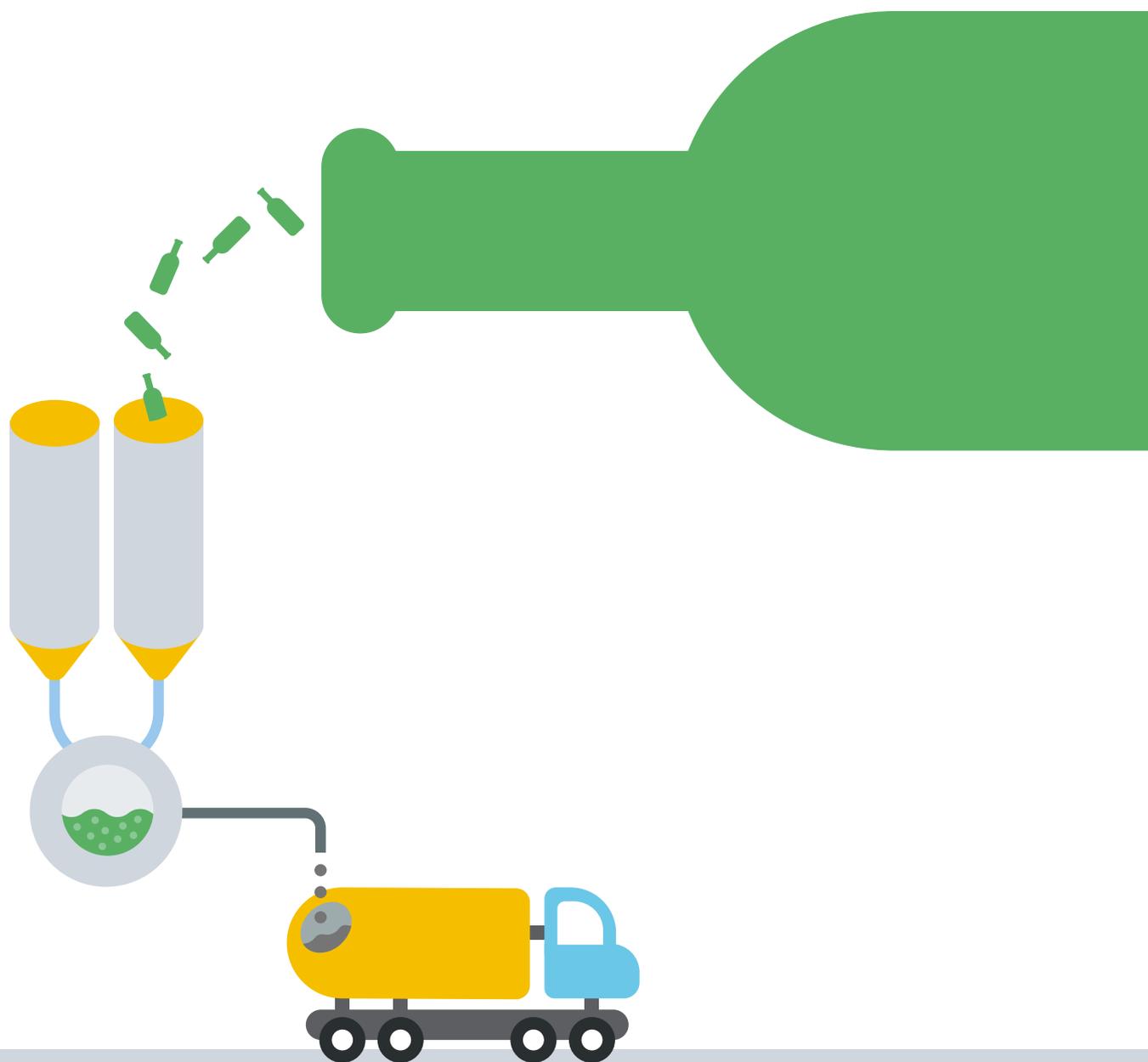


THE CIRCULAR ECONOMY AND THE PROMISE OF GLASS IN CONCRETE

Case Study October 2016



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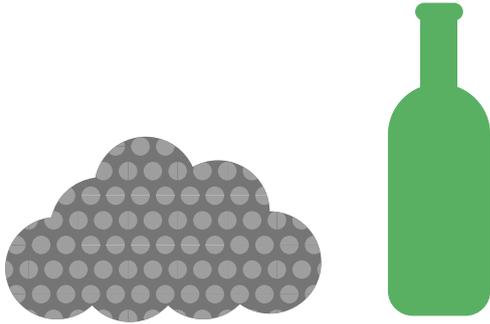
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WHY ARE WE CONCERNED ABOUT CONCRETE - AND WHY ARE WE CONCERNED ABOUT GLASS?

As most are aware, concrete is an essential component of the built environment. Still, most people spend little time thinking about the materials that go into concrete: gravel, sand, water, cement, and, in some cases, fly ash or slag.

Cement, concrete's primary binding element, generates large amounts of CO₂ during its production. And the primary substitute for a portion of cement in concrete - fly ash - typically contains varying levels of arsenic, cadmium, chromium, mercury, lead and other contaminants considered potentially toxic.

At the same time, post-consumer glass is a growing problem in many regions of the United States. Despite glass being 100% recyclable, cities across the country are abandoning their glass recycling programs over profitability concerns and challenges finding effective end markets for the material.

The Ellen MacArthur Foundation (the Foundation) was created in 2010 to accelerate a transition to a circular economy, one that is restorative and regenerative by design. A circular economy relies on three principles:

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1. Preserve and enhance natural capital by controlling finite stocks and balancing renewable resource flows
 2. Optimise resource yields by circulating products, components and materials in use at the highest utility at all times in both technical and biological cycles
 3. Foster system effectiveness by revealing and designing out negative externalities.
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The Foundation has been working with our global partner Google to explore the adoption of circular economy business models. Google's goal is to embed circular economy principles into its infrastructure, operations and culture. A main focus of this effort is thinking in cascades, and focusing on the health of the materials they are utilizing in their work environments.

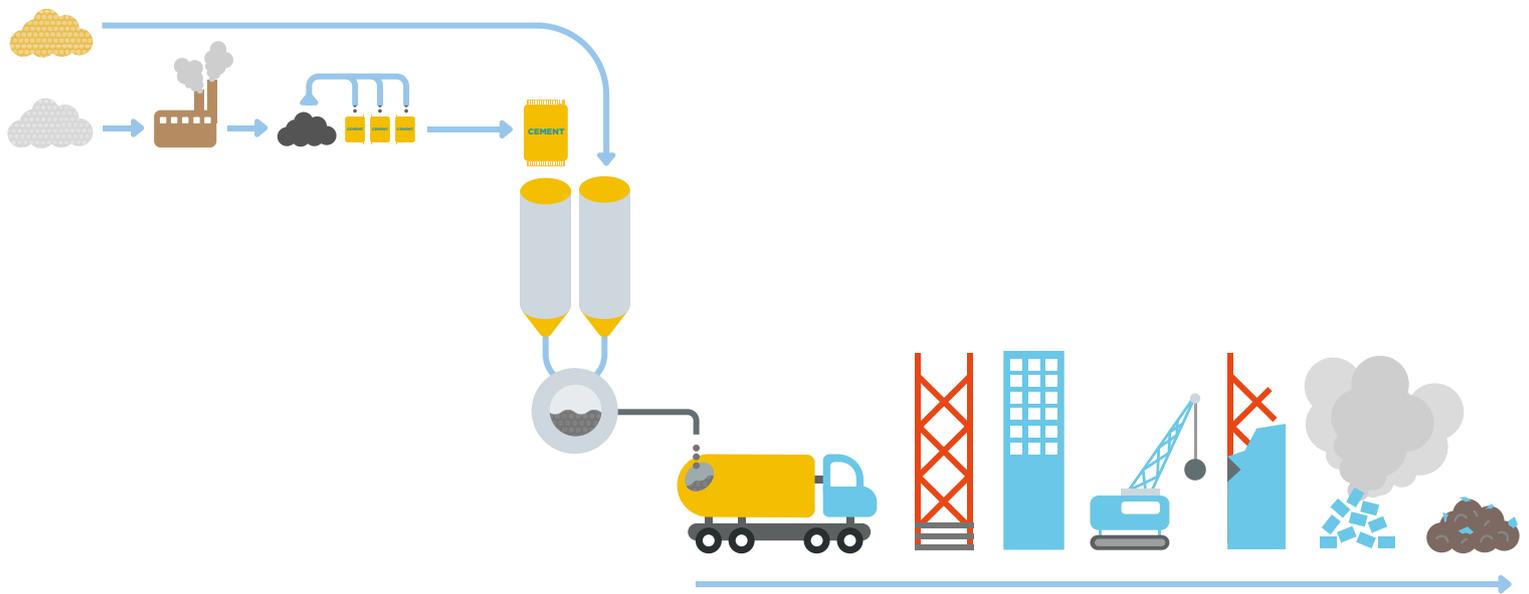
The question the Foundation, Google, and companies like Unilever are asking: could post-consumer glass, ground into a powder, be used as an additional substitute material in concrete, and as such reduce carbon footprints, minimize exposure to potentially toxic materials, and find a much-needed use for post-consumer glass?

The opportunity provided by the use of glass in concrete is a potential solution that uses circular economy principles to unlock value and create new business opportunities: first, by finding a use for glass of higher value than landfill, and second by decreasing the negative externalities of the construction sector. By using glass in concrete, it would be possible to:

- Re-utilize the 8 million tons of post-consumer glass that is landfilled each year
- Reduce the 90 million ton annual demand for cement, the production of which leads to 90 million tons of CO₂ emissions (equivalent to nearly 20 million cars)¹
- Minimize exposure to heavy metals and other potentially toxic components in concrete – especially during the renovation and demolition of buildings
- Localize supply chains and contribute to the transition towards a circular economy.

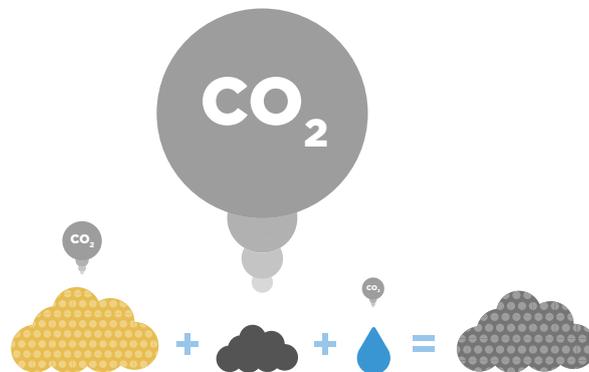
To discover whether using post-consumer glass in concrete is a viable business model, the Ellen MacArthur Foundation surveyed over a dozen stakeholders, including glass pozzolan producers, concrete suppliers, waste recyclers, and municipal government officials. The Foundation also spoke with Building Product Ecosystems, a collaborative that evolves codes, infrastructure, and field logistics to implement systemic improvements with purchasers and their supply/recycling networks.

¹ <https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator>



THE MAIN CO₂ CHALLENGE FOR CONCRETE IS CEMENT

The construction industry accounts for 4% of US GDP and 80% of its material consumption. In 2015, 600 million tons of concrete were produced to meet the demand of the construction market in the US. For context, if this amount were split into cubes one metre in diameter and the cubes stacked on top of each other, the resulting tower would reach halfway to the moon. And this is just one year's production.



And when we talk about concrete, we talk about cement. Concrete is normally made with a mix (roughly) of 75% aggregate (gravel and sand), 15% cement, and 10% water. Though it represents only 15% of concrete, cement is responsible for 96% of its CO₂ emissions. One ton of cement accounts for approximately 1 ton of CO₂ emissions (with half of that due to the fossil fuel combustion required to produce cement, and the other half coming from the kilned chemical conversion process involved in making clinker, the fusing of limestone and alumino-silicate materials like clay). This means that US cement production, which amounted to 90 million tons in 2015, generated greenhouse gases equivalent to the annual emissions of 20 million cars (12% of all vehicles in the US). Globally, cement production is responsible for 7% of annual GHG emissions.

CURRENT CEMENT SUBSTITUTES ARE ALSO PROBLEMATIC

To reduce cost and CO2 footprint of its product, the concrete industry began using two main cement substitutes: fly ash and slag. Fly ash, the most widely used, is essentially a by-product of the coal combustion process used in electricity generation. Ground, granulated blast furnace slag - or just slag - is a by-product of the iron smelting used to make steel. These cement substitutes also help to increase the performance of concrete.

Mixing fly ash into concrete has three main advantages over cement:

- Under certain conditions it can improve durability and strength of concrete
- It can reduce the cost of concrete, by 2-10%. Savings are driven by the price and availability of fly ash, which in turn depend on the proximity of coal-fired power plants: as stocks of waste fly ash build up, these plants need places to dispose of it
- It reduces the CO2 footprint of a ton of concrete by 25-40%.

Despite lower costs and significant CO2 advantages, there are problems to consider in using fly ash in our buildings. First, it contains high levels of heavy metals (especially mercury). To date, the leaching of heavy metals from fly ash added to concrete has not been shown to be an issue to human health, but the full impact over the life-cycle of concrete remains unknown, especially when buildings are renovated or demolished. Circular economy thinking challenges us to consider what is next for a product or a material, and to change from a 'life-cycle' perspective, to an approach that emphasises use-cycles. To enable products to be used many times over we must design them not to contain toxic materials. In the near-term, companies concerned about the health and exposure to toxicity of their employees may also see a reason to take a similar approach.

Second, as more companies seek to reduce their carbon footprints and increase their use of renewable energy, the continued use of fossil fuel by-products in their office buildings is increasingly counter-intuitive and contradictory. In addition, by offering the coal industry a market for their waste products, the use of these by-products only further sustains the economics of fossil fuel extraction and consumption.

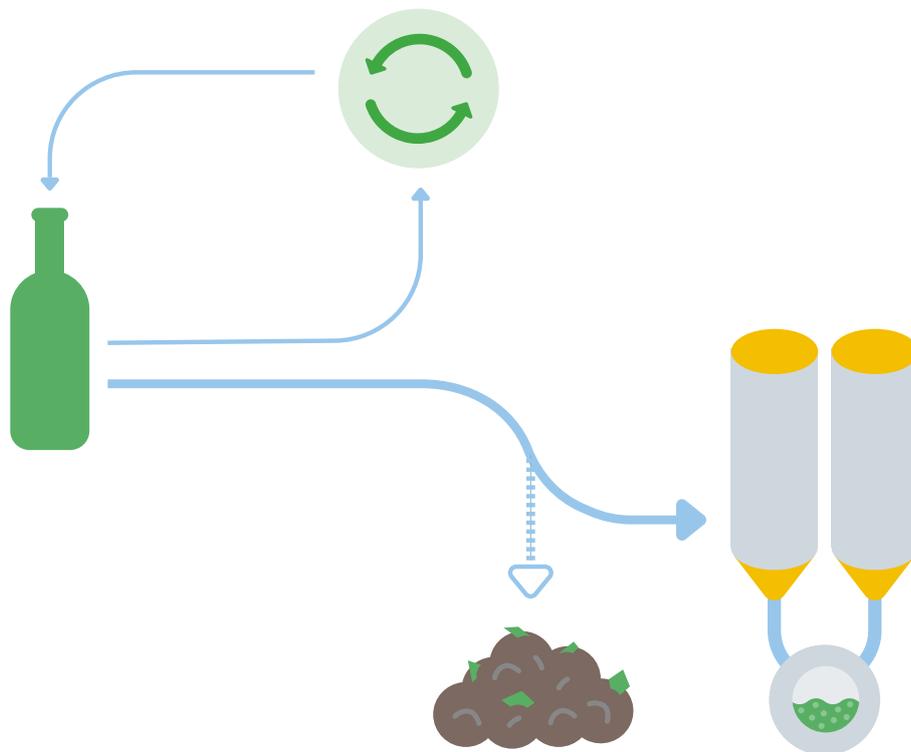
Finally, the market may be moving away from the economics of fly ash. In 2015, as the price of natural gas fell, US coal production declined by nearly a third. The Obama administration has signalled its intent to reduce US utilities' reliance on coal, and in 2015 the EPA announced the Clean Power Plan, which aims to cut carbon emissions from coal-fired power plants. The policy was stayed by the Supreme Court in February 2016, with a final legal decision not expected until 2018, but the uncertainty created has meant no new coal-fired plants are planned for the near future. According to the Energy Information Agency, if the Clean Power Plan is upheld, coal production will fall another 25%. And even if it is overturned, US coal production levels will continue to stagnate.² Many US States also have their own emissions goals and renewable energy standards that encourage utilities to look beyond coal - for example, Oregon passed a bill in 2016 to eliminate by 2030 its use of electricity generated by coal.

So what happens when the supply of materials like fly ash and slag declines, and they need to be imported from further away? In areas such as California where there are no large coal-fired power plants, the concrete industry sources fly ash from other parts of the country (as well as from China), and slag that increasingly comes from Japan, Europe or Brazil. These longer supply chains entail not only more complicated logistics, but potentially higher CO₂ emissions.

² <http://www.eia.gov/todayinenergy/detail.cfm?id=26992>

CASCADING POST-USE GLASS INTO THE CONCRETE SUPPLY CHAIN IS A CIRCULAR ECONOMY OPPORTUNITY

Enter glass. As most are by now aware, glass is easily recyclable. Cities and citizens have been recycling it for decades. Since 1980, the collection of glass for recycling – whether at home, at the curbside, or via bottle bills and deposit programs – has increased fourfold in the US. The problem is that Americans still fail to re-use a lot of glass: 11 million tons per year, and 750,000 tons in California alone. And of this discarded glass only about one-third is recycled. Even in California, which has the highest glass recycling rates in the country, only three-quarters of glass is re-used (thanks largely to the wine industry). The State landfills the remaining 200,000 tons of 100% recyclable glass each year, losing economic value in the process.



The glass recycling problem is worsening, with city after city in the US abandoning their recycling programs. The issue is primarily economic: sorting the different kinds of consumer glass once it has been used is complex, dirty, and costly; while an insufficient market for recycled glass further harms the investment case. As a result, some cities end up paying \$40/ton to send recyclable glass to landfill.

GLASS CAN HELP REDUCE CO2 EMISSIONS FROM PRODUCING CONCRETE

Recycled glass, when ground into fine powder, can be substituted for a portion of the cement in concrete just as fly ash and slag are. Initial pilot projects are proving the technical viability of this approach, both for concrete used in sidewalks (in Montreal, New York City, and on Google's Campus in Mountain View, CA) and in buildings (in Montreal and soon, in New York City as well).

Using glass as a cement substitute reduces the carbon footprint of concrete by between 20-40%. The grinding of glass into pozzolan requires little energy and emits 18 kg CO₂ per ton of glass.³ Compare this with fly ash, the production of which emits 201 kg CO₂e/ton (a figure arrived at by attributing some of the emissions from coal combustion to fly ash production).⁴

According to Ellen MacArthur Foundation estimates, this new business model may result in an increase in the price of concrete by around 2-5%. In California specifically, our current estimate is that the use of glass pozzolan as a cement substitute is 3% more expensive than a standard mix of concrete (on a delivered cubic yard basis). These are real costs, but participating companies purchasing concrete made with glass may value the opportunity to reduced long-term toxicity and lower CO₂ emissions, while at the same time contributing to the development of a product that follows circular economy principles. Building a market relies as much on economies of scale as on mastering the technical challenges.

Glass pozzolan facilities currently operating on the East Coast need about 40,000 tons of glass input per year. A similar level of input for potential new, similar facilities on the West Coast would require the diversion of about 15-20% of the post-consumer glass currently being sent to landfills in California. With the participation of the right stakeholders in the concrete and building industry, it may be possible to achieve this using existing infrastructure and supply chains. The efforts of a few companies like Google and Unilever could be just the push this industry needs. But for this solution to be truly impactful, it will require the involvement of both the private and public sector, and at the federal, state and city level – potentially with the cooperation of municipalities such as Los Angeles, New York, or Phoenix. For cities generating greater and greater amounts of glass debris, while at the same time requiring increasing quantities of building materials, the use of glass in concrete enables them to both divert these resources from landfill and reduce their carbon emissions.

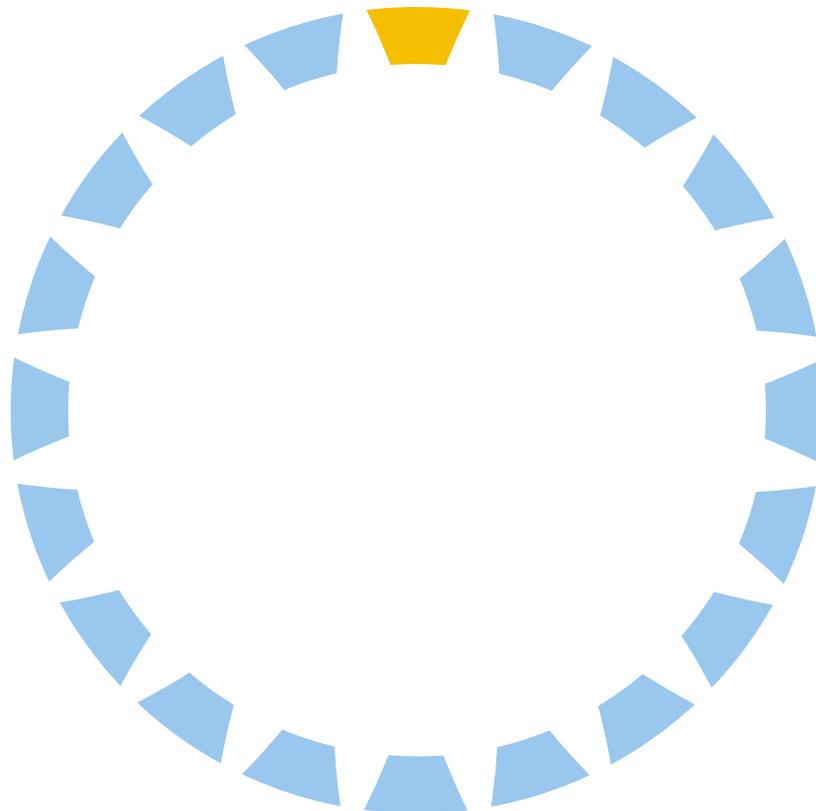
³ Glass Recycling - Life Cycle Carbon Dioxide Emissions. (2003). A Life Cycle Analysis Report Prepared for British Glass. Enviro Consulting Ltd, p.19.

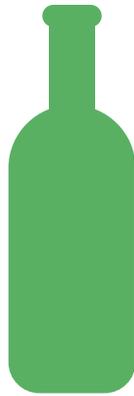
⁴ Carbon Footprint of Fly Ash. (2015). AHSTRANS Conference. Danish Technological Institute, p.24.

TOWARDS A VALUABLE CASCADE OF MATERIALS CIRCULAR ECONOMY

Using recycled glass in concrete would allow companies, building developers and cities to leverage a local, non-toxic resource in a product that is core to our built environment. The approach offers a viable solution to two pressing problems: concrete's high CO₂ emissions and the increasing difficulty faced by cities in processing their post-use glass. If successful, this project presents a unique opportunity to create a virtuous circle of awareness and adoption, resulting in greater economies of scale and a steeper learning curve.

This virtuous circle can start to eliminate the trade-off in our built environment between reducing carbon emissions and increasing health on the one side, and reducing costs on the other. Diverting glass from landfill to be used to make concrete is a great example of cascading a technical material to another valuable use - one of the key principles of value creation in the circular economy.





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