

# **Green Innovation Product for Sustainable Waste Management:**

## **A Case Study on Upcycling Glass Bottle Waste via Flameworking**

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**Abstract** — The management of glass bottle waste remains a critical environmental challenge in urban centers like Yogyakarta, Indonesia. This study investigates the upcycling of this waste stream into high-value, functional products, such as platters, through a combination of cold working (cutting) and hot working (flameworking), within the Green Innovation Product (GIP) paradigm. An experimental methodology was employed, comparing the efficiency of a small, updraft kiln (2023 experiment) with a larger, downdraft kiln (2025 experiment). Results demonstrated that while utilizing the entire glass bottle (neck, body, and base) enhanced material efficiency, the larger kiln's stacked firing arrangement was ineffective, as only the top layers melted completely even with extended firing durations up to 120 minutes. The study concludes that scaling production efficiency is contingent not on kiln size alone, but on achieving uniform heat distribution, for which a single-level, flat-bed kiln design is proposed. This research confirms the technical feasibility of transforming glass waste into commercially viable products and underscores the necessity of appropriate technology integration to realize the principles of GIP, offering a scalable model for sustainable waste management and local entrepreneurship.

**Keywords** – Glass Waste Upcycling, Green Product Innovation, Flameworking, Kiln Efficiency, Sustainable Design, Circular Economy

### I. INTRODUCTION

Glass waste persists as a significant environmental and logistical problem in Yogyakarta, Indonesia. Its non-biodegradable nature and potential hazard make it frequently rejected by municipal waste collection services, leading to accumulation and a lack of effective recycling solutions. Initiatives since 2017, including the "Zero Inorganic Waste" movement, have had limited success in addressing this specific waste stream [1]. While traditional Indonesian craftsmanship includes both cold (e.g., cutting, grinding) and hot (e.g., melting, fusing) glass processing techniques, a scalable, efficient, and sustainable method to transform this problematic waste into valuable goods is still needed. This study builds upon previous research by the authors in 2023, which established a baseline for processing glass bottles using a combination of techniques in a small, updraft kiln [9]. The present research aims to scale this process by employing a larger kiln, with the objective of determining the optimal parameters for

temperature, firing duration, and cooling to efficiently produce functional, user-centric products like platters. The research is framed within the strategic concept of Green Innovation Product (GIP). GIP focuses on creating products that minimize environmental impact throughout their lifecycle, often by reducing resource exploitation and leveraging renewable technologies for recycling and reuse [11]. This aligns with the Resource-Based View (RBV) of the firm, which suggests that unique, valuable, and hard-to-imitate capabilities are sources of sustainable competitive advantage [2]. The ability to effectively transform waste into high-value products constitutes such a capability, providing a long-term edge in the market for sustainable goods [19], [21]. While existing literature often discusses glass waste in the context of downcycling for construction aggregates [7], [10] or for structural cast components [3], this study distinguishes itself by focusing on upcycling—adding value by creating artistic and functional consumer products. This approach addresses a local problem with a community-

ble solution, filling a critical gap in the application of GIP principles to small-scale, high-value glass waste processing.

#### A. Green Innovation Product (GIP) and Resource-Based View (RBV)

GIP represents a paradigm shift from traditional linear production models. It encompasses the modification of product design and processes across the entire lifecycle to mitigate negative environmental impacts, extending beyond the mere creation of a “green” product [11]. Key drivers include the prospect of competitive advantage, cost reduction, market benefits, and enhanced reputation [13]. From an RBV perspective, GIP can be seen as a strategic resource. A firm’s or community’s capability to innovate and create value from waste streams is a unique competency that is socially complex and difficult for competitors to replicate, thereby forming the basis for a sustained competitive advantage [19].

#### B. Glass Waste as a Resource

Glass is an ideal material for a circular economy due to its 100% recyclability without loss of quality. However, as noted by Butler and Hooper [5], it remains a major component of municipal solid waste with unique management challenges. Previous creative research has explored its potential in jewelry design [16] and decorative tableware [8], [17], demonstrating its aesthetic potential. The technical exploration of flameworking for glass waste has also been reviewed [20], but often without a strong GIP framework or a focus on production scalability.

#### C. Technical Foundations: Hot Glass Working with Kilns

The core technical method in this study is flameworking using a gas-fired kiln, a technique less common in Indonesia compared to cold working. Bristogianni *et al.* [3] demonstrate that with controlled melting and casting, waste glass can be transformed into robust products, validating the principle of thermal reforming. The primary challenge, as identified in this study and supported by craft literature, is mastering the firing and annealing schedule—the precise control of heating and cooling rates to ensure the glass melts uniformly and solidifies without internal stress (cracking).

## II. RESEARCH METHOD

#### A. Materials and Equipment

Materials from waste glass bottles (uniformly Bintang beer bottles) were collected in Yogyakarta.

Equipment in the 2023 experiment used a small, updraft pottery kiln without a thermocouple. Equipment in the 2025 experiment used a larger, medium-sized downdraft kiln equipped with a thermocouple for temperature monitoring. Ceramic molds and graphite separator were used in both experiments (Fig. 1).



Fig. 1. Comparison The Kiln Size.

#### B. Experimental Procedure

The experimental stages for the 2025 study were:

- 1) **Collection and Preparation:** Bottles were collected, washed, and sorted.
- 2) **Cold Working:** Bottles were cut into standardized pieces using the cold technique, utilizing all parts of the bottle: neck, body, and base.
- 3) **Hot Working:** Glass pieces were arranged on a ceramic mold and fired in the kiln. The initial firing duration was set at 60 minutes, with a peak temperature recorded at 722.6 °C.
- 4) **Cooling:** The kiln was sealed after firing for a controlled cooling period of 24 hours.
- 5) **Analysis and Re-testing:** The results were compared against the 2023 benchmarks. Due to incomplete melting, the experiment was repeated with extended firing times of 90 and 120 minutes.

#### C. Data Collection and Analysis

Data was collected through direct observation, digital temperature recording, and comparative analysis of the resulting products based on criteria such as form integrity, surface texture, deformation, and adhesion to the mold. Production efficiency was evaluated based on the success rate of melting per firing cycle and the utilization of raw material (entire bottle).

## III. RESULT

The key finding from the 2025 experiments was that scaling up production by simply using a larger kiln and stacking glass pieces was ineffective. Despite increasing the firing time from 60 to 120 minutes, only the glass pieces on the top layer of the stack melted completely. The downdraft design and stacked arrangement created an uneven thermal gradient, insulating the lower layers from the necessary heat intensity (Fig. 2). This finding is critical, as it highlights that production efficiency in GIP is not merely a function of equipment size but of system design (Table. 1)..

However, a significant success was the effective incorporation of the entire glass bottle-neck, base,



Fig. 2. Experiment Stacking Glass in The 2025.

Table 1. Comparative Analysis of 2023 and 2025 Experiments

Variable	2023	2025
Kiln Type	Updraft (Small Kiln)	Downdraft (Medium Kiln)
Firing Duration	60, 70, 75 min	60, 90, 120 min
Glass Arrangement	Single-layer	Multi-layer
Material Use	Only bottle body	Entire bottle (body, neck, base)
Key Result	Successful melting for single-layer capacity	Inefficient melting; only top layers fused

and body—into the process (firing with small kiln). This represents a substantial improvement in material efficiency and waste minimization, a core tenet of GPI, compared to the 2023 process which used only the body (Fig. 3).



Fig. 3. The Production Result Use Small Kiln.

#### IV. DISCUSSION

##### A. Aligning Process with GPI Principles

The implementation of Green Product Innovation (GPI) in this research serves as the principal conceptual framework guiding both the experimental direction and the evaluation of glass bottle waste processing into economically valuable products. As an innovation focused on environmental dimensions, GPI goes beyond

modifying product materials or aesthetics; it integrates resource efficiency, product life-cycle considerations, and low-emission process engineering within the design and production system. Porter and van der Linde, as discussed by Mariyamah and Susi [14], emphasize that GPI can become a new source of competitive advantage when it focuses on improving the productivity of raw materials and energy. In this study, that paradigm was realized by utilizing glass bottle waste as the primary raw material—previously difficult to process—to create household products, such as platters, that are both functional and aesthetically valuable. This approach positions green design thinking as the core of innovation, where design decisions—from mold geometry and furnace type to the composition of glass arrangements—are determined by efficiency principles rather than by visual appeal alone.

Empirical findings indicate that the success of green product innovation lies in optimizing all glass components, rather than limiting them to the bottle body. The neck, base, and body can now be processed simultaneously through a combination of hot and cold techniques. This transformation represents more than a simple material substitution; it embodies the circular economy principle at the micro scale, ensuring that no material is wasted. From the perspective of green process innovation theory [11], this approach demonstrates tangible ecological efficiency through reduced consumption of primary resources and lower residual waste output. From a resource-based view [12], innovation practices based on local resources—such as clay furnaces and gas fuel—constitute a form of capability differentiation that is difficult to replicate because they are rooted in contextual uniqueness, including local craftsmanship, traditional firing techniques, and adaptive design. Therefore, efficiency should not be measured solely by production time or quantity, but by the ability to minimize new inputs, extend the functionality of recycled materials, and generate new value through design engineering.

The quality of products produced through this green innovation process reveals a strong interrelationship among design, process, and final performance. The experiments show that a maximum temperature of 900°C, with a firing duration of 60 to 90 minutes, produces stable melting and preserves the glass texture. This finding demonstrates that green innovation does not diminish product quality but rather enhances both aesthetic and structural characteristics. Qin *et al.* [18] state that successful GPI originates from precise process control in which every stage of design and production accounts for environmental impact and product performance. This research also highlights the importance of mold design innovation as an integral component of GPI. Reusable clay molds not only reduce production costs but also extend the lifespan of production tools, thereby decreasing the need for

additional energy and materials. From a sustainable design perspective, this aligns with Tseng's concept of eco-efficiency [21], which aims to create greater value with lower environmental impact through technological and design innovation.

The environmental and social impacts of the product innovation developed in this study represent a key dimension for evaluating GPI success. Cheng *et al.* [6] demonstrate that green innovation, integrating both process and product dimensions, can reduce carbon emissions and enhance long-term organizational financial performance. Within this research context, experimental results show that gas-fueled furnaces are more efficient than conventional energy sources, achieving greater temperature stability and lower emissions. The social implications are also significant. Glass-waste-based production activities have the potential to create new economic opportunities for local artisans while strengthening the green entrepreneurship ecosystem. Social sustainability emerges as a direct outcome of GPI, in which communities evolve from consumers to active producers within a circular economy. Collaboration between design researchers and artisan communities reinforces the principle of collaborative sustainability, as articulated by Maziriri and Maramura [15], which underscores that the success of green innovation depends heavily on cross-sector partnerships that combine technical and social knowledge.

Overall, the findings of this research demonstrate that green product innovation extends beyond the creation of environmentally friendly products to the establishment of an efficient, adaptive, and ecologically just production system. Through furnace design exploration, mold engineering, and comprehensive utilization of glass waste, this study shows that green innovation can be effectively implemented within a local context while maintaining scientific rigor and productivity. Future development will involve redesigning the furnace into a flat-burner system to increase melting capacity and reduce firing time, thereby achieving both quantitative and qualitative efficiency. This approach is expected to enhance this research's contribution to the green manufacturing model in Indonesia's craft sector, creating a production system that is not only economically viable and functional but also ethically responsible and environmentally sustainable.

### B. Technological Fit for Green Innovation

Inefficient firing in the larger kiln reveals a misalignment between the technology and GIP objectives. An energy-intensive process that fails to maximize output contradicts the GIP goals of resource efficiency and lower relative costs [13]. The solution identified—shifting to a single-level, flat-bed kiln—is a necessary technological adaptation to ensure that the production process itself is “green.” This would ensure even heat distribution, reduce firing times, and increase

successful yield per energy unit, thereby truly aligning the method with its innovative purpose.

This research consciously moves beyond the down-cycling pathways prevalent in the literature. While using glass as a construction aggregate [10] solves a volume problem, it yields a low economic return. In contrast, creating curated platters and functional art represents upcycling, significantly increasing the monetary value of the waste material. This strategy directly creates the “market benefits” and “competitive advantage” cited as key outcomes of GIP [13]. The copyrights obtained for the “Textured Curved Platter” and “Trio Mini Platter” are tangible manifestations of this unique, value-added capability, resonating with the RBV theory.

### C. Implications for Local Sustainability

The study provides a replicable model for community-level waste management (Fig. 4).

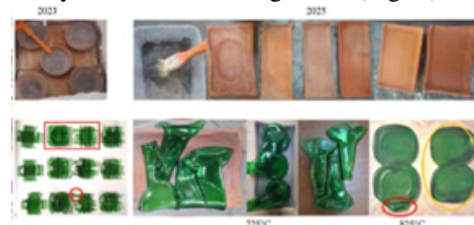


Fig. 4. Local Based Pottery in the Production Process.

Using locally available pottery-based materials, pottery kilns, and waste glass offers a practical alternative to large-scale, capital-intensive recycling plants. This approach empowers local artisans and entrepreneurs, fostering a circular economy microcosm that addresses the “Zero Inorganic Waste” policy not through disposal, but through value creation.

The key parameters that require careful attention are the firing temperature and stacking configuration. The optimal firing temperature ranges between 725°C and 825°C. For ceramic furnaces, the most effective stacking configuration is a single-level arrangement.

## V. CONCLUSION

This study confirms the feasibility of upcycling glass bottle waste into high-value functional products using a combination of cold and hot working techniques, underpinned by the principles of Green Innovation Product. However, it conclusively demonstrates that production efficiency is not automatically achieved by scaling up equipment size. The critical factor is the design of the firing system to ensure uniform heat distribution. The primary limitation was the inefficiency of the stacked firing arrangement in the downdraft kiln. Therefore, the main recommendation for future work is the design, construction, and testing of a customized, flat-bed kiln that facilitates single-layer firing. Further research should also explore the optimal molding materials and annealing cycles for

different product shapes. By refining the technology to match the ambition of the GIP strategy, this approach can be optimized to become a truly sustainable and scalable solution for transforming urban glass waste into a source of economic and aesthetic value. And for further research, we can consider more related matters about: quantitative evaluation, experimental replication, and statistical validation, for the scientific strengthening of the findings; such as: identify independent and dependent variables clearly (kiln type, firing duration, glass layer arrangement), use basic descriptive statistics (mean, standard deviation) or simple correlation to show consistency and reliability across firing trials, discuss the trade-off between kiln size, energy efficiency, and quality of the melted glass more quantitatively (not just descriptively), include quantitative performance metrics, explain environmental conditions (ambient temperature, humidity, fuel pressure) to enable reproducibility, etc.

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