state of development using a six-stage maturity model. Findings reveal heterogeneous progress—glass reuse is evolving rapidly and becoming increasingly product-specific, whereas advancements in sustainable energy sources for glass production remain limited, highlighting a continued need for technological innovation. This study focuses on a comparison of the groups and assesses their overall impact on energy reduction within the broader context of the industry based on the technology readiness level framework developed by the European commission.

Keywords

Circularity; Reuse; Remanufacture; Recycling; Circular economy; Collaborative initiative

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1. Introduction

Climate-related objectives are rapidly moving from policy frameworks into day-to-day decision-making in the construction sector. Across Europe and beyond, regulatory pressure and client expectations are increasingly shaping how materials are selected, specified, and evaluated. The glass and facade industry, while responsible for a comparatively small share of global emissions, plays a significant role at the building scale, particularly in highly glazed commercial buildings. As a result, the sector is under growing pressure to reduce emissions while maintaining performance, cost efficiency, and scalability.

In recent years, the industry has responded with a range of initiatives, including the publication of Environmental Product Declarations, the introduction of products with recycled content, and the establishment of sustainability-focused roles within companies. Despite these developments, circular and low-carbon solutions have not yet become mainstream. Implementation remains fragmented, and many innovations are still in early stages of development or limited to pilot projects.

The CircuClarity initiative, founded in 2022, provides a practical lens through which these developments can be assessed. Bringing together stakeholders from across the value chain—including manufacturers, fabricators, engineers, architects, and researchers—the initiative facilitates the exchange of applied knowledge and scalable solutions. The insights presented in this paper are derived from this collaborative environment and focus on real-world progress rather than theoretical potential. This paper is based on [1] and provides a brief overview and an assessment of developments as relates to circular practices in the glass and facade industry that have taken place between 2022 and 2025 and that have been shared and discussed with the participants of the CircuClarity platform.

2. Approach

The aim of this study is to provide decision-makers with a clearer understanding of which innovations are ready for implementation and which require longer-term development. Instead of focusing on theoretical models, the analysis is based on observed industry activities presented at major international events between 2022 and 2025. These include Glasstec and Glass Performance Days, which serve as key platforms for both academic and industrial exchange.

Innovations are assessed using a simplified readiness framework adapted from technology readiness levels [2], ranging from early-stage concepts to fully commercialized solutions. In parallel, their practical relevance is evaluated based on two criteria: their potential to reduce carbon emissions and their applicability across the industry. This dual perspective allows for a more grounded assessment of which developments are likely to have meaningful impact in the short to medium term.

The analysis is structured around five thematic areas that reflect the main fields of activity within the industry: energy, secondary materials, material recovery systems, design for disassembly, and data and communication. These categories provide a practical framework for understanding where progress is occurring and where barriers remain.

Fig. 1: CircuClarity groups based on relevant topics within the industry.

2.1. Readiness Assessment

Based on the nine Technology Readiness Levels (TRL) framework developed by the European Commission [2], a simplified set of six stages was derived to better reflect the specific context of climate neutrality and circularity in the glass and facade industry, see Table 1. These stages, referred to as readiness levels (RL), were defined through their application to a range of observed innovations, allowing for a more practice-oriented assessment of development progress**.**

Table 1. Technology Readiness Levels

Level	TRL	Description
1	Relevance Addressed	Corresponds to the initial recognition of a problem and the formulation of a basic solution approach. At this stage, the underlying principles are understood, but no concrete concept has been developed yet.
2	Solution Proposed	Describes the stage at which ideas and concepts are articulated. These may include not only technological approaches but also new product designs, workflows, or business processes that respond to the identified challenge
3	Lab Testing	Concepts are translated into experimental applications. Early prototypes, materials, or processes are tested under controlled conditions. Since experimental validation and laboratory testing often overlap in practice, they are considered jointly at this stage
4	Prototype Stage	Marks the transition from controlled environments to real-world application. Solutions are tested within a building context, and their performance is demonstrated under practical conditions. This stage typically includes pilot projects or demonstrator buildings
5	Product Pioneering	Refers to the first introduction of a solution into the market. At this point, the product or process has been fully developed and is applied commercially, often without direct competition. This stage represents the completion of development from a technical standpoint.
6	Commercial Product	Describes solutions that are no longer novel but have become established in the market. These products are used across multiple projects and can be considered part of standard industry practice.

In addition to the assessment of Readiness, Environmental Relevance is assessed based on two key aspects: the extent of carbon reduction and the degree to which the innovation can be applied across the industry. On this basis, three levels of relevance are defined, see Table 2.

Table 2. Relevance Levels

Level	Relevance	Description
H	High relevance	Innovations combine substantial emission reductions with broad applicability across the flat glass sector
M	Medium relevance	Only one of these conditions is met, either through significant carbon reduction or wide applicability
L	Low relevance	Impact is limited to specific applications or when their contribution to emission reduction is comparatively small

3. Current State of Innovation

3.1. Energy

Energy use remains the dominant factor in the environmental impact of flat glass production, with the float process accounting for the majority of emissions. While incremental efficiency improvements have been achieved over past decades, the transition to climate-neutral production requires fundamental changes in energy sources, such as electrification or the use of green hydrogen.

The float process is the most carbon-intensive stage in the glass life cycle due to the high-temperature melting of raw materials, which is traditionally powered by fossil fuels. Although furnace efficiency has improved significantly—from approximately 6,000 kWh/t of glass in 1990 to around 1,000 kWh/t in 2022 [3]—decarbonizing this phase remains essential for achieving climate neutrality. Current industry roadmaps emphasize the transition toward renewable energy sources, particularly green hydrogen, despite associated technological and financial barriers [3;4].

Recent developments demonstrate that such transformations are technically feasible but still in early stages of implementation. Pilot projects, including hybrid and partially electrified float lines, indicate progress toward scalable solutions. However, these initiatives involve significant technological and financial challenges and are unlikely to achieve widespread adoption in the short term.

A key recent initiative is the Volta Project, launched in 2023 by two major float glass manufacturers in Czech Republic and operational since early 2025. The project retrofits a micro scale float line (rolled glass) into a hybrid system combining 50% electrification with 50% oxygen-gas combustion. Pilot-scale production is already underway, with plans to scale the technology to a 750 t/day float line and transfer it to conventional industrial plants [5;6].

In contrast, measures targeting downstream processing stages, such as the use of decentralized renewable energy in fabrication facilities, are already being implemented. Although their overall impact is limited compared to the float process, they represent practical steps that can be adopted immediately. Overall, the energy domain is characterized by high potential impact but relatively slow progress, with meaningful transformation expected over a longer time horizon.

3 main strategies can be identified – Electrification of the float process, the use of cullet in the float process to reduce energy demands and the use of decentral renewable energy.

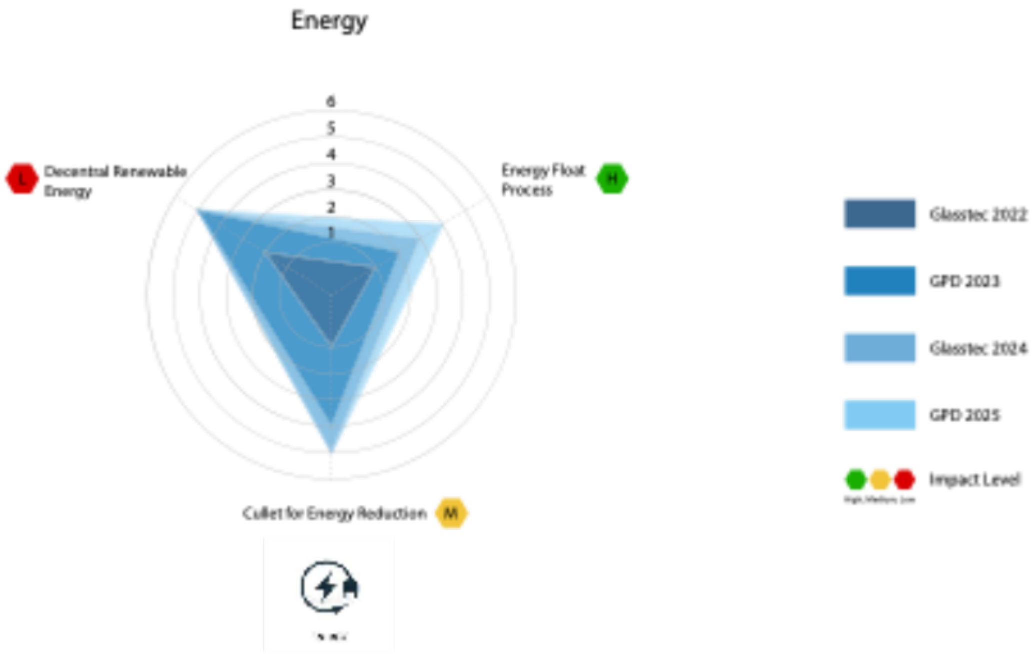

Fig 2: Readiness assessment Energy.

3.2. Secondary Materials

The use of secondary materials represents one of the most dynamic areas of development within the industry. Approaches such as reuse, remanufacturing, and recycling offer varying levels of environmental benefit and implementation complexity [7]. Among these, remanufacturing stands out due to its potential to avoid the energy-intensive melting process entirely. By recovering and reprocessing existing glass panes, significant reductions in carbon emissions can be achieved.

Recent projects have demonstrated the technical feasibility of remanufacturing insulating glass units using a combination of reused and new components [8;9]. These developments mark a transition from experimental applications to early-stage commercialization. At the same time, recycling remains the most widely adopted strategy due to its compatibility with existing production processes [10]. Products incorporating post-consumer cullet are increasingly available, although their overall impact is constrained by material availability and quality requirements.

Reuse applications, such as the relocation of windows or the repurposing of glass elements in secondary functions, are also being explored. However, these are often limited to niche scenarios and informal exchanges, reducing their scalability. Overall, secondary materials offer substantial opportunities for near-term impact, particularly where remanufacturing and high-quality recycling can be integrated into standard practice.

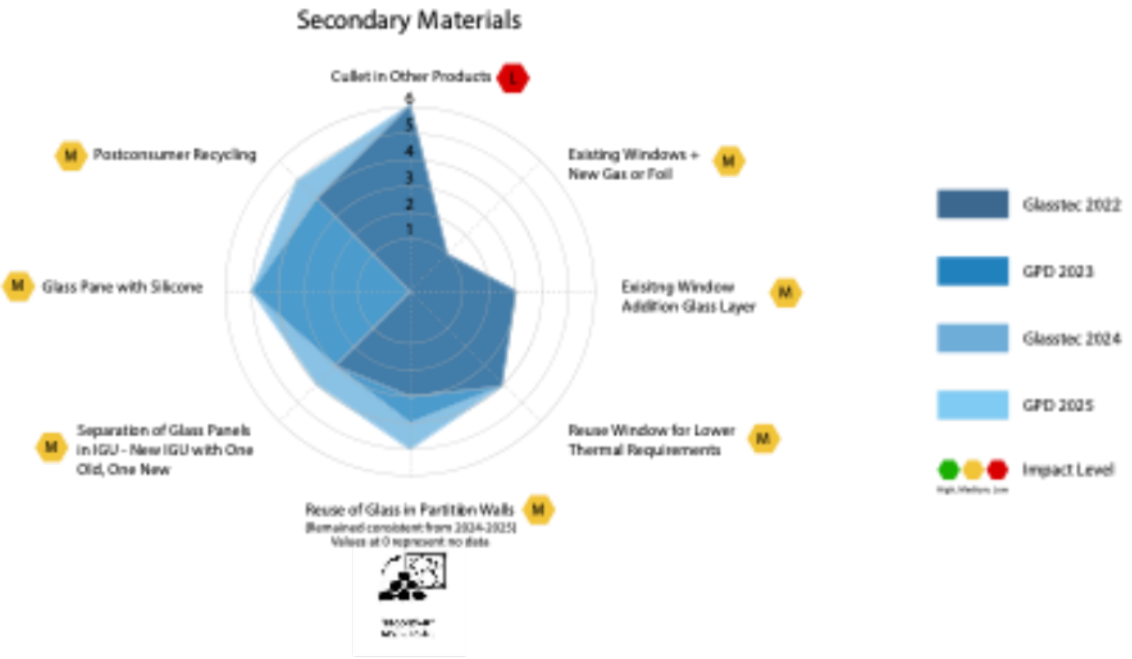

Fig. 3: Readiness Assessment Secondary Materials.

3.3. Material Recovery Systems

The effectiveness of circular strategies depends heavily on the ability to recover materials at the end of a building's life cycle. In practice, this remains a major bottleneck. Glass is frequently lost during demolition due to insufficient planning, contamination, or lack of economic incentives for separation and collection.

Emerging recovery systems aim to address these challenges through improved logistics, stakeholder coordination, and business models. Examples include manufacturer-led collection schemes and regionally organized recycling networks [11;12]. In some cases, particularly for interior glass partitions, take-back systems have enabled multiple reuse cycles, supported by collaboration between manufacturers, contractors, and specialized intermediaries [13;14].

Despite these advances, recovery systems are not yet widely implemented when compared with the container glass industry [15]. Their success depends on early integration into project planning, including considerations for selective dismantling, transport, and storage. Without such coordination, even technically viable reuse and recycling options remain inaccessible. As a result, material recovery represents an area of medium impact with significant potential for improvement through organizational and procedural changes.

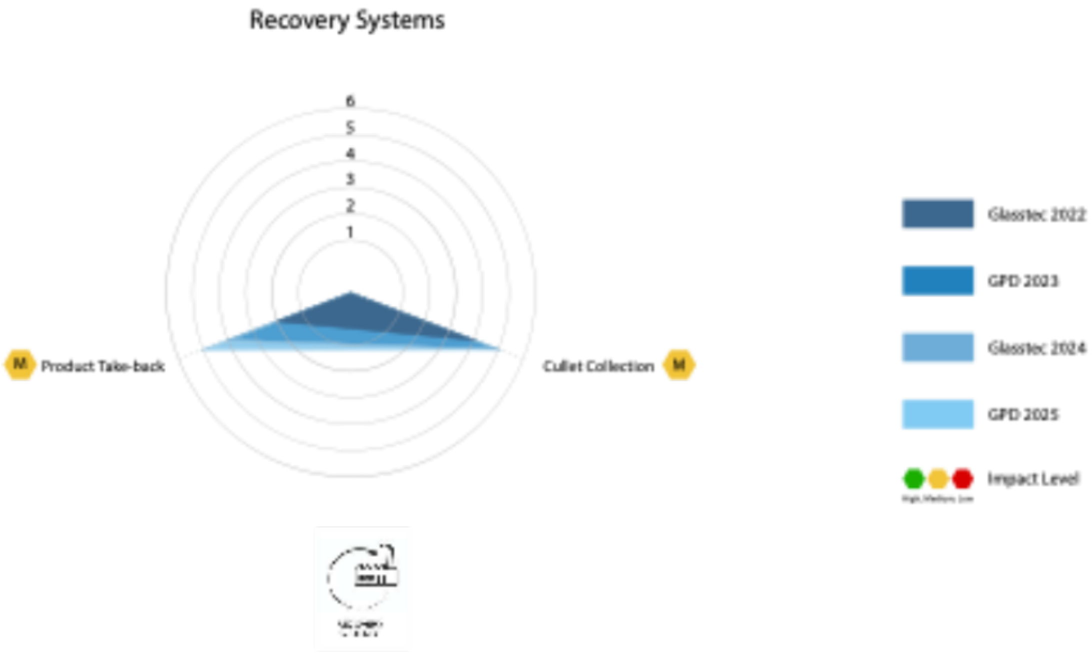

Fig. 4: Readiness Assessment Material Recovery Systems.

3.4. Design for Disassembly

Design for disassembly has long been discussed as a prerequisite for circular construction, but its practical application is only now gaining traction. Research and prototype testing have confirmed that facade systems can be designed for efficient disassembly, enabling future reuse or remanufacturing [15;16].

Interestingly, recent findings challenge some conventional assumptions. For example, mechanical fixings such as screws, often considered inherently reversible, can be more time-consuming to dismantle than adhesive systems when appropriate tools and methods are used and the intent for disassembly is considered in the design of adhesive properties [17;18]. These insights highlight the need for performance-based evaluation of disassembly strategies rather than reliance on intuitive design choices.

While the long-term benefits of design for disassembly are clear, its immediate impact is limited. The advantages are realized only at the end of a building’s service life, which may span several decades. Consequently, adoption depends on forward-looking decision-making and alignment with broader circularity goals.

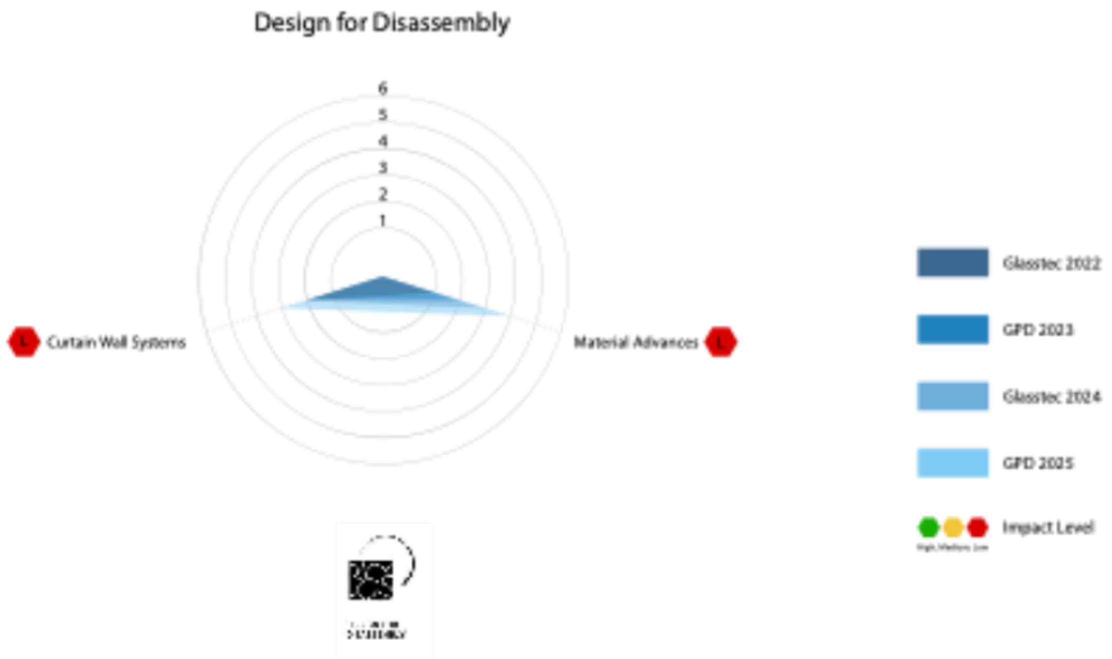

Fig. 5: Readiness Assessment Design for Disassembly.

3.5. Data and Communication

Data and communication play a critical role in enabling circular and low-carbon practices, yet their integration into industry workflows remains incomplete. Product-level data, particularly in the form of Environmental Product Declarations, is increasingly available and widely used. However, building-level data structures, such as material passports and digital twins, are still in early stages of development.

Tools for life cycle assessment and circularity evaluation are becoming more accessible, but their integration into design and construction processes is often limited [19]. Similarly, digital platforms that facilitate information exchange between stakeholders are emerging but have not yet achieved widespread adoption [20,21].

Advances in data collection and analysis, including the use of artificial intelligence to assess building stock, offer promising opportunities for the future [22]. However, realizing this potential requires closer collaboration between the construction industry and digital technology providers. At present, data and communication function as enabling factors rather than direct drivers of emission reduction, with their full impact yet to be realised.

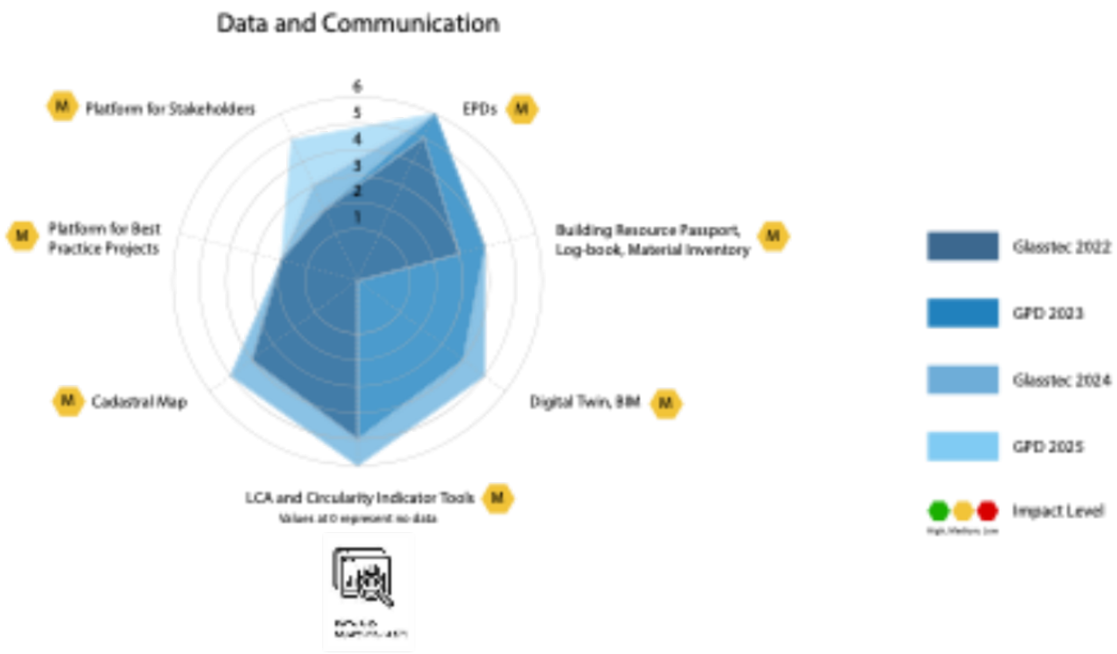

Fig. 6: Readiness Assessment Data and Communication.

4. Discussion

The analysis reveals a clear disparity in the pace of innovation across different areas of the industry. Developments related to secondary materials and recovery systems are progressing relatively quickly and are already entering early stages of commercialization. In contrast, the decarbonization of primary production processes remains a long-term challenge requiring systemic change.

For design and engineering professionals, this distinction is critical. Many effective solutions are already available and can be implemented without waiting for technological breakthroughs. These include the use of recycled or remanufactured materials, the integration of recovery strategies into project planning, and the consistent application of existing data tools. At the same time, expectations regarding climate-neutral glass production must be aligned with the longer timelines associated with energy infrastructure transformation.

The findings also highlight the importance of collaboration. Innovations are often driven by individuals and organizations willing to challenge established practices and engage across traditional boundaries. Platforms such as CircuClarity demonstrate how knowledge exchange and joint initiatives can accelerate progress, particularly in areas where coordination is essential.

5. Conclusion

The transition towards circularity and climate neutrality in the glass and façade industry is underway but remains uneven. While significant progress has been made in areas such as secondary materials and early-stage recovery systems, large-scale transformation—particularly in energy-intensive production processes—will require sustained effort over the coming decades.

In the short term, the greatest opportunities lie in the consistent application of existing solutions. By prioritizing the use of secondary materials, planning for material recovery, and leveraging available data tools, stakeholders can achieve meaningful reductions in environmental impact. At the same time, continued investment in innovation, infrastructure, and collaboration will be essential to address the more complex challenges ahead.

Ultimately, the industry possesses both the technical capability and the emerging practical experience needed to support this transition. The key challenge now lies in scaling these solutions and embedding them into standard practice.

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