

Paving the way to Net Zero by repurposing waste

R. Janani*, W. Deng*, D. J. Backhouse†, F. Kabir-Kazi*, G. Wie-Addo*, A. H. Jones*, C. M. Jackson‡, C. Holcroft§, P. A. Bingham*

The 2015 Paris Agreement marked a key turning point in the global efforts against climate change. More than five years into its endorsement, the UK government (in a joint effort with industry) has published multiple decarbonisation roadmaps¹⁻⁶ outlining the challenges and potential pathways for various industrial sectors to minimize their emissions and energy consumption. The UK's Net Zero emission target by 2050 calls for urgent transformation of the six foundation industries (FIs: glass, ceramic, cement, paper, metal and bulk chemicals) valued at £52 billion / year⁷. These industries underpin UK supply chains by producing 75% of the overall fundamental materials for industrial sectors⁷. However, the FIs are energy- and resource- intensive and contribute significantly to UK CO₂ emissions. The CO₂ emissions from the UK ceramics sector alone were estimated in 2012 to be 0.94 Mt / year, in addition to 0.28 Mt / year in electricity production for use within the sector¹. In 2018, the UK concrete and cement sector contributed 1.5% of all UK CO₂ emissions (>5.3 Mt)⁵ while in the same year the glass industry emitted >1.4 Mt of CO₂⁸. These numbers come as no surprise since the FIs heavily rely on fossil fuels. According to the reported UK 2019 statistics⁸, 3.5 Mt of glass is melted per year which translates to 6 TWh of natural gas and 1 TWh of electricity consumption. The energy costs for the glass industry are estimated to be around £240 million / year. Reduction in production costs has been a key driving force for these sectors to move towards a carbon-neutral energy strategy, even prior to the emission reduction legislations. Considerable improvements in the energy efficiency of furnaces (≈50%) in the glass sector over the past 40 years⁸ and a 27% reduction in carbon intensity of the cement sector since 1990⁵ are some of the outcomes of these efforts. However, there remains a wide range of transformations to existing infrastructure and manufacturing processes that must be achieved in order to help meet the decarbonisation objectives.

During the highly anticipated Glasgow Climate Change Conference (COP26) in November 2021, parties reached an agreement to "phase-down" unabated coal power and to "phase-out" inefficient fossil fuel subsidies in order to transition to low-transmission energy sources⁹. Recently, British Glass set out its Net Zero by 2050 strategy⁸ to complement the 2014 and 2015 glass sector decarbonisation roadmaps^{6,10}. These documents highlighted that reduction in combustion emissions, process emissions and expansion of the circular economy are key strategies to enable incremental improvements of the glass industry (as well as other FIs) towards zero emission. Encirc's objective to utilise hydrogen to melt glass by 2025, with the support of the HyNet scheme, is an excellent example of a step-change towards zero CO₂ emissions in the glass industry¹¹. Nonetheless, any opportunity to make improvements (however major or incremental) to the process emissions or circular economy within FIs should not be overlooked.

* Materials and Engineering Research Institute, Sheffield Hallam University, Sheffield, S1 1WB, UK

† Glass Futures Ltd., Sheffield, S35 2PY, UK

‡ Department of Archaeology, University of Sheffield, Sheffield, S1 4ET, UK

§ Glass Technology Services, Sheffield, S35 2PY, UK

Carbonates used as raw materials in the FIs are another key contributor to the overall CO₂ emissions, making up 10-25% of emissions from the glass sector⁸ and 70% from the cement sector³. Sourcing reliable alternative raw materials that can not only replace the carbonates but also reduce processing energy requirements while remaining financially viable is a great challenge. The EnviroAsh project has aimed to overcome this challenge by identifying routes to convert and optimise waste-streams from across FIs and energy sectors (e.g. waste ashes) into new raw materials. This would allow converting disposal costs into opportunities for income generation whilst helping to reduce environmental impact. This project expands upon an established consortium, with a proven track record of developing raw materials from wastes within the UKRI-funded EnviroGlass 2 project (reference no. 104382) and the BEIS-funded BiomAsh project (Glass Technology Services, Sheffield Hallam University, Power Minerals, Glassworks Services), introducing new partners from the glass industry and other FIs (Encirc, Glass Futures, Hanson, Wienerberger, Saica, Drax and University of Sheffield) to expand the range of wastes to be investigated and final products that can benefit from these materials.

Whilst this is a new and focused approach, utilising waste products such as ash as raw materials in the manufacture of glasses, ceramics and cement is nothing new! For example, the incorporation of ashes in ceramic manufacture in China dates back to 1500 BC in the Shang period when unexpected yellowish-green glaze began to appear on wood-fired ceramics. Lime-rich wood ashes in the high-temperature kilns are believed to have reacted with the surface of the clay body resulting in the thin yellowish glaze¹². The wood ash glazing technology gradually developed and became widespread towards the end of the Shang period and the beginning of Zhou dynasty. Ceramics from this period are known as proto-porcelain. Similarly, it is believed that halophytic plant ashes (rich in sodium salts) were used as the alkali source for the earliest glasses until 800 BC¹³. They were predominantly replaced by natron** during the Hellenistic and Roman Empires and Sasanian dynasty. Unreliable supplies of natron glass necessitated plant ashes (primarily wood ash) to become the primary alkali for glass made in northern Europe from 800 AD and continue to be utilised until the 17th Century. Wood ash glasses, also known as forest glasses, manufactured during this period in Central Europe can be differentiated by their CaO/K₂O content which is associated with the composition of the wood and the proportion of twig (bark content)¹⁴. Today and to a lesser extent, plant ashes are still used for glass and ceramic glazing. Application of other types of ashes such as coal-combustion fly ashes has been explored and utilised in the production of construction ceramics with positive results^{15,16}. Utilisation of certain ashes as the pozzolanic^{††} admixture (e.g. rice husk ash) is currently being investigated in cement and concrete production¹⁷, while fly ashes are already being used as partial replacement for cement in concrete (High Volume Fly Ash Concrete¹⁸).

Despite their historical use, the utilization of waste ashes as raw materials in FIs is yet to meet its full potential. Variations in chemical and physical composition of the waste ashes (and other waste products more widely), consistency of supply, presence of undesirable

**A sodium-rich evaporite formed during the drying of lakes and seas, also called trona.

††A finely divided siliceous and aluminous material that reacts with calcium hydroxide in the presence of moisture to form compounds having cementitious properties.

compounds and lack of industrial-scale proof of concepts are some of barriers that require addressing. Based on the available literature and the experience within the EnviroAsh consortium, a waste supply chain map (Figure 1) was generated to help identify potential waste sources (from FIs and energy sectors) as raw material for different products across the glass, ceramics and cement sectors. This is a great step towards optimizing the flow of resources within and in between FIs.

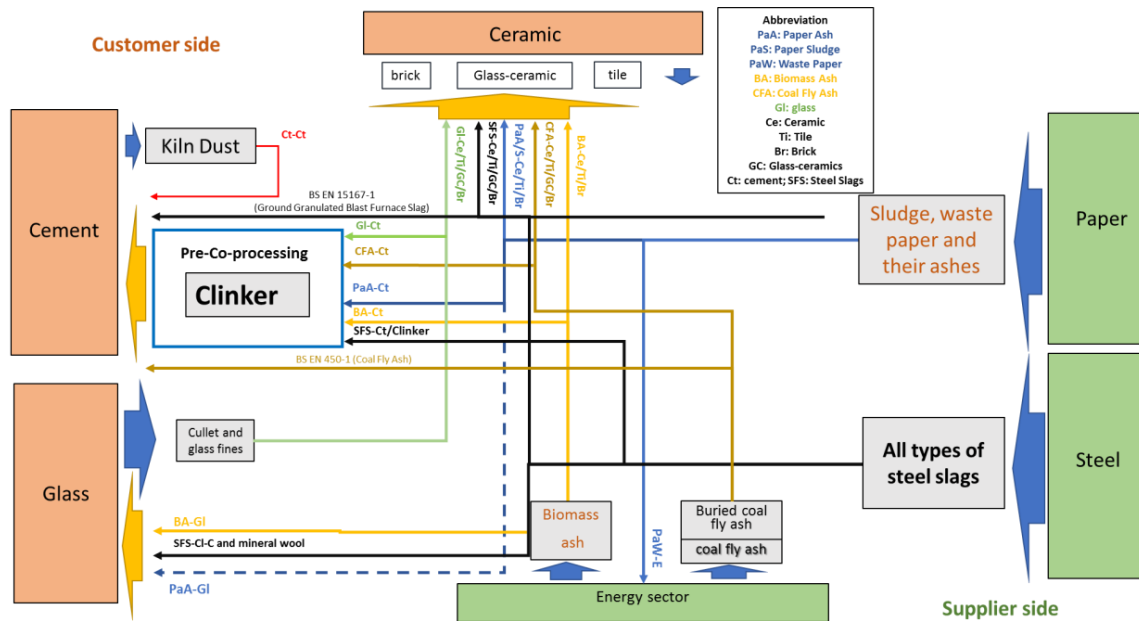


Figure 1. Proposed supply chain map illustrating potential waste-streams from FIs and energy sectors to the glass, ceramic and cement industries.

The transition from waste to ready-to-use raw material may require treatment and / or sorting procedures. The presence of problematic elements such as Cl and S and other undesirable compounds such as heavy metals and organic residues can limit the application of waste products in some FIs, although the specific requirements can differ between glass, ceramics and cement applications. During the span of the EnviroAsh project, a variety of different techniques was examined in an attempt to sort and purify the waste materials. Magnetic separation (wet, dry, and electrostatic), air density and specific gravity separation as well as ash washing are examples of the techniques explored, some with promising results. Examples of green container glasses produced with the addition of washed waste plant ashes are presented in Figure 2. The overall comparability of the ash-containing glass samples with the benchmark glass is highly encouraging. The amber shade in the glass sample made with the finer ash particles (D) is due to the presence of higher levels of carbon-bearing compounds. Therefore, identifying the appropriate treatment(s) required for each waste material (for this example, a separation technique such as sieving) enables control over the physical and chemical properties of the final product.

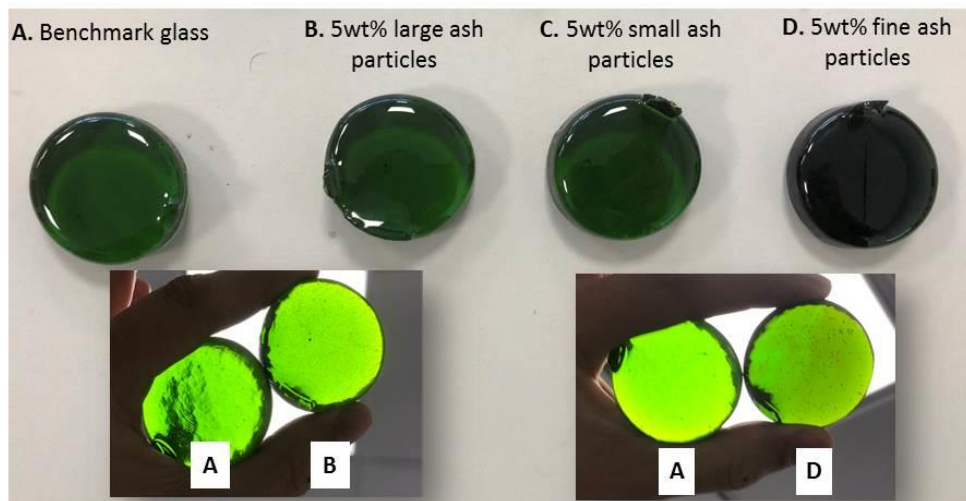


Figure 2. Optical images of green container glasses produced with and without additional 5wt% (washed) plant-based biomass ash with a particle size ranging from large to fine.

Given the compositional diversity of waste materials, careful consideration of the end-product properties is crucial when it comes to selection of the waste. Under the umbrella of the EnviroAsh project, the feasibility of a wide range of waste materials for application in glass, ceramic and cement products were examined. For instance, over 20 types of ashes (including plant ashes) were incorporated in heavy clay at 10-20wt% for the production of ceramics (Figure 3). Apart from changes to the colour of the product against the benchmark sample (which can in some cases be desirable), improvements in compressive strength¹⁹ and variations in other properties such as porosity and pore size distribution^{20,21} can confer benefits to the end-user. While industrial trials are currently under discussion, the work carried out during this project will feed into current activities being undertaken by the EPSRC TransFIRE and TFI Network+ projects to help FIs face the challenges set out by environmental legislation and meet the CO₂ reduction commitments enshrined in UK law. Actions taken today by the industry and all of us across the UK will directly support delivery of UK Net Zero emission commitments by 2050.



Figure 3. Optical image of ceramic samples showing a representative heavy clay ceramic sample (a) and those produced by incorporating 23 different types of waste ashes into the heavy clay at 20wt% (b-w).

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