Circular raw materials for the glass industry

Allen Zheng* discusses alternative raw materials for use in the glassmaking process and suggest the circular economy will only thrive through cross-industry innovation and partnership.

The circular economy is often defined as a systemic solution to address the global challenges of resource scarcity, waste generation, and environmental degradation.

It differs from the traditional linear economy of "take, make, dispose" and advances the recycling economy by introducing multiple interconnected loops that maximise resource value (***Fig 1***).

For the mining industry, the shift to a circular economy calls for a holistic approach to product lifecycle. This transition challenges mining companies to innovate in resource regeneration and collaborate with downstream partners for unconventional sourcing, such as utilising byproducts, co-products, intermediate products or waste streams, as valuable alternative inputs.

Achieving this requires both strong technical and commercial partnerships to create synergies, reduce costs, and scale solutions efficiently. Cross-industry collaboration and innovative thinking are essential to create more interconnected systems and ensure the circular economy functions effectively.

Rio Tinto has been actively contributing to this transformation with its Start label that provides certified environmental, social, and governance (ESG) performance of Rio Tinto's products, promoting lifecycle management and transparency across the supply chain.

The glass industry currently relies heavily on glass cullet as a key component in addressing ESG and circularity. By using cullet, glass manufacturers reduce the need for virgin raw materials, lower energy consumption, and decrease carbon emissions. However, the industry faces challenges due to limited cullet supply. Inadequate recycling infrastructure, inefficient collection and sorting systems, and regional disparities in availability have created a supply-demand imbalance.

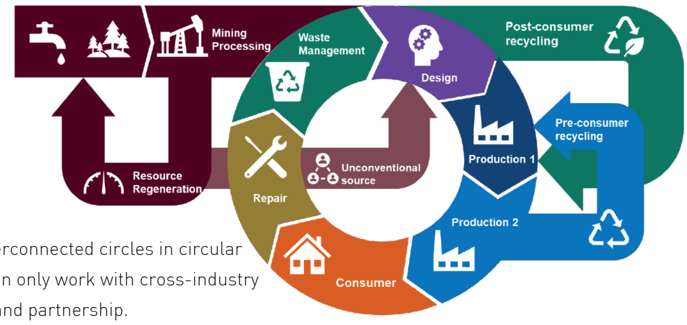

Fig 1. Interconnected circles in circular economy can only work with cross-industry innovation and partnership.

These constraints threaten the glass industry's ability to meet its sustainability goals. Hence, it is crucial to look beyond cullet and explore other circular raw materials to ensure the glass industry's long-term sustainability and circularity objectives.

Alternative circular raw materials

Rio Tinto offers a portfolio of products spanning various stages of the value chain, such as iron ore, bauxite, and copper concentrate are widely recognised. Others, including gold, sulphuric acid, and gypsum, are intermediate products or co-products that may be less familiar to the public. Additionally, there are products that remain largely unknown – either because they involve minerals identified but never marketed or are associated with future projects that remain confidential.

To date, borates have been a key primary product from Rio Tinto supplied to the glass industry. In this article, we will highlight a few examples of circular raw materials sourced from Rio Tinto's operations around the globe that may be of interest to the glass industry, categorising them into oxide mixtures, salts and minerals for ease of discussion.

Oxide mixtures

Glass is an inorganic, non-crystalline material made from a mixture of oxides. The selection of raw materials, or batch formulation, depends on factors such as cost, availability, quality and environmental considerations. While key glassmaking oxides like SiO_2, Na_2O, and CaO are typically sourced from primary materials including silica sand, soda ash and limestone, alternative raw materials containing pre-existing mixtures of oxides can also be utilised. Unlike naturally-occurring minerals, these oxide mixtures are chemically processed and produced as byproducts, co-products, or waste streams from mining or chemical processes. Although these mixed oxides may be unsuitable for other industries, they can serve as viable alternatives for batching, as all materials ultimately melt into a uniform mixture of oxides in glass (***Table 1***). The avoidance of primary materials is particularly beneficial when it comes to raw materials like soda ash and limestone. By eliminating the use of carbonates, the release of CO_2 from the batch materials can be prevented. For DC and DF, we successfully produced C-glass melt and foam glass melt in the lab, as shown in ***Fig. 2(a)*** and ***(b)***.

Non-conventional oxide mixtures lack an established benchmark for easy reference. Therefore, collaboration with glassmakers is essential to define physical

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Product Code	$3Al_2O_3{\cdot}2SiO_2$	SiO_2	Al_2O_3	Na_2O	K_2O	CaO	Fe_2O_3	MgO	Mn_2O_3	Fe_2O_3	B_2O_3	TiO_2	Carbon
MRP[1]		0-3%[2]	85-90%	7-8%		~1%	<0.5%	0-2%	0-0.2%[5]				
CBF[1]	28-44%	38- 50%		0.05 - 0.6%	0.2 - 1%		0.7-1.5%			0.7-1.5%		0.4-1.1%	<1.2%
DF[3][4]		SiO_2 > CaO > Al_2O_3> Akali > MgO> Fe_2O_3								high			
DC[3][4]		SiO_2 > Al_2O3> Na_2O > Fe_2O3 > CaO > B_2O3								high	Yes		
BF[3]		SiO_2 > Al_2O_3 >CaO >MgO>Akali								low	Yes		
BC[3]		SiO_2 > CaO > Al_2O_3>MgO>Akali								low	Yes		

Note:
(1) The product is readily available, with particle size distribution (PSD) customisable to meet customer requirements.
(2) Silicon (Si) may exist in its pure elemental form.
(3) Products are still under development; therefore, a non-disclosure agreement (NDA) will be required for further disclosure.
(4) Batch-free melting experiments have been completed and are available for certain glass types.
(5) Specifications and consistency can be tailored to meet specific needs.

Table 1. Examples of oxide mixture that could be suitable for replacement of primary materials.

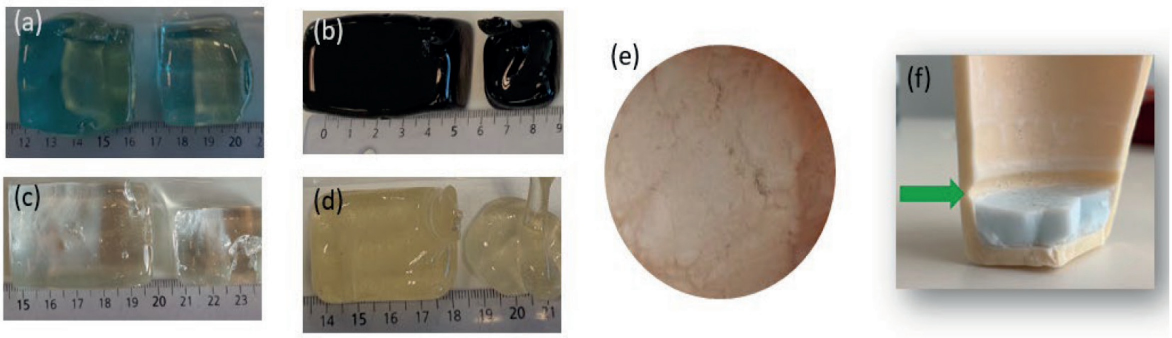

Fig 2. (a) and (b) C-glass and foam glass melts were produced using DF and DC as alternative oxide sources.
(c) and (d) Glass ceramics and specialty glass produced using Z-salt as a replacement for spodumene, demonstrating comparable quality.
(e) Photograph of pure Z-salt in an alumina crucible prior to the melting process.
(f) The alumina crucible shows erosion after the melting process, with the bluish colour in the solidified bottom possibly attributed to dissolved Al^{3+}.

and chemical specifications, including thresholds and consistency.

Salts

Rio Tinto could also offer highly purified chemical salts for the glass industry, with some adhering to globally-accepted specifications. Examples include pure $CaCO_3$ and pure Na_2SO_4. While these products are not presented as mixtures, they are co-products of existing processes, potentially sharing a relatively low carbon footprint. These salts could be particularly convenient for glassmakers adjacent to our operations or projects.

In addition to conventional purified salts, Rio Tinto plans to offer salt compounds. A notable example is a product currently under development and temporarily named “Z-salt.” Z-salt features a combination of sodium (Na), boron (B), and lithium (Li), all serving as effective flux agents in glassmaking. This pure compound has been tested in batch-free glass melting trials with CelSian. The trials revealed that the compound functions as a powerful 3-in-1 flux, reacting with and eroding alumina crucibles during the melting process (***Fig 2f***).

These trials also demonstrated that the compound is a viable alternative to spodumene for producing specialty glass and glass-ceramics (***Figs 2c*** and ***2d***). With the rising demand for electric vehicles and the competing sourcing for spodumene, Z-salt provides a reliable alternative lithium source for glass formulations where lithium is essential, and boron and sodium are acceptable. In addition to speciality glass and glass ceramics, we are eager to collaborate with glassmakers to explore its potential in enamel frit applications (where B, Na, and Li are all required) and other glass uses.

Naturally occurring minerals

Rio Tinto also offers naturally occurring-minerals suitable for the glass industry, such as dolomite and kaolin, from either its operating or legacy assets. While these minerals were identified but not yet marketed due to considerations like size or business priorities, they are available and can be made accessible if there is a

Fig 3. Photo of “Cirlica” sourced from existing operating assets.

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compelling business case. We welcome potential partners to come forward and discuss their interest.

Another example in this category is silica sand (***Fig 3***), which typically contains 94wt% silica, 1wt% alkaline oxides, 1.5wt% CaO, 1wt% Al_2O_3, and less than 0.5wt% Fe_2O_3. This product, temporarily named "*Cirlica*" is readily available but never marketed.

The mineral is uniform, fine, and offers an alternative to traditional silica sand or glass cullet.

We are planning to conduct glass melting trials and seeking interested glassmaking partners to collaborate and refine the project's scope.

Summary

The benefits of using a range of circular materials are extensive, including cost reduction, improved resource security, positive social impact, lower carbon footprint, waste reduction, regulatory compliance, and fostering innovation. (***Fig 4***).

While the examples of circular raw materials listed above are not exhaustive, they demonstrate the possibilities available to glassmakers – spanning across the entire periodic table.

We encourage glassmakers to share their specific material needs or challenges with us. We recognise that, for the glass industry, understanding the impact of alternative batching materials on the melting process and ensuring product consistency are crucial considerations for advancing this discussion. Therefore, collaboration is key to innovative sourcing solutions.

Partnering with Rio Tinto also opens opportunities for joint marketing, amplifying the value and impact of our collective efforts. Together, we can drive progress, innovation, and sustainability in the glass industry. ■

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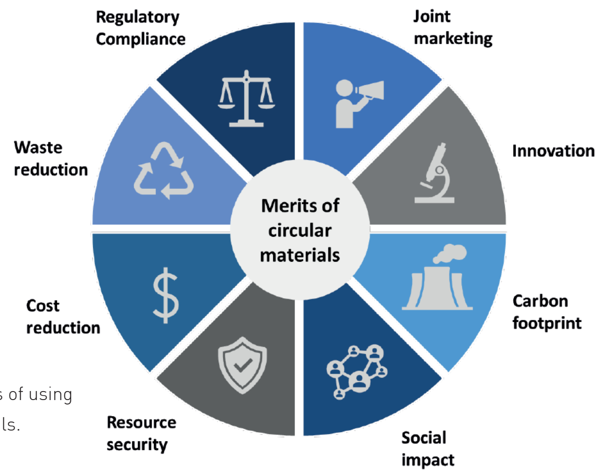

Fig 4. Benefits of using circular materials.