Construction flat glass recycling

Viability study & value report

Re-thinking the life-cycle of architectural glass

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ABSTRACT

This report aims to apply circular economy principles to the life cycle of just one of many materials used in the construction of our buildings and infrastructure of our towns and cities.

In the construction industries, glass is used for a wide range of products including internal partitions and display cases, but primarily it is used as architectural glass in windows and glazing systems of all building types and across all sectors. Glass is also utilised in photovoltaic panels applied to buildings and infrastructure projects.

Glass is an inert material that has the potential to be recycled in a closed-loop system indefinitely. Coupled with the short service life of insulating glass units (double and triple glazing) there appears to be a disparity between the material's potential and its current utilisation.

In the UK, we generate almost 200,000 tonnes of post-consumer glass waste each year. Much of this goes to landfill or is crushed into aggregate.

Using recycled glass to make new glass products generates significant energy and CO_2 savings, and contributes towards creating a circular economy. This report reviews the existing linear glazing manufacturing process and proposes a circular approach to end of life glass materials through recycling at high level, back to the glass-making furnace.

Limitations, barriers and viability of such an approach are discussed and a strategy developed for the implementation of the operational system that would produce a sustainable business case for the recycling of post-consumer construction flat glass.

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Special thanks to Valli Murthy, Environmental Advisor for British Glass and Chris Holcroft from GTS who have both provided their time and energy in research and development of this report.

FIGURE 1
Collaborators & contributors

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1. INTRODUCTION

It was during design development for a recent refurbishment project in Glasgow that we began to consider the possibility of recycling construction glass. Some 3000m^2 of double glazed units are to be removed from a public museum building and we were concerned with where that glass would end up after removal. This refurbishment project is The Burrell Renaissance Project and is to become a pilot project for the process developed in this report.

1.1 AIM

The aim of the report is to research the economic, technical, environmental and logistical viability of post-consumer construction flat glass closed-loop recycling, including a study of the regulatory drivers, opportunities and barriers.

1.2 CONTEXT

According to the European Commission, construction and demolition waste (CDW) is one of the largest by mass and most voluminous waste streams generated in the EU. It accounts for approximately 25%-30% of all waste generated in the EU and consists of numerous materials, including concrete, bricks, gypsum, wood, glass, metals, plastics, solvents, asbestos and excavated soil, many of which can be recycled[1].

A Deloitte sustainability study showed that despite its recyclability, end-of-life building glass is almost never recycled into new glass products[2]. Instead, it is often crushed together with other building materials and put into landfills or recovered to low-grade fill applications.

Most of the flat glass used in buildings could be dismantled and recycled in glass furnaces. The flat glass industry is starting to explore the development of end-of-life building glass collection, sorting and recycling and is ready to use more recycled glass in its manufacturing process, and therefore save raw materials, energy and reduce CO_2 emissions[3]. The key step is to keep the post-consumer glass contamination free during the deconstruction and collection process.

Across the EU, the proper recycling of all building glass waste compared to the business-as-usual scenario could avoid 925,000 tonnes of landfilled waste every year and could save around 1.23 million tonnes of primary raw materials annually (of which 873,000 tonnes is sand) and reduce carbon emissions by in excess of 230,000 tonnes annually[2].

Glass manufacturers are ready to take back waste flat glass to be recycled into new flat glass products, provided quality specifications are met. Flat glass manufacturers agree on and support the principle of closed-loop recycling to increase the recycled content of flat glass products, as there is potential to increase the percentage of recycled glass used in the manufacturing process[3].

One of the objectives of the Waste Framework Directive (2008/98/EC) is to provide a vehicle for moving towards a European recycling society with a high level of resource efficiency. In particular, Article 11.2 stipulates, "Member States shall take the necessary measures designed to achieve, that by 2020, a minimum of 70% (by weight) of non-hazardous construction and demolition waste… shall be prepared for re-use, recycled or undergo other material recovery"[4]

"A Deloitte sustainability study showed that despite its recyclability, end-of-life building glass is almost never recycled into new glass products Instead, it is often crushed together with other building materials and put into landfills or recovered to low-grade fill applications."

1.3 VALUE

Arup has developed an understanding of the current recycling logistical structure and typical refurbishment construction process and supply chain. We have investigated the processes required to write a robust specification for the recycling of construction flat glass in refurbishment projects.

Designs and specifications for new façades should follow guidance to maximise the potential of glass to be recycled.

This can drive the increase of waste construction flat glass recycling, therefore reducing virgin raw material use and reducing the carbon intensity of flat glass manufacturing.

It is likely that in the next few years, the construction & demolition industry will need to become more resource efficient and circular in its practices. For example, the UK government has recently set a target to work towards 'zero avoidable waste by 2050'[5].

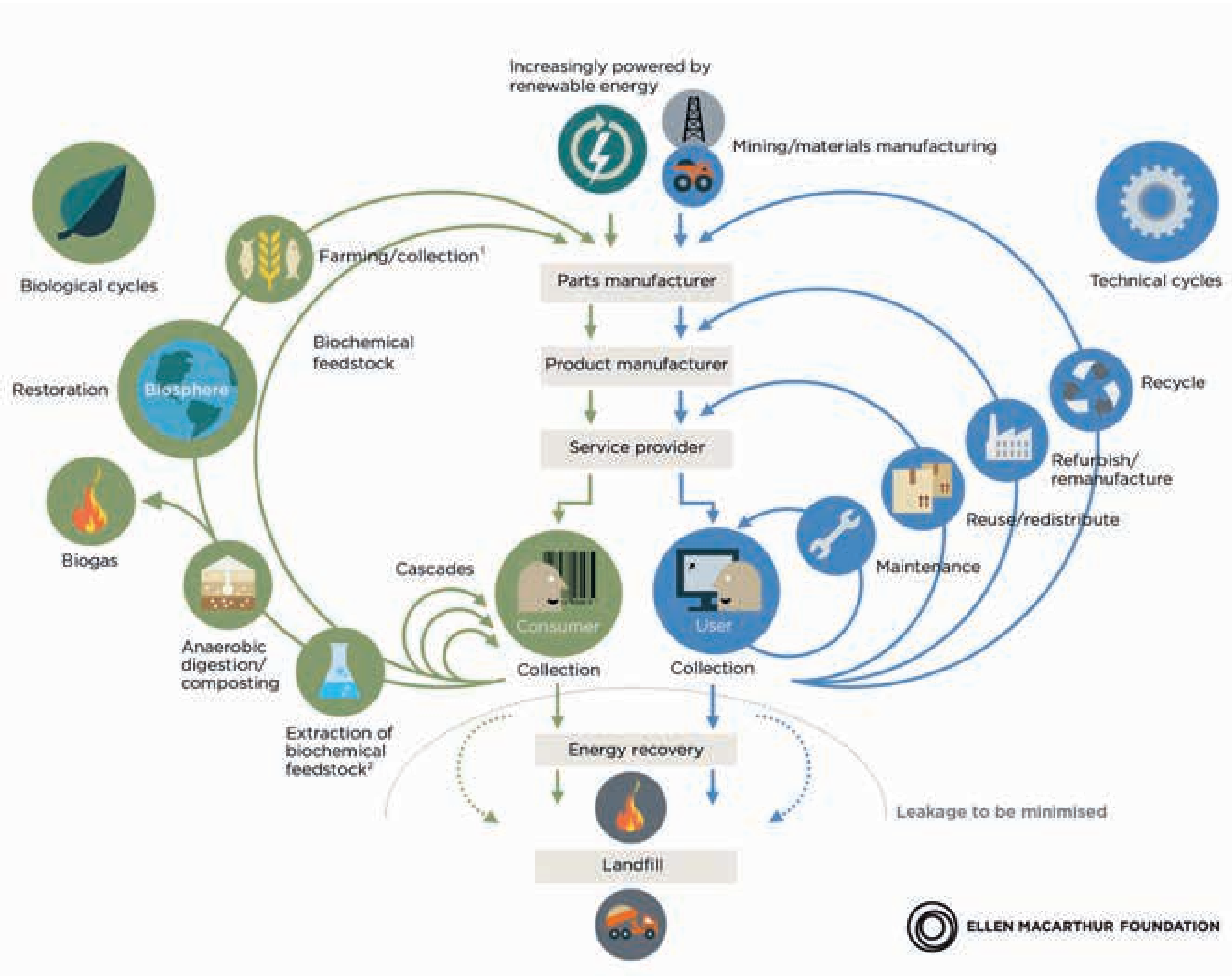
"Designs and specifications for new façades should follow guidance to maximise the potential of glass to be recycled."

FIGURE 2

The Lloyd's building in London © Arup

2. WHAT IS THE CIRCULAR ECONOMY?

The scarcity of non-renewable resources is not a new phenomenon; whatever your position on climate change, there can be no doubt about humanity's overuse of the world's natural resources. As a society, we must move away from this '**take, use, dispose**' mentality, and as members of the construction industry, it is our duty to take on this challenge.



The circular economy approach provides a framework, for designers and engineers to work, to build more sustainable, greener buildings and infrastructure projects and decouple economic growth from finite resource consumption.

Arup is a "Knowledge Partner" with the Ellen MacArthur Foundation, whose mission is to "accelerate the transition to a circular economy"[6]. Set up in 2010 the charity is at the forefront of change across industries. At Arup our focus is on the positive change design can make.

"We believe that existing practices regarding materials, energy and waste produced cannot be sustained."

Figure 3, a diagram by the Ellen MacArthur Foundation, describes the circular economy and shows two streams. The Biological Cycles, on the left, include farming and soil fertility as examples. More importantly for this research and in the built environment are the Technical Cycles, shown on the right. This cycle considers finite material resources and routes to circular process such as reuse, refurbishment and recycling.

FIGURE 3

Circular economy
© Ellen MacArthur Foundation

[1] hunting and fishing

[2] can take both post-harvest and post-consumer waste as an input

Adapted from Cradle to Cradle Design Protocol by Braungart & McDonough

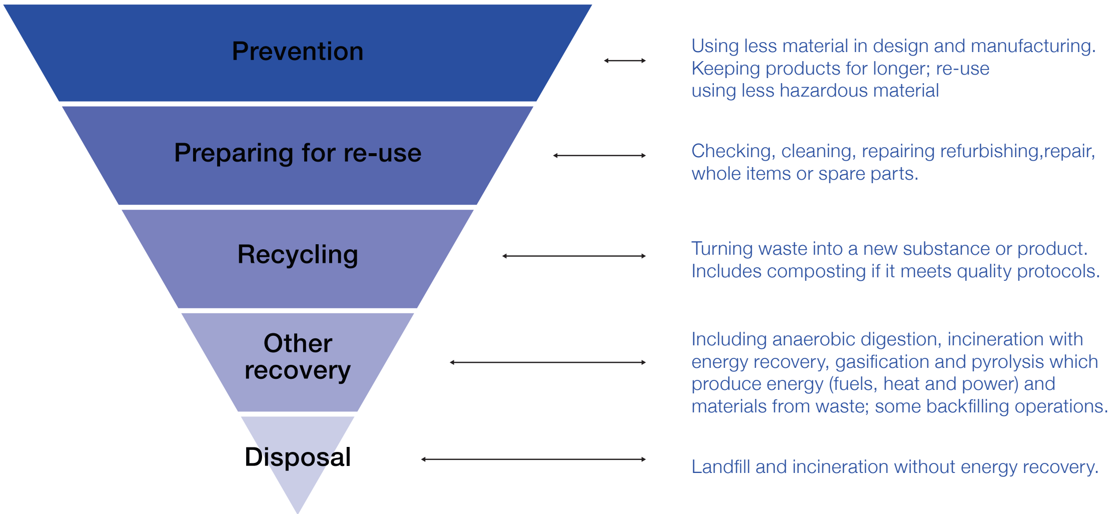


FIGURE 4

UK waste hierarchy

The reuse and repurposing of existing building stock aligns absolutely with this philosophy, and the varying degrees of intervention that are possible when upgrading an existing building could fall into any one of these cycles.

Typically, glass replacement in existing buildings must meet thermal performance and solar control requirements to improve energy and fuel conservation.

It is important to understand that recycling of materials is almost the last resort and least sustainable approach to achieving true circular economy because it requires the most primary energy.

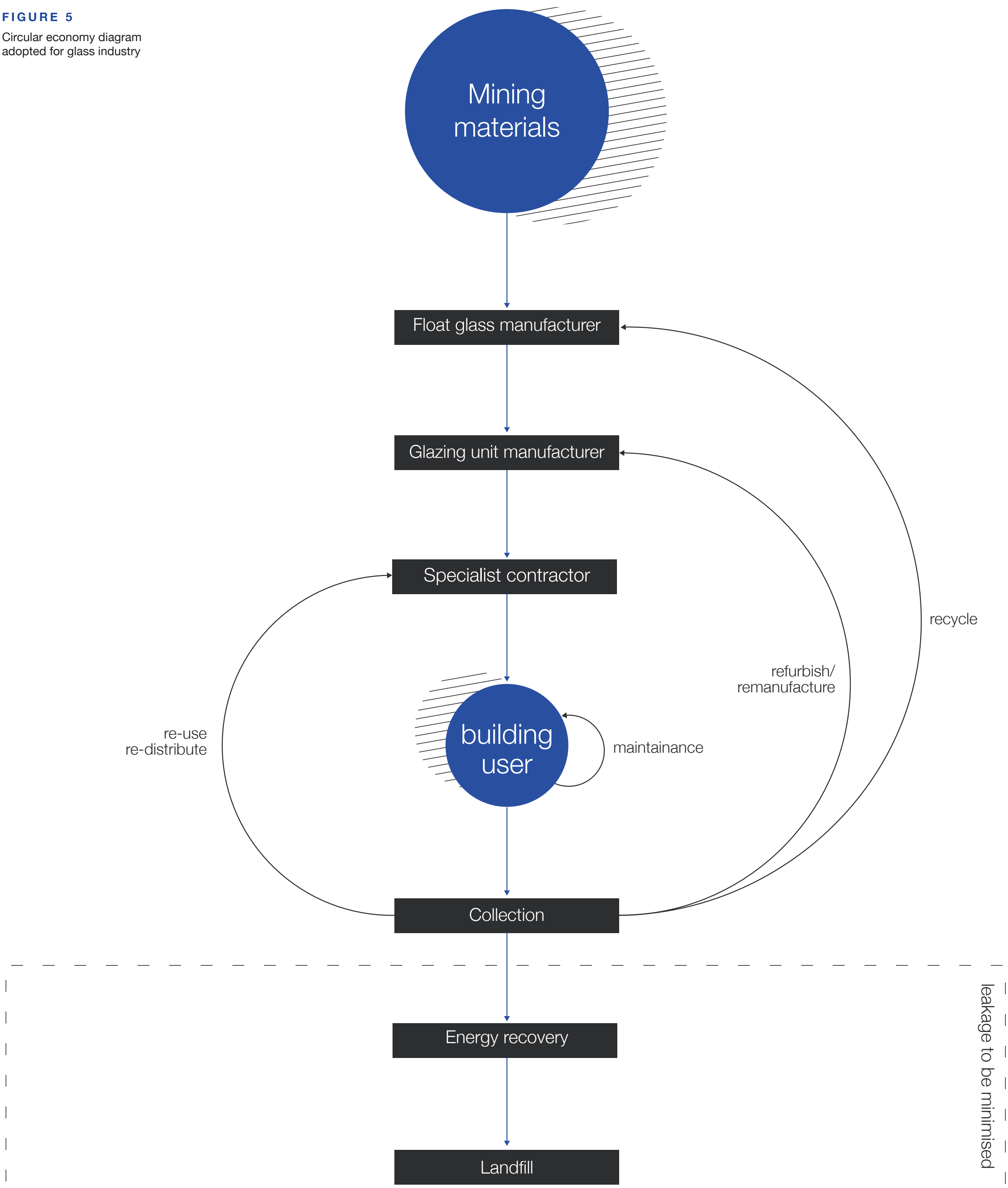
However, it is an important step nonetheless because most glass in the building envelope is currently used in the form of hermetically sealed insulating glass units whose components are not easy to separate and re-use. The widespread use of heat treatment on glass in buildings also makes that glass problematic to re-shape and re-purpose.

New designs adopting circular economy principles may enable reuse or longer term utilisation of glass materials in the built environment by avoiding obstacles at end of life.

"As a society, we must move away from this take, use, dispose mentality, and as members of the construction industry, it is our duty to take on this challenge."

FIGURE 5

Circular economy diagram
adopted for glass industry



3. RAW MATERIALS

Glass manufacture is an ancient process. The history of man-made glass dates back to before 3000BC, flourishing in the Roman Empire and becoming an art form in the stained glass windows of 13th and 14th century cathedrals across Europe.

Material	Glass composition %	Reason for adding
Sand	72.6	-
Soda ash	13.0	Easier melting
Limestone	8.4	Durability
Dolomite	4.0	Working & weathering properties
Aluminia	1.0	-
Others	1.0	-

FIGURE 6

Raw materials of float glass manufacturer % of raw materials[7]

The primary ingredient is high quality silica sand, which makes up over 70% of the raw material of modern glass manufacture. Adding soda ash to assist the melting process and limestone and dolomite for durability and weathering performance mostly completes the raw material input. All these materials are mined or quarried, processed and transported prior to arriving at the float line.

Sand with more than 95% or more of silica content is called silica sand. Due to its use in specific non-aggregate applications, and because it occurs within only a limited number of locations within the UK, silica sand is treated differently from general construction aggregate sands in terms of mineral planning. Only the purest silica sand is used in glass manufacturing and in the mid-1980s, glass manufacturing became the largest consumer of silica sand in the UK.

While UK sand mining sites are not facing shortages of silica sand suitable for a wide range of specialist end uses, in the case of clear glass the sands which meet the most exacting requirements in terms of chemical purity and consistency are likely to be relatively scarce.

From the four individual sites in England, which currently supply sand for glass manufacturing, only one is thought to have 10 years of permitted reserves - and that is for coloured container glass and not clear glass.

There are also 3 sites in Scotland, with higher reserves, which already provide raw materials to the glass manufacturers in the North of England.

Overall, while there is no indication from the UK glass industry of an impending critical shortage, there is, however, considerable uncertainty regarding the long-term security of silica sand supply to support the manufacturing of glass within the UK and the industry would certainly welcome additional supply options.

Glass cullet is also a valid alternative to silica sand. All glass manufacture includes a percentage of glass cullet and for every one tonne of cullet used in the manufacture of float glass, 1.2 tonnes of raw material is saved[11]. Cullet is broken glass returned to the furnace for re-melting. Most glass manufacturers use pre-consumer glass from their own breakages or from offcuts from local glass processors. Currently the average quantity of cullet entering the furnaces of European glass manufacturers averages 20-25% but can range between 10-40% of the raw material input into the furnace[9].

> "Long-term risk of such finite resources is real and costs of extraction are somewhat volatile even now, whilst supply is considered abundant."

4. CURRENT LINEAR PROCESSES

The existing linear process of construction glass manufacture is described. We have identified the possibilities and limitations of glass recycling at each step.

4.1 FLOAT GLASS MANUFACTURING PROCESS

The float glass process that we know today and widely used for construction and automotive glass manufacture was patented by Sir Alastair Pilkington in 1952[7].

The raw materials are melted in a furnace at over 1300 degrees Celsius then poured continuously from the furnace onto a shallow bath of molten tin. On the surface of the tin the glass spreads out and forms a level surface. Thickness of the manufactured glass can be controlled by varying the rate at which the glass ribbon is drawn off the bath.

Annealing occurs by controlled cooling through a continuous lehr and the name "annealed glass" is often used to describe float glass directly off the float line without further treatment.

Modern operations allow glass thicknesses of between 0.4mm and 25mm, typically in widths of around 3m. Glass float lines operate 24 hours a day, 365 days a year and usually do not stop for between 10-15 years. A single defect may require the process to be stopped and can therefore have a severe impact on production.

A single float line can produce a ribbon of glass 6000km long over the year[7]. It is an energy intensive process which produces CO_2 through both the generation of electricity or combustion of natural gas to heat the furnace and the glassmaking chemical process in which CO_2 is released from the carbonate raw materials: soda ash (sodium carbonate); limestone (calcium carbonate) and dolomite (calcium magnesium carbonate) in the melting tank.

"A single float line can produce a ribbon of glass 6000km long over the year It is an energy intensive process which produces CO_2"

In fact, the release of CO_2 bubbles helps to remove air bubbles from the melt during the refining process, so current glassmaking processes require some carbon dioxide release to produce glass without bubbles.

The manufacture of one square meter of low-e double glazing leads to the emission of 25kg of CO_2 according to NSG Pilkington[10].

A reduction of CO_2 emissions in the order of 250-300kg for every tonne of cullet added to the furnace can be realised[11].

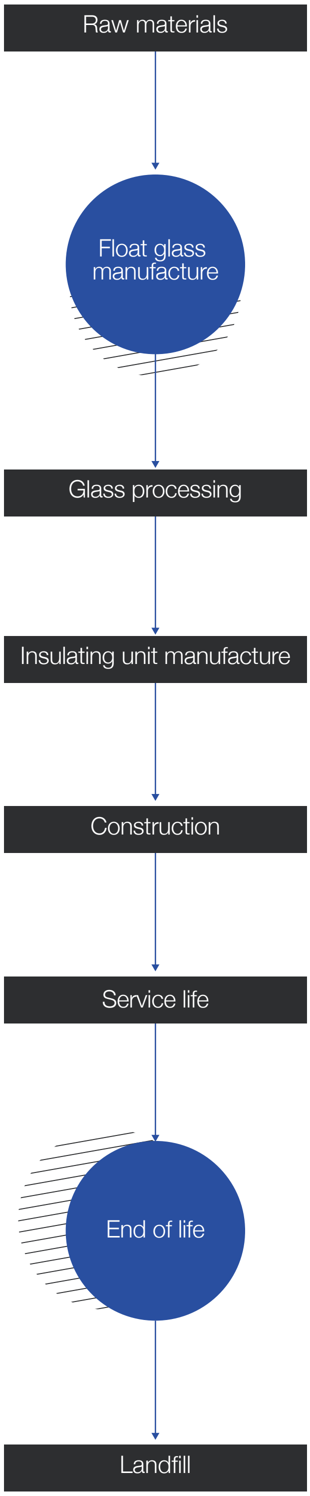


FIGURE 7
Glass manufacturing and processing in a linear model

FIGURE 8

Float glass during the manufacturing process © Arup

4.2 FLOAT LOCATIONS

In the UK there are currently 3 operating glass float lines; operated by Pilkington in Merseyside, Saint Gobain and Guardian both in Yorkshire.

In addition to the 3 float lines, there is also a rolled glass line in the UK operated by Pilkington.

Around 700,000 tonnes of glass is produced in the UK each year from the three lines.

4.3 JUMBO GLASS PANES

The float process typically produces glass panes of 6 metres long x 3.21 metres wide, which are referred to as a jumbo pane. The very nature of the process does allow longer glass sizes to be produced and some efforts continue in this field (such as Apple's signature stores) but restrictions from handling, processing and transportation limit the use of larger glass sizes in the construction industry.

4.4 GLASS PROCESSING

The next step is glass processing which contains a wide range of possible procedures. They are summarised here to assist the understanding of the potential limitations for recycling that may occur due to the processing methods.

4.4.1 Cutting and shaping

The first step is often cutting to size followed by edge working. Edge working may be the required finish where edges are exposed or prior to further processing which relies on high quality edges to minimise breakage. Drilling or shaping is typically undertaken prior to any heat treating for strength.

4.4.2 Laminating

Laminating of glass utilises PVB, ionomer or resin interlayers sandwiched between two or more panes of glass, laminated together under heat and pressure to form a safety glass that performs very differently from monolithic glasses. This is typical of the front windscreen in your car or cantilevering glass balustrading.

Laminated glass provides some challenges when looking to recycle this material. The layers need to be separated and the laminate layer removed. This is achieved by a pulverizing and separating machinery, crushing and grinding the glass into small pieces in the process. This size is not preferred for cullet by the float glass manufacturers but may be suitable for recycling in the container glass industry.

The PVB interlayers, once separated from the glass, are also a valuable resource, particularly recycled for use in the manufacture of carpet tiles.

Alternative delamination procedures that do not utilise pulverizing have been developed but are not yet in wide scale use in the UK. A company called "Delam" in Melbourne, Australia has patented a system for delaminating flat and curved laminated glass using heat, time and steaming of panes up to 1.8m x 3.5m in size[12].

The automotive industry should be closely watched for developments in this field. It is driven to increase recyclability of vehicles under the EU's "End of Life Vehicles" (ELV) directive and in particular the recycling of laminated windscreens, and adoption of their technology may increase the potential to recycle laminated construction glass in the future.

4.4.3 Heat treating and testing

Heat strengthening and toughening (also known as tempering particularly in the US and Australia) changes the surface characteristics of the glass to provide increased stress resistance. Heat strengthening produces glass that is around twice the strength of annealed glass. Toughened glass, which is cooled more rapidly, is around four to five times the strength of annealed glass. Toughened glass will break into small pieces of glass (dice) and as such is considered a safety glass.

Heat strengthening or toughening has no negative effect on the ability to recycle the glass.

Unfortunately, heat-treated glass (especially toughened glass) suffers from potential spontaneous breakage due to critical inclusions in the glass, particular of Nickel Sulphide (NiS). To reduce the risk of critical inclusions making it onto the building site, a heat soak testing method is available which requires the glass to be held at a high temperature for a defined period. This test procedure should initiate critical inclusions to cause glass breakage during the test process. It is not 100% successful but significantly reduces the risk of a critical inclusion reaching a building and spontaneously breaking at some point in the future.

The test procedure itself has no negative effect on the ability to recycle the glass.

The requirement to ensure against nickel contamination of any glass cullet used in the remelting process however is of utmost importance to ensure good quality glass. Minor contact with stainless steel during removal, storage and transportation can cause significant contamination that may cause critical inclusions.

4.4.4 Glass coating

Coatings to the glass are applied for a number of reasons, but particularly for the control of solar gains through the glass or for improved thermal performance. Coatings can be applied on the float line or later during processing. Glass coatings typically consist of very fine layers of metal (silver for example) applied to the glass surface.

These coatings are not detrimental to the ability to recycle glass and are burnt off in the remelting process.

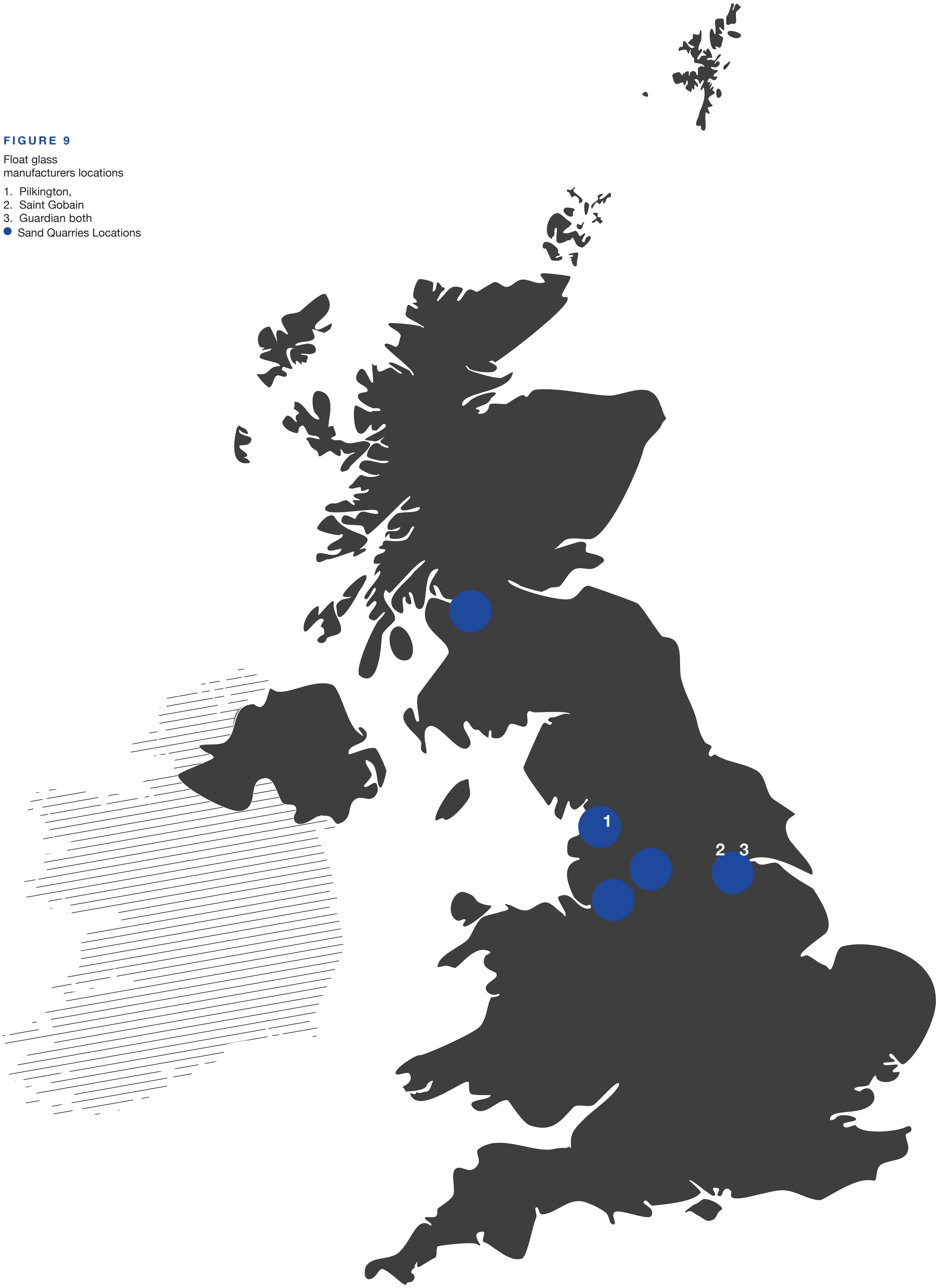
4.4.5 Printing

Screen-printing and digital printing utilises ceramic frits applied to the glass for architectural, shading or privacy requirements. These ceramic patterns are fused into the composition of the glass following application-using heat-treating techniques described previously. The presence of ceramic frit does not currently allow the glass to be returned to remelting through the recycling loop.

FIGURE 9

Float glass
manufacturers locations

1. Pilkington,
2. Saint Gobain
3. Guardian both
● Sand Quarries Locations



4.5 INSULATING GLASS UNITS

With the glass processing complete, single glazed units for uninsulated uses can be sent directly to site.

For most projects though insulating glass units are required as either double or triple glazed units. These units provide an insulated building envelope which building regulations continue to push to greater levels of performance in an effort to reduce building energy and fuel consumption.

By separating multiple panes of glass with edge spacers to create cavities between the panes and filling with inert gas, the thermal performance of the unit is significantly improved.

The edge seals utilise various polymer compounds to form an airtight seal around the perimeter of the unit. These seals are important to the performance and the service life of these insulating units but are not considered in detail in this report. However, we will return to the performance of these seals and insulating units later in the report.

4.6 SITE INSTALLATION AND DESIGN LIFE

The assembled insulated glazing units are now ready for installation into buildings. Typically, the glass is installed into window and glazing framing systems constructed on site, or in factory conditions for unitised curtain walling.

With perhaps the exception of uPVC window frames used in residential building, typically the framing members that support the glazing units will have a predicted service life commensurate with the building's design life. This may be in excess of 60 years. However, the glazing units will have a predicted service life of only approximately 25 years[13]. This is due to the polymer edge seals which degrade and fail whilst the inert glass panes themselves could have a much longer (possibly indefinite) service life. So, we are not seeing the full potential of the glass in service.

The glazing industry is currently exploring options and developing methodologies to move away from this traditional insulating glazing unit approach of relying on sealed cavities that shortens the service life of glass so drastically. But the short to medium term there will not be a rapid move away from the extensive use of this type of double and triple glazed insulating units. Indeed, as thermal performance requirements continue to become more onerous, there is an expectation that more glazing units will need to be replaced with a continued prevalence towards triple glazing.

> "In the UK there are currently 3 operating glass float lines; operated by Pilkington in Merseyside, Saint Gobain and Guardian both in Yorkshire... Around 700,000 tonnes of glass is produced in the UK each year from the three lines."

TABLE 1

Amount of waste glass per year in tonnes, for residential and tertiary building projects in the UK and Europe[2].

	Residential buildings	Tertiary buildings	Total		
	Refurbishment	Demolition	Refurbishment	Demolition	R&D
UK	107,000t	7,000t	62,000t	23,000t	199,000t
Europe	825,676t	62,205t	454,206t	195,616t	1,537,703t

4.7 END OF LIFE

At the end of these insulating glass units' service lives, which may be as little as 25 years, where is all this glass destined? Some of the numbers are staggering[2]:

9.2 million square metres of glazing was replaced in the UK in 2013 equating to; 107,000 tonnes of glass per year removed during residential refurbishment works and;62,000 tonnes removed from the renovation of tertiary buildings, which includes commercial, retail, leisure, educational buildings and the like. And then more from demolition as is indicated in the table;

In the UK, we have in the order of 199,000 tonnes of glass available for recycling, if correctly collected. These figures are likely to continue to increase in the future as more pressure is applied to improve the thermal performance of existing building stock in a drive to reduce building energy use[2].

The wide scale adoption of photovoltaic solar panels in the construction industry is part of the global drive to move away from carbon intensive forms of energy production. PV panels consist of 76% to 89% (by weight) of glass depending on the technology utilised to construct them[14].

Current life expectancy of solar panels is about 30 years. As these panels begin to fail and be decommissioned in the future, there will be a further source of glass available for re-use or recycling in addition to glass available from refurbishment and demolition.

Solar cells tend to use toughened glass, which is difficult to cut or process for re-use and it likely that recycling of the glass may be more suitable than re-use.

A requirement of the Waste Electrical and Electronic Equipment (WEEE) Directive regulates that solar cell manufacturers are bound by law to make sure that solar panels do not become a burden on the environment[15].

9.2

million square metres of glazing was replaced in the UK in 2013

107,000

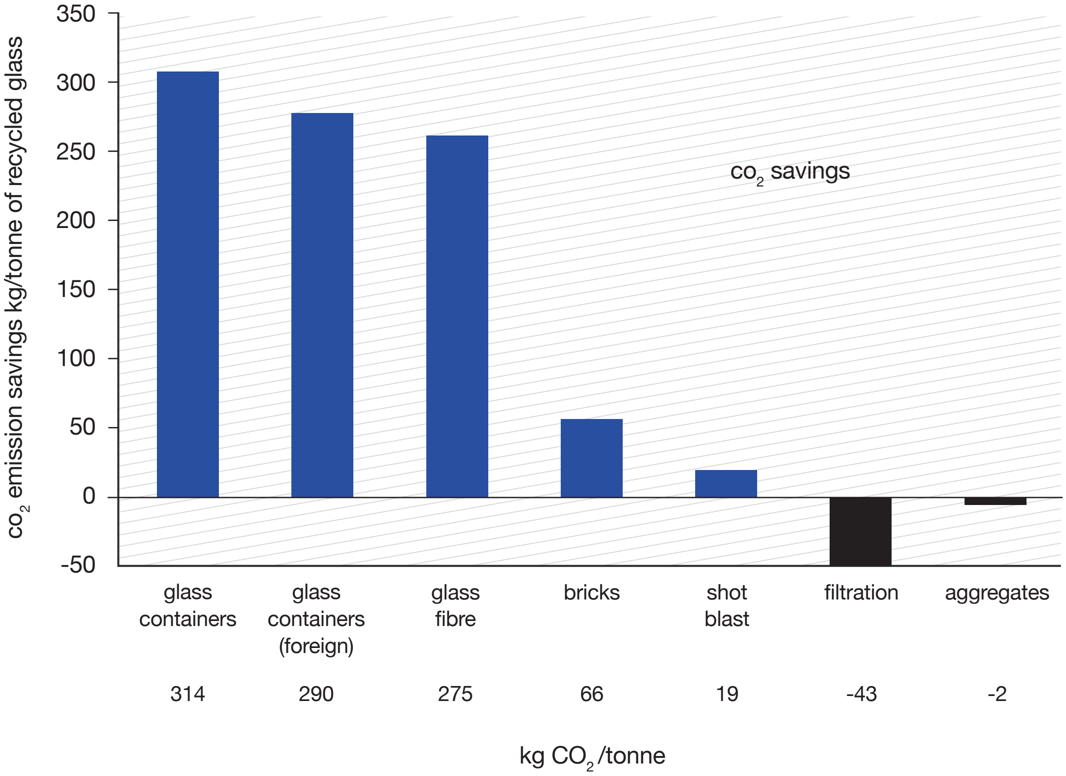
tonnes of glass per year removed during residential refurbishment

62,000

tonnes removed from the renovation of tertiary buildings.

FIGURE 10

CO_2 savings from different glass recycling alternatives © British Glass[16]



"Of the 199,000 tonnes of post-consumer waste glass generated in the UK, it is estimated that the majority is not recycled back to glass. Most of it is down cycled into aggregate or deposited to landfill."

4.7.1 Downcycling

Of the 199,000 tonnes of post-consumer waste glass generated in the UK, it is estimated that the majority is not recycled back to glass. Most of it is down cycled into aggregate or deposited to landfill.

Some of the waste glass is used in manufacture of glass wool insulation, aggregates, and ballotini products. These are low value or non-circular material streams and they are not recyclable again and therefore are not considered closed loop recycling processes.

The CO_2 savings associated with these potential recycling activities are indicated in Figure 10 above. In addition, our research indicates that recycling back to float glass saves a similar amount of CO_2 as recycling to glass containers.

Waste sent to landfill	Rate from 1/4/16	Rate from 1/4/17	Rate from 1/4/18
Standard rated	£84.40/tonne	£86.10/tonne	£88.95/tonne
Lower rated	£2.65/tonne	£2.70/tonne	£2.80/tonne

TABLE 2

Landfill tax rates - obtained from GOV.UK (19/01/2018)

4.7.2 Landfill

When any waste stream is deposited to landfill, it is subject to Landfill Tax. This is an environmental tax, introduced in a form of a fee per weight of material deposited to landfill. It was introduced by the UK government in 1996 in order to encourage alternative routes for the end of life materials - reuse, refurbishment and recycle.

Glass is classified as "inactive waste" in Group 2 of the UK Government Summary of Landfill Tax (Qualifying Material) Order 2011[17] and the lower rate applies to clean segregated glass material or mixed material that meet the requirements of "inactive waste" in the above Order such as with rocks, soil, bricks, concrete, etc.

The landfill tax cost in 2013 was £80/ tonne for standard rate and £2.5/tonne at lower rate. It has been increased a number of times since. Table 2 above shows the revisions in past couple of years;

If glass waste is mixed with other "active waste", such as plastic or wood, the standard rate is applied. Currently our research indicates that waste segregation in the demolition sector is not sufficient by the contractors to attract the lower rate of landfill tax and that the standard rate would apply for materials (including glass) being sent from demolition projects. Further study of the demolition process for closed loop recycling needs to be undertaken to understand the current obstacles. These could then be expanded to promote the segregation of waste to divert further glass from landfill to recycling and reuse opportunities.

Current practice in the refurbishment sector shows that the separation for transportation to landfill is unlikely to take place. Glass and window frames arriving as mixed waste at a landfill site would attract the standard landfill tax rate.

As such, there is great potential in this sector to improve practices during the renovation process, as components are removed in a more controlled manner. This would allow the sorting of materials on site and lead to a financial incentive for contractors to recycle materials instead of depositing to landfill.

In Europe the glass industry has been driving legislation to remove glass from the "inactive waste" designation, to ensure that it attracts the highest rate of Landfill Tax and therefore the greatest incentive to recycle the glass at higher value opportunities[18].

5. CIRCULAR PROCESSES

We have been through the cradle to grave linear approach that is the traditional methodology for the glass industry. How can this be challenged and altered to better suit the circular economy?

Other industries, such as structural steel, indicate that 7% of reclaimed steel materials is reused and that 93% is recycled, with 0% going to landfill[19]. The glass industry therefore has a long way to go to emulate other material waste streams which have successfully converted their linear processes to circular.

Float glass manufacturers already use a percentage of cullet in the mix of raw materials added to the furnace. There are three primary sources of this cullet; pre-consumer internal cullet, pre-consumer external cullet from glass processing and fabrication and finally post-consumer glass from refurbishment and demolition opportunities.

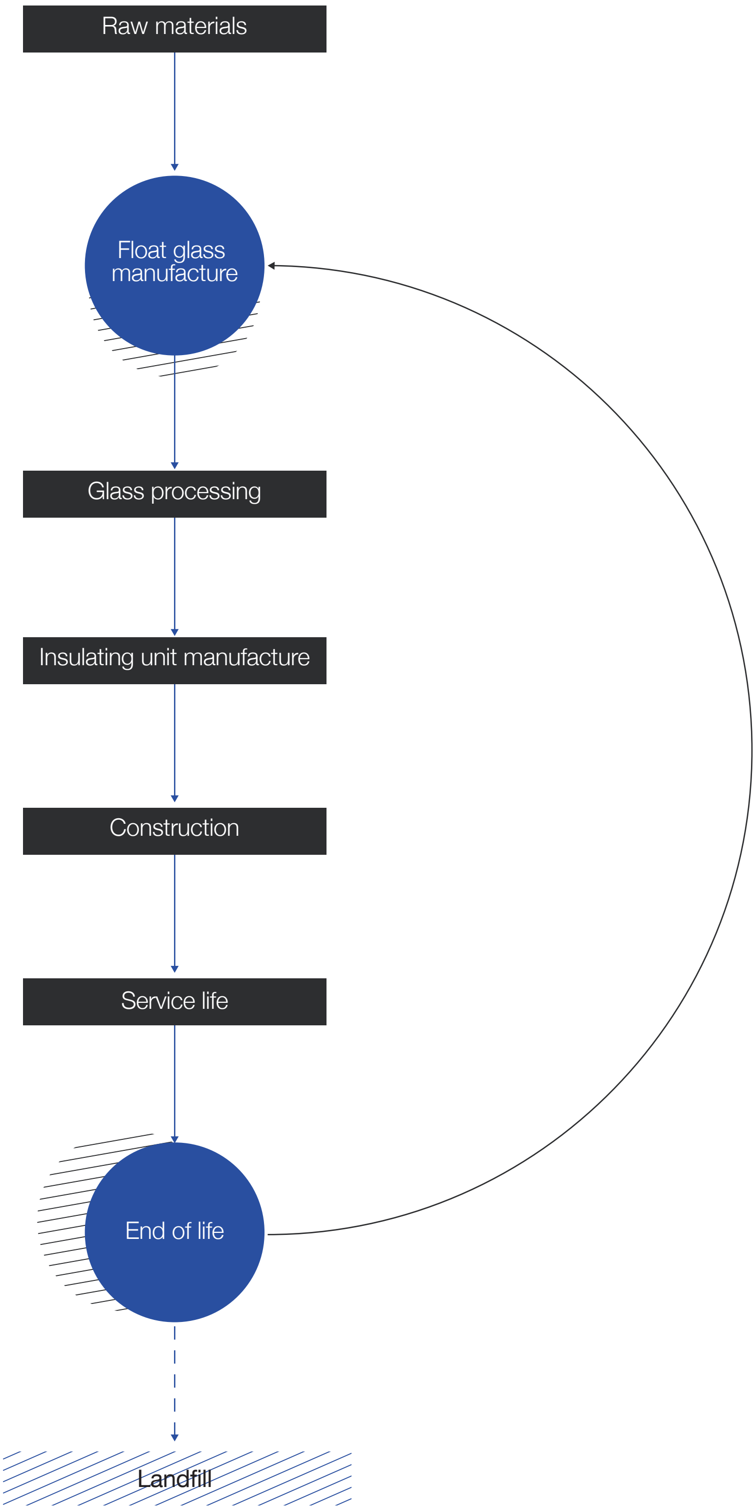
Internal cullet consists of rejects or offcuts from the float line and typically makes up 20-25%[9] of the volume of raw material mix on average in European float manufacturers. We understand that some manufacturers, such as Saint Gobain in the UK, have used over 40% cullet[20].

External cullet is the recycled glass from the processing industry including glazing unit manufacturers. The quantity of external cullet used by Saint Gobain is claimed to have reduced raw materials consumption by 25%, energy consumption by 8% and CO_2 emissions by 10%[20]. A few glass manufacturers run cullet recycling schemes where they collect off-cuts from processors and return them to the float line on the vehicle that delivers new stock.

"Other industries, such as structural steel, indicate that 7% of reclaimed steel materials is reused and that 93% is recycled, with 0% going to landfill[19]. The glass industry therefore has a long way to go..."

FIGURE 11

Circling the linear approach



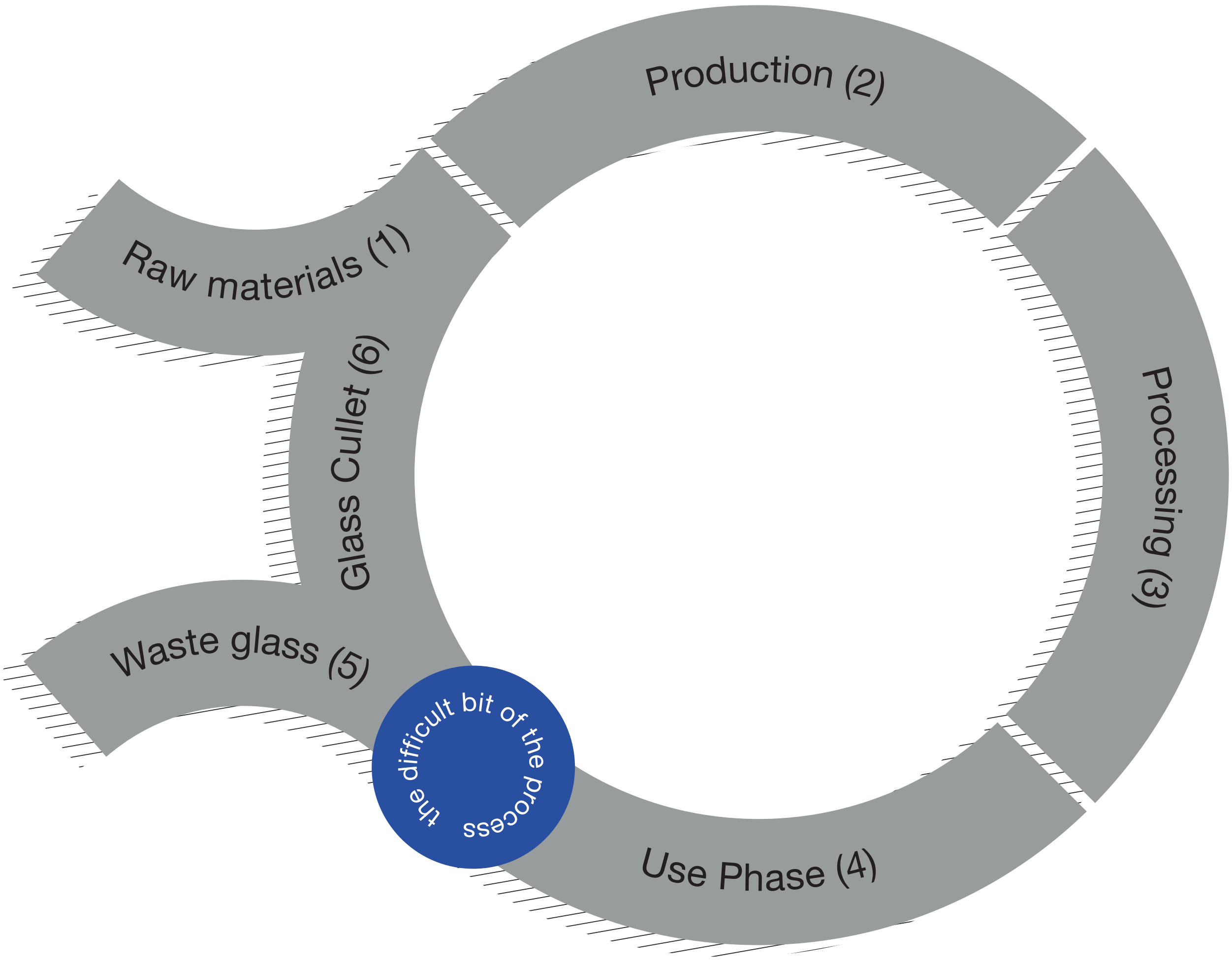


FIGURE 12
Circular process of glass life

Alternatively, glass merchants collect cullet from processors and sell it to glassmakers in the flat and container industries after grading and selection.

The quantity of post-consumer glass (that has seen service in buildings) included in the cullet flow is currently very low.

How can we deal with the collection and recycling of post-consumer glass to allow it to be kept at high value and returned to the float line for remelting? This is the difficult bit and where we focus the remainder of this research.

We must consider all costs, material values and emissions if we are to consider the viability of post-consumer construction glass recycling. There are demolition or refurbishment contractor costs in removal, significant transportation costs in moving materials around, processing, storage and transportation to the float line. All the while maintaining the very high quality of the cullet that the glass manufacturers will demand.

5.1 GRADES OF CULLET

Of course all glass removed from buildings will not be suitable for moving directly back to the floatline. We have already discussed laminated glass and ceramic fritting processes that can limit the quality of the cullet gathered.

The glass recycling industry has developed three primary qualities of glass cullet and these are described as;

5.1.1 Class C

This grade of cullet is contaminated glass product not suitable for remelting. This grade may include ceramic fritted and printed glass, container glass and glass with spacer bars, putty, lead beading and the like included in the mix.

This class of cullet is likely to be used for road paint manufacturer and aggregate use.

5.1.2 Class B

Class B is referred to as mixed cullet and may include some contamination. For example, laminated glass usually ends up in this class, as it is very difficult to completely remove the interlayer materials from the glass under the pulverising technique of delamination. However, technology is advancing and improving this process (as described in previous sections).

This grade of cullet might be suitable for glass wool insulation and coloured container glass.

It is considered "the holy grail" to be in a position to move Class B cullet to the float line for remelt, but significant barriers limit this opportunity at this time. Opportunities to develop technology to sort and/or clean this grade of cullet could be developed to increase the utilisation of Class B cullet in float glass manufacture.

5.1.3 Class A

Class A is the clean clear cullet suitable for transportation directly to the floatline for remelt to new flat glass product. Zero contamination is allowed in this class and the float lines are very demanding of this quality. Demand significantly outstrips supply for this material class.

Currently much of this material comes from pre-consumer glass from offcuts in processing and glass manufacturing, but the opportunity exists to increase the collection of post-consumer Grade A cullet from our existing building stock.

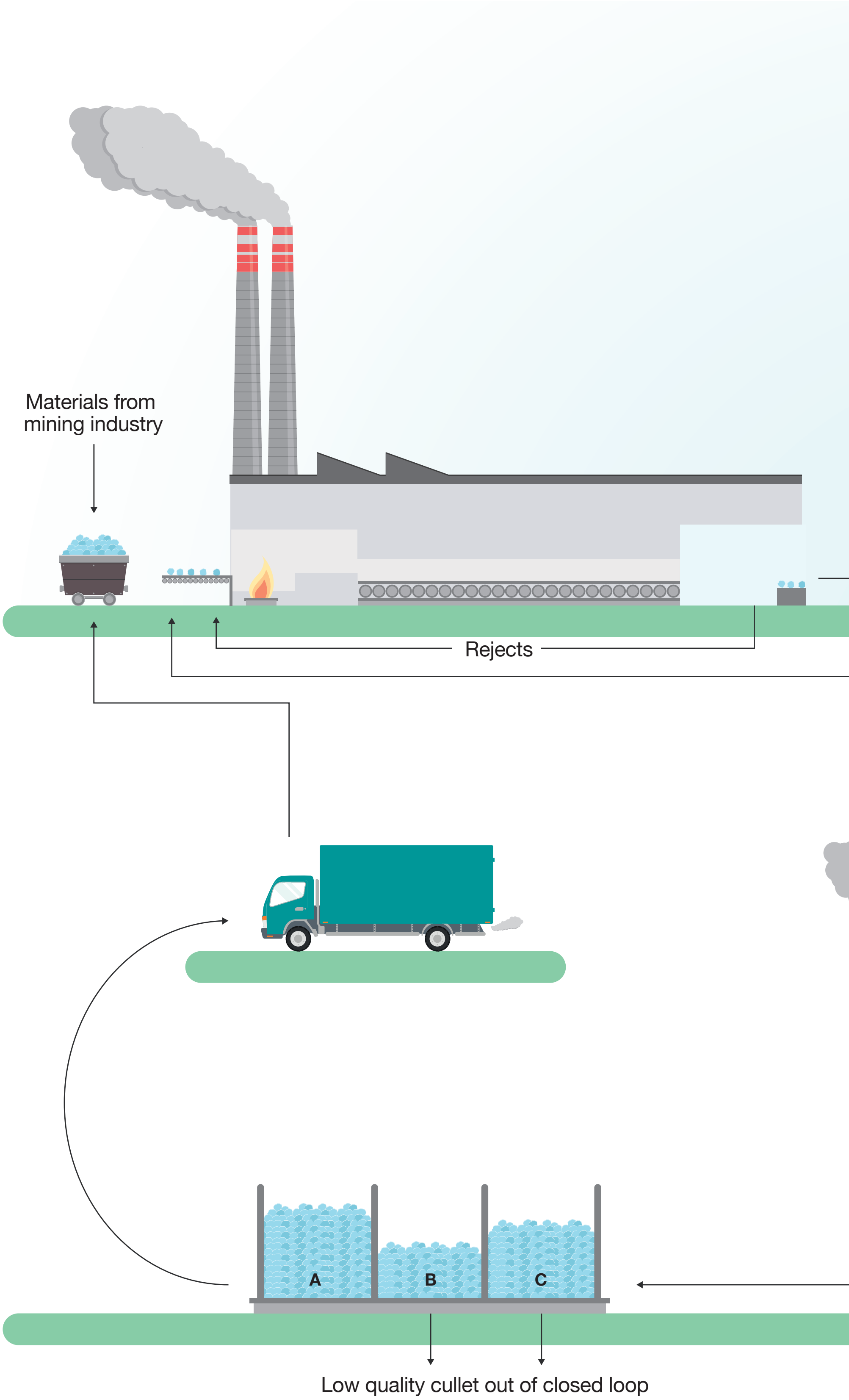
5.2 VALUE

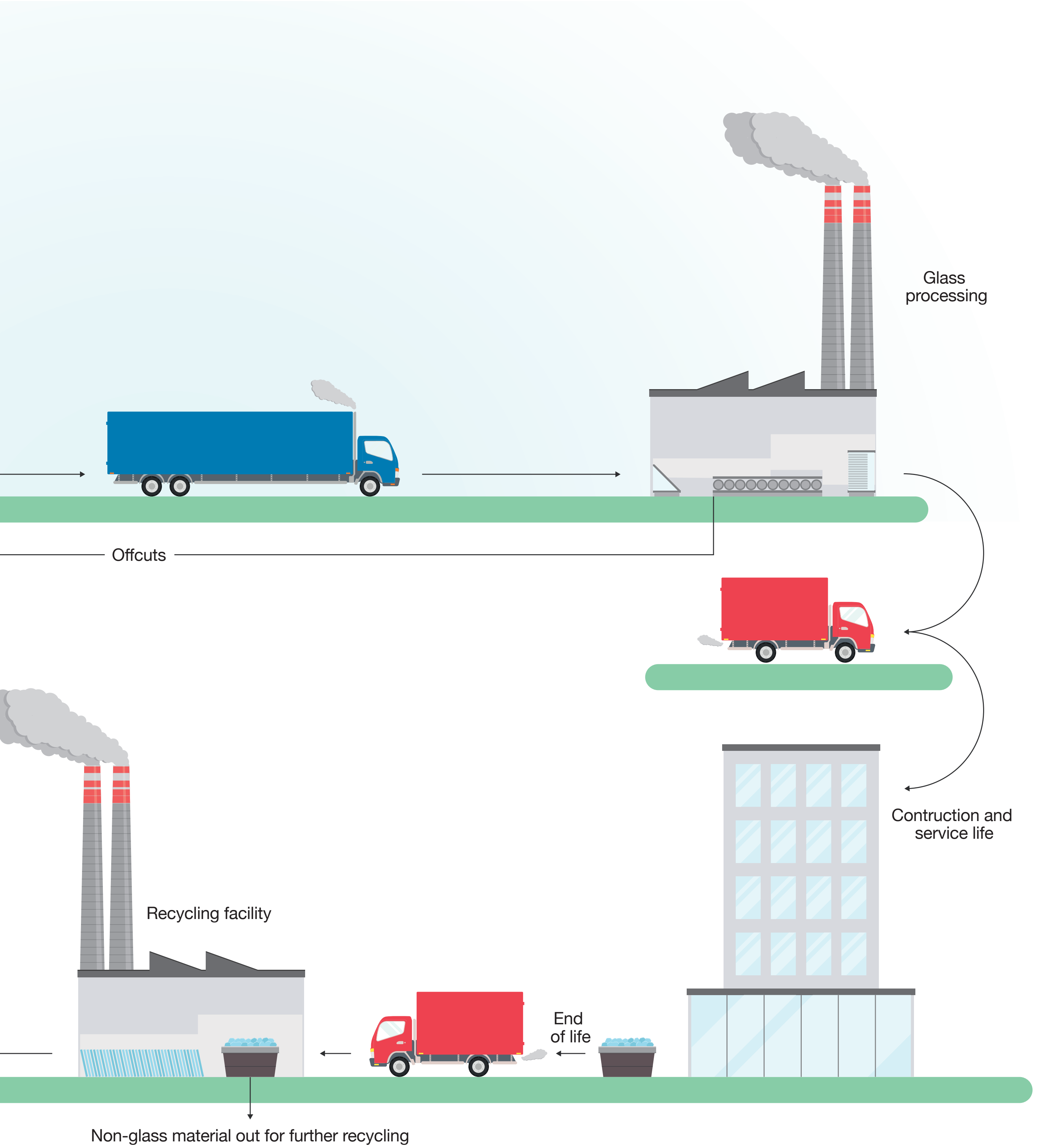
The financial implications of cullet cost vs raw material costs will be studied in more detail in a future report and based on a pilot project. It should also be considered that with prices, raw material costs and environmental taxes all volatile and generally increasing the quantity of Class A cullet available for use in float line furnaces would become more financially attractive. It is important that sufficient value cullet material has a network to develop that is financially sustainable.

"How can we deal with the collection and recycling of post-consumer glass to allow it to be kept at high value and returned to the float line for remelting? This is the difficult bit and where we focus the remainder of this research."

FIGURE 13

A circular economy closed loop process map




Glass
processing
Offcuts
Contruction and
service life
Recycling facility
End
of life
Non-glass material out for further recycling

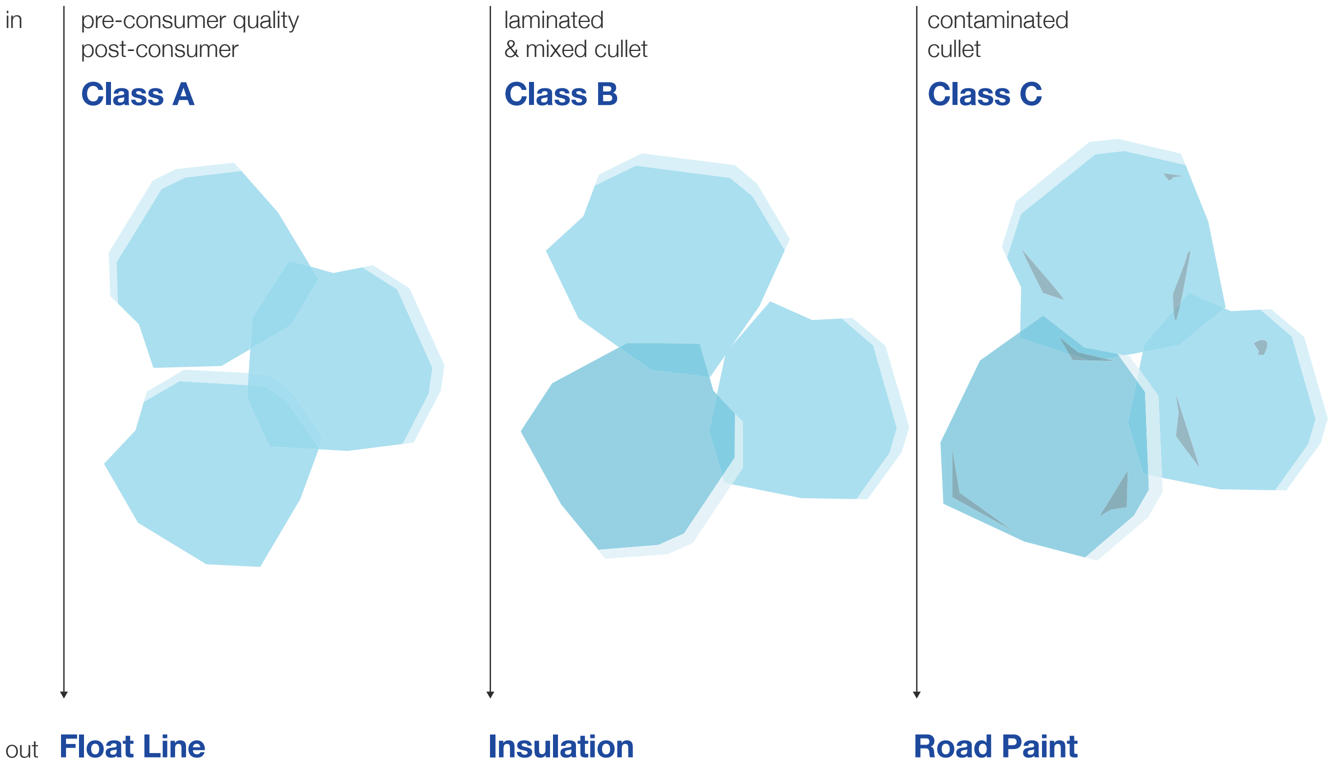


FIGURE 14
Grades of cullet

5.3 HOW TO ACHIEVE CLASS A CULLET

Contamination is the biggest technical challenge to overcome in order to increase the availability of quality cullet for the remelt process.

Currently the collection method requires that contamination is very carefully controlled. Removal of the glazing units from the building site to a factory environment for disassembly appears to best provide the quality control required.

Going forward, as the value of cullet increases, development of technology may allow for lower grade cullet such as Class B to be processed and cleaned to a quality that could be used in flat glass production. This has occurred in the glass container industry where there has been significant investment in machinery that can sort and improve the cullet quality.

Disassembly processes have been developed for the recycling of the constituent parts of solar PV panels. Further research is required into the quality of the retrieved glass to understand if it can be recycled in a closed-loop system.

6. ENVIRONMENTAL BENEFITS

6.1 RAW MATERIAL USE

For every one tonne of cullet used in the manufacture of float glass, 1.2 tonnes of raw material is saved[11]. This reduces requirements for mining and quarrying, as well as the associated processing and transportation.

The energy and CO_2 reductions of these activities has not been included in the pilot project analysis but are significant. Further research could be undertaken to estimate these potential carbon savings to add to the benefits outlined in this report.

6.2 ENERGY USE

As cullet melts at a lower temperature than raw materials, for every 10% cullet added to the furnace, 3% less energy is used. British Glass have described this as 300 kWh of energy saved for every one tonne of cullet used[11].

6.3 CO_2

A reduction of CO_2 emissions of 250-300kg is realised for every tonne of cullet added to the furnace[11].

6.4 LANDFILL

And of course by recycling construction glass in a closed loop cycle, we are reducing the materials to landfill and associated disposal costs.

Every tonne of cullet utilised saves

1.2 tonnes
of raw materials

300kWh
of energy

300kg
of $C0_2$ emissions

7. BARRIERS, PROCESS & RISK

7.1 REFURBISHMENT MARKET

Refurbishment projects hold the majority of glass material for recycling, representing almost 85% of the glass quantity available for recycling in the UK[2]. It is clear that this market should be the focus of the drive to increase recyclability of post-consumer glass and indicates that there is great potential to increase the amount of glass recycled on refurbishment projects, and prevent significant deposits to landfill.

Refurbishment projects may be in the residential or tertiary sectors and the method of procurement and disassembly may vary significantly between the two.

7.1.1 Residential sector

Modern residential buildings, particularly low-rise and individual housing units, tend to have uPVC or timber framed windows installed into openings in the building façades. There is a great opportunity to improve the circular economy performance of this sector[2] as it represents over 63% of glass available for recycling from the refurbishment market.

At the time of refurbishment, typically the windows and their frames are fully removed from the building, whilst the remaining façade is likely to be kept, perhaps being upgraded during the works.

FIGURE 15
Typical residential sector refurbishment project
© CMS

FIGURE 16

Residential sector window frames following glass removal ready for further recycling processing
© Arup

As the window frames and glass units need to be removed more carefully than during demolition, they are more likely to be stored separately, which makes it easier to collect the glass without contaminating it at source - a crucial enabler for recycling.

Opportunity and value is increased due to the viability of recycling the uPVC frames and other elements such as aluminium spacer bars from the window units.

These replacement works are likely to be undertaken by a specialist window supply and installation company, often directly appointed by the building/home owners or, for public housing, local authorities.

We have observed in our research a number of window companies actively seeking to improve their recycling process through their own initiatives. This is encouraging and should continue to be promoted. These companies utilise this process as part of their social corporate responsibility and promote their business activities as "green" or "sustainable" to potential customers.

A key driver for this move is a growing consumer awareness and desire to buy "green" products and that such activity may win more work. Education of the public to grow awareness of the issues and accessibility to these companies will continue to promote these opportunities.

For public and social housing, legislation should be established that requires the contracts for window replacement to include recycling of all removed materials in closed-loop schemes so that the large opportunities and quantities of potential materials are not overlooked in this sector. Government Buying Standards (GBS) could be more ambitious to encourage further uptake of recycled content entering the supply to glass manufacturers.

FIGURE 17

Typical curtain wall system on a tertiary building
© Arup

FIGURE 18

Double glazed units removed from tertiary buildings awaiting recycling process
© Aup

7.1.2 Tertiary sectors

Tertiary buildings, as described in Glass for Europe research and adopted in this report, represents buildings from the remaining building sectors which includes commercial, retail, leisure, government, health, sport and educational sectors.

These sectors currently represent around 37% of the available glass materials for recycling in the refurbishment market[2].

Beginning in the 1950's and 60's, following the development of float glass manufacture, there has been an increasing trend towards designs, particularly in the tertiary sector, that utilise more and more glass on the façade. More recently, thermal performance requirements have also driven a move to double and even triple glazed units. As such, there is likely to be an increasing amount of waste glass from this sector in the future, as the curtain wall cladding from these eras become ready for significant refurbishment and glass replacement.

Two primary means of refurbishment can be considered for these building types, both of which would release the glazing units for recycling. A full strip of the facades leaves the primary structure only which may be repurposed and reclad in a new system. Alternatively, materials that are beyond their serviceable life are replaced progressively. This approach is likely to include gaskets, and insulated glazing units for modern curtain wall systems, whilst reusing metallic framing systems.

Demolition contractors tend to be employed for the removal of full façades as described previously. Glass units may be carefully removed, but research suggests that this material usually ends up in aggregates or landfill[9]. This is believed to be due to lack of awareness of recycling options, economic uncertainty of the recycling processes and difficulty in the separation and storage required to achieve sufficient quality of material to prove viable for closed-loop recycling. This needs to be addressed through further education of the demolition industry.

Façade upgrading through progressive replacement of glazing units may prove most suitable for increasing glass-recycling opportunities. The careful removal of the glass units to ground, storage and processing for recycling can all be achieved with less impact on the required disassembly methodologies. There is opportunity for façade remediation engineers, designers, architects and specifiers to ensure that through early engagement in these projects, suitably drafted specifications and documents can be included in the contractual agreements with the contractors responsible for the works, to ensure that closed-loop recycling processes are followed.

7.2 DEMOLITION MARKET

Demolition contractors also undertake full building demolition projects. Our research indicates that most glass from demolition projects is mixed with recycled hard core to create an aggregate material that can be used for foundations[9].

With current demolition practises, it is likely to be economically challenging to recycle glass from demolition projects because it is often broken during demolition and mixed with other materials. Once mixed with foreign materials, it is very difficult to separate glass to the standard required by quality specifications for glass manufacturing.

Most potential may be with high-rise buildings in cities, where for safety demolition is controlled, and introducing measures to keep glass separated may not add significantly to the cost and time of the process.

While recycling of waste glass is viable in refurbishment projects, the demolition projects present a bigger challenge. We speculate that the challenges lie in the additional cost and time required to carefully separate materials, but to confirm this we propose further research among contractors as an important next step in understanding current barriers.

Some specific questions of interest for further research are;

- How do demolition contractors currently deal with glass waste from demolition sites?
- What would stop demolition contractors from utilising disassembly methodologies?
- Do they consider the impact of landfill tax in their current operations?
- Who specifies the demolition procedure? Is there opportunity to stipulate requirements for recycling of materials in contractual arrangements?

7.3 FINANCIAL CONSIDERATIONS

Potential costs to a building contract that intends to undertake glass recycling have been outlined below;

7.3.1 Glass removal

For either a refurbishment or a demolition type project, the glass requires to be deglazed from the framing system. Depending on the framing system employed this may be undertaken on-site, such that only the glazing units are removed, for example in the refurbishment of curtain wall systems. Alternatively, the frame and glazing is removed in one unit, which may be appropriate for a residential window, and deglazing undertaken at ground level or in a factory environment.

The costs associated with these activities will be project specific and need to be considered when specifying glass recycling on a project. The demolition or façade contractors would provide a price for undertaking these works as part of a tender process.

7.3.2 Land fill tax

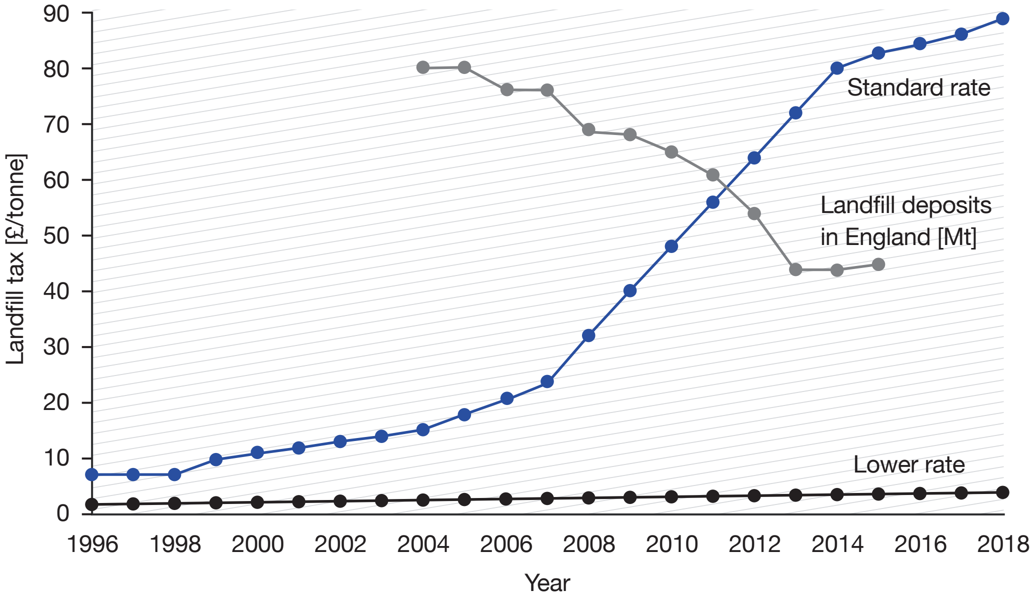
By recycling the glass from the building, all landfill taxes can be avoided. The incentive to do so rises considerably when the higher rate of tax is charged. The “inactive” status of glass currently makes the rate of landfill tax in the UK insufficient to promote the uptake of glass recycling.

Increasing the landfill tax would result in giving financial incentive to contractors, and consequently clients, to divert the glass waste from landfill and ideally return it for closed loop recycling. Removing glass from the “qualifying material list” would encourage further glass recycling.

According to the UK Department for Environment Food and Rural Affairs the amount of waste deposited in landfill has been gradually reducing[17].

FIGURE 19

Landfill tax value compared to the deposits to landfill in England [8,17]



Waste management or recycling facilities will usually take separated waste glass from site free of charge, or require the contractor to pay transportation costs. From the contractor's perspective, this is a saving, compared to the landfill tax (regardless of the landfill tax rate) and should be actively encouraged to support glass recycling.

After the glass waste is processed at the glass recycling facility, which includes removal from frames and sorting into 3 categories of quality, they sell the cullet to float glass manufacturers. There is no standard rate for the value of cullet; rather we understand that this is negotiated individually between parties.

"By recycling the glass from the building, all landfill taxes can be avoided. The incentive to do so rises considerably when the higher rate of tax is charged. The "inactive" status of glass currently makes the rate of landfill tax in the UK insufficient to promote the uptake of glass recycling."

7.3.3 Unit deconstruction

Our research has shown that there is a growing market for waste management or recycling facilities to take framed windows and insulated glazing units away from site to breakdown to clean and segregated cullet in a factory environment.

This methodology appears to provide the best opportunity to collect all elements of the units to gain the most reward for their constituent parts. In addition to the glass, the aluminium spacer bars are of value and, as described above, the uPVC window frames have value to a recycling operation.

From our research it appears that the value of the cullet paid by the float manufacturers indicates sufficient incentive to transport and deconstruct the materials in this way, using unskilled staff in the breakdown operations.

Moving the cullet following breakdown and bagging appears to be most cost effective when the glass manufacturers backhaul the material on otherwise empty transportation following material deliveries in the local area of the recycling facilities.

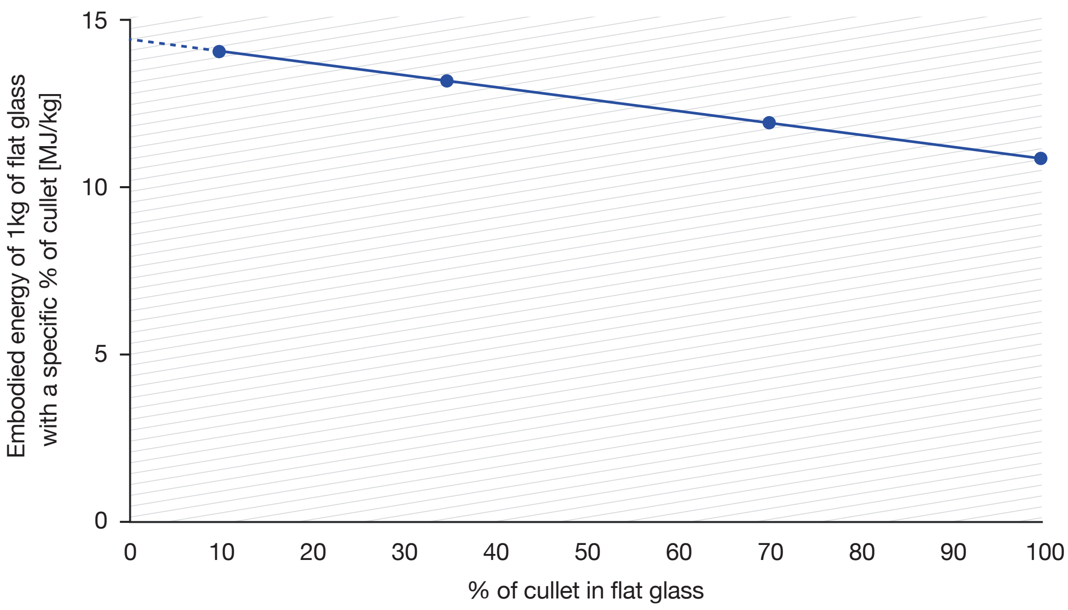


FIGURE 20

Graph showing embodied energy of 1kg of flat glass in relation to % of cullet used in the flat glass manufacture[21]

"Our research indicates that up to 50% cullet content may be possible, assuming availability of the high quality cullet required, without alteration to the existing float manufacturing processes."

7.4 FLOAT GLASS MANUFACTURER

7.4.1 Financial incentive

Once the quality cullet arrives at the float line, financial savings can be found for the manufacturer by a reduction in energy costs and subsequent reduction in emission charges (currently called "climate change tax" in the UK). Our research indicates that the current cost per tonne of cullet is less than the cost per tonne of raw material and for every tonne of cullet utilised, 1.2 tonnes of raw materials are saved, further increasing the financial benefit of increased cullet use.

Commercial sensitivities have proved it difficult to acquire float manufacturers costs of raw materials and cullet expenditure information. More detailed research of the potential financial implications of the proposed pilot project is required and will form part of a follow up report on completion of the project.

Other commercial benefits for the float manufacturer include the increased furnace life and reduced maintenance requirements, due to lower melting temperatures necessary when cullet quantity increases.

7.4.2 Current utilisation

All three UK flat glass manufacturers currently use recycled glass in their manufacturing process and want to use more. There is strong market demand for cullet that can meet quality and cost criteria. Currently the cullet is collected by glass recyclers, or is backhauled by a flat glass manufacturer. Our research found that the best known backhauling system is operated by Saint Gobain whose glass may contain up to 35% recycled content[20].

Our research indicates that up to 50% cullet content may be possible, assuming availability of the high quality cullet required, without alteration to the existing float manufacturing processes.

7.4.3 Quality of finished product

Assuming the availability of high quality glass cullet and the high quality demands of the flat manufacturers, no reduction in quality of the glass product is expected. Our research has not indicated that the manufacturers plan to produce a lower quality alternative with higher recycled content rather increasing cullet content whilst maintaining the current quality standard.

There has been a steady reduction in iron content of the raw materials of standard glass production, in an effort to reduce the green appearance of float glass, moving towards lower iron content and clearer glass. The use of older production run glass cullet risks increasing the iron content and there may be some correlation between iron content (and hence colour) and recycled content that needs to be appreciated as glass recycling grows. Specifying very low iron glass may reduce the opportunity to utilise recycled content.

Risk of critical inclusions (particularly of Nickel Sulphide) that may lead to spontaneous breakage of heat-treated glass products must be considered. This risk is not exclusive to increasing recycled content but there is the potentially increased risk of contamination during the removal and processing of post-consumer glass that should not be ignored. This risk is currently managed by introducing heat soak testing procedures into the glass processing.

7.4.4 Embodied Energy

As can be seen from this study, clear environmental benefits can be realised from the increasing of cullet in glass manufacture. Previous Arup studies have calculated the embodied energy of glass at various recycled content and these calculations indicate a reduction from approx. 14MJ per kilogram of float glass with 10% cullet, 13.2MJ per kilogram with 35% cullet and reducing to 12MJ per kilogram with 70% cullet content[21].

7.5 CONSTRUCTION PROCUREMENT PROCESS

A significant challenge for the implementation of glass recycling on refurbishment and demolition projects is the existing procurement structure and processes used in the industry.

In the early stages of refurbishment and demolition projects, clients and design teams should be defining the specification for the removal and recycling of building materials during the works. A knowledge of appropriate and available recycling methodologies needs to be disseminated to clients and specifiers to allow a greater uptake of recycling early in the life of a project, specifying the requirements to contractors prior to their engagement on the project.

Arup has successfully specified the contractor's requirement to recycle glass at this high level closed-loop process during refurbishment and glass replacement projects. Further opportunities to do so and the development of a UK network of flat glass recyclers can only improve the success of glass recycling and lead to an increase in recycled content in this material. Defining standard clauses that can be included in contractual documents would assist the industry to adopt these requirements for recycling of building materials.

Tender responses could require the contractors to state the level of recycled glass content from their supply chain and allow a measure between contractor returns. This could potentially have a positive effect on the promotion of increasing recycled content by the glass manufacturers, as they currently do not openly advertise this information.

Commercial sensitivities of building product manufacturers may require some overcoming as we have found the glass manufacturers to be particularly secretive of their processes to maintain competitive edge. Legislation may be required to make the release of this information compulsory for clarity on recycled content of products.

7.6 CONSTRUCTION ASSESSMENT METHODS

Currently the BREEAM Refurbishment and Fit-Out (RFO) Technical Standard[22] does not provide a methodology for earning points for the off-site recycling of glass from building projects. Glass does not appear on Table 64 or 65 and we would encourage its inclusion in future revisions of BREEAM standards. Although it is referenced as inert on table 66, clarity of eligibility of recycling in a closed-loop system in a network that may or may not include the original manufacturer is required.

BREEAM RFO in category Wat-01 also states that materials sent to a Material Recovery Facility (MRF) does not qualify for credit points. As this appears to be the most likely scenario for retrieval of high quality glass cullet from refurbishment projects, we would encourage reconsideration of this regulation during future revisions of the standard.

Sustainability assessment methods such as BREEAM should be updated to put a greater emphasis on the reuse and recycling of building materials from existing building stock and the capturing of the potential materials available from the refurbishment and demolition of these buildings.

8. OPPORTUNITIES

8.1 CHANGE TO EXISTING PROCESSES

When in 1973, E.F. Schumacher wrote Small is Beautiful[23], he described, for the successful development of any new concept, that it was the people who needed to change, not just the process. He stated that for this to happen, “it starts with people and their education, organisation and discipline”. He said “without these three, all resources remain latent, untapped, potential.” We think this is particularly relevant for the process of change that is required in the glass, refurbishment and demolition industries to fully realise the potential of post-consumer construction glass recycling.

This report marks Arup’s beginning of the education part of this process, others in the UK (British Glass, Zero Waste Scotland) and Europe (Glass for Europe and FERVER) are also talking about the potential for the increase in construction glass recycling. We need to continue this discussion. We need further project examples and dissemination of these case studies to the industry to prove it is a viable and achievable alternative.

Organisation requires a network to develop and discipline might equally be described as sustainability, in all its forms, where a concept can grow and continue to flourish due to its financial, social and environmental sustainable business practices.

8.2 NETWORK

The growth of the construction glass recycling industry requires a new network to develop. We have observed that this network is already organically growing in the central belt of Scotland and that the network indicated here can be expanded and duplicated around the UK, creating a sustainable industry that can supply the demand of high quality glass cullet to the glass float lines in northern England.

The model, simplified in Figure 21, is suitable for global adoption but based on local coordination.

The developing network in the central belt of Scotland has a number of sites, which include building refurbishment and demolition projects from all sectors, each of these include a design team, contractor and client. A small number of collectors are active who are willing to collect and transport the glass units in the order of 50 miles to break down the glazing units, removing frames and spacer bars for financial benefit.

A broker coordinates the cullet materials available from a number of small collectors, this broker has connections with the float glass manufacturers and the experience and business acumen to develop this relationship and gain the best financial rewards for larger quantities of high quality cullet from a number of collectors. The broker can organise, arrange transportation and gain best economies by utilising backhaul opportunities from the float manufacturers glass delivery logistical systems. In the observed model, the transportation distance between collector and float glass plant is in the order of 200 miles.

Figure 22 shows that the same model could be replicated with similar collection and manufacturer transportation distances for a similar network in various locations of urban development across the UK, including London and the south east.

As transportation distances between main populations and glass-manufacturing plants does not vary greatly across much of the developed world, this network arrangement could be replicable across the globe.

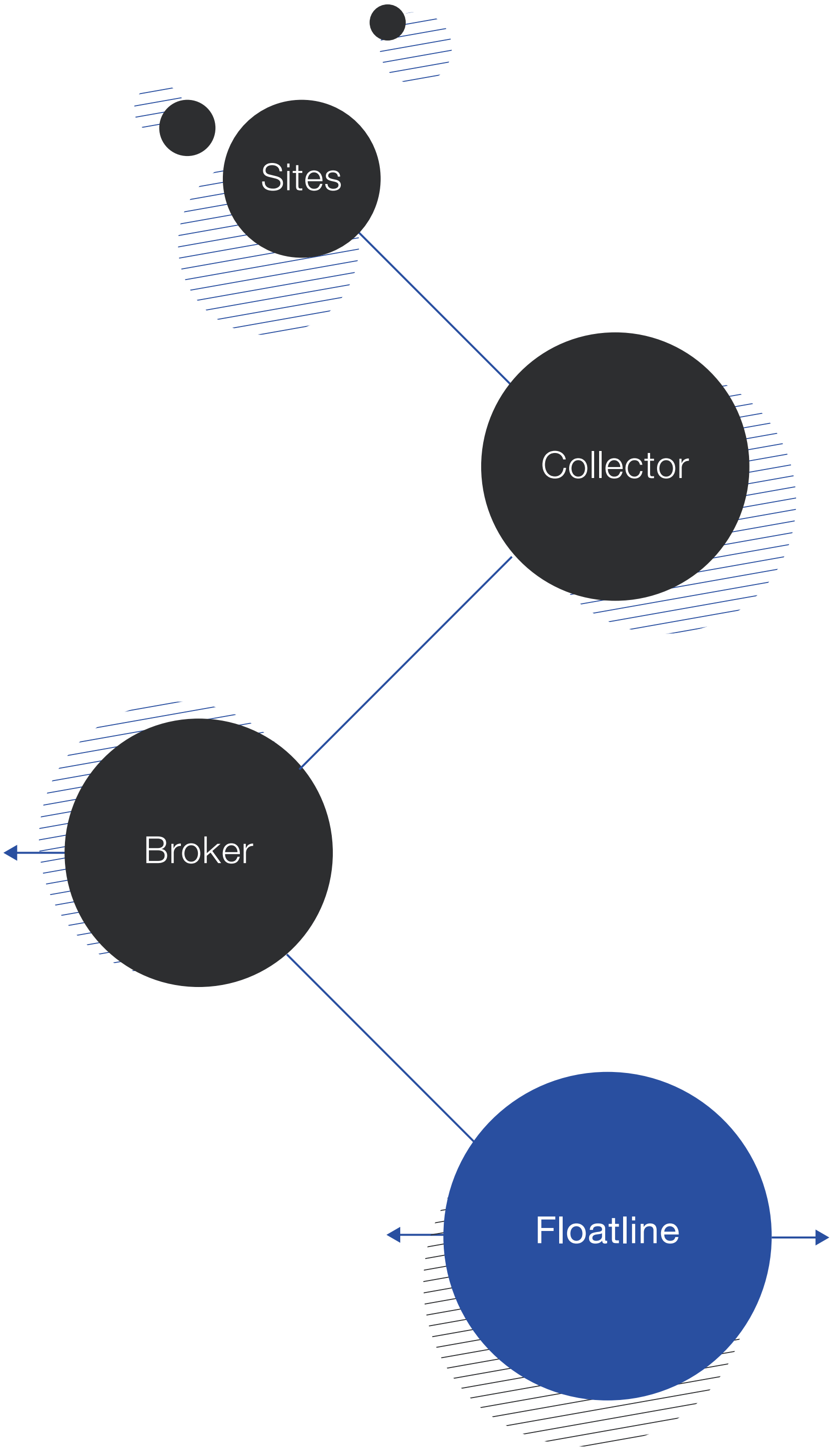


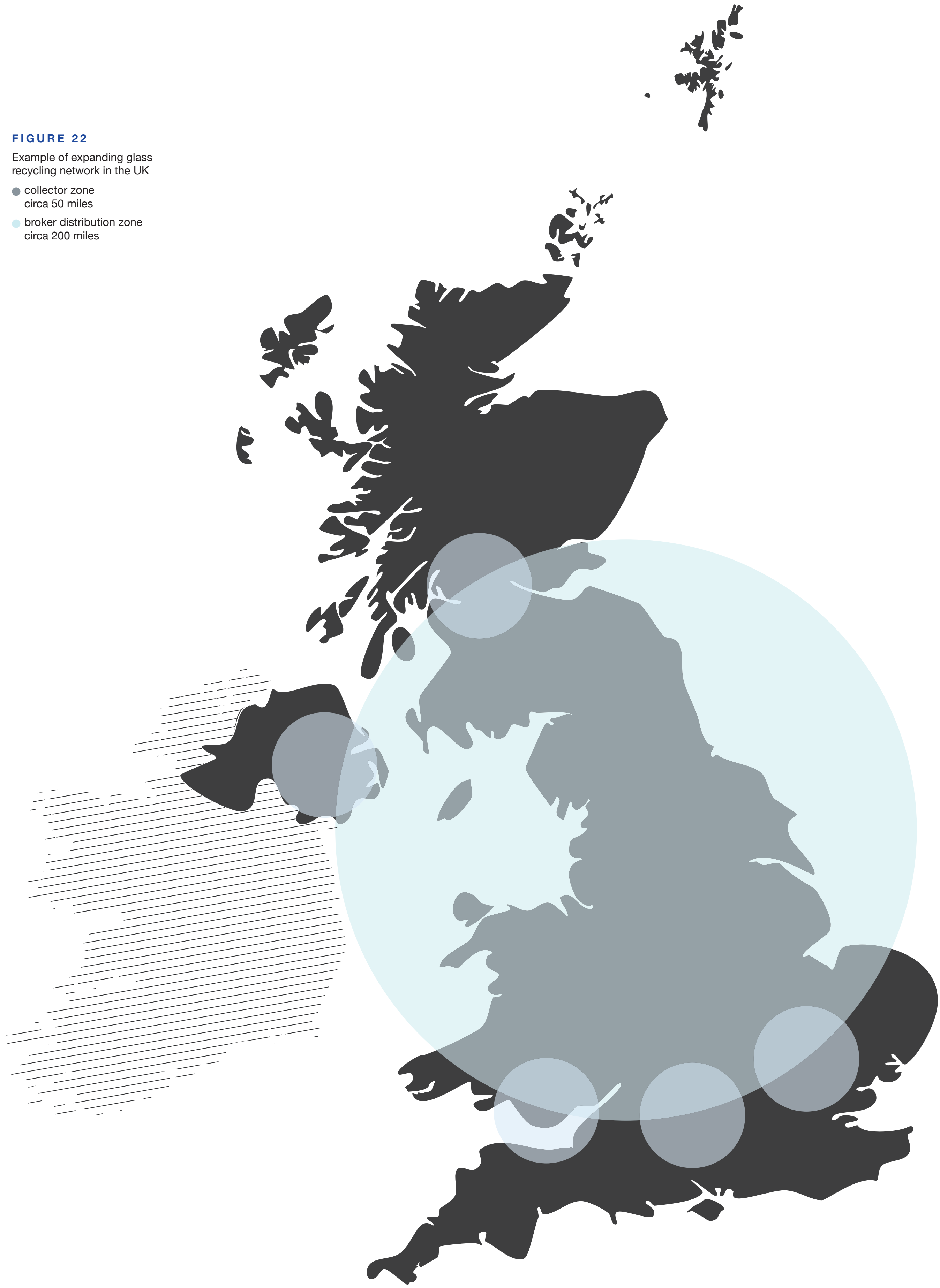
FIGURE 21

A simplified model of a new glass-recycling network

FIGURE 22

Example of expanding glass recycling network in the UK

- collector zone circa 50 miles
- broker distribution zone circa 200 miles



8.3 SUSTAINABLE BUSINESS

The discipline for developing the new sector and ensuring its long-term success requires sustainable business practices to emerge.

8.3.1 Financial

The demand for high quality Grade A cullet in the UK is real and already exists, so developing a network to feed this demand with sufficient quality supply makes sound economic sense.

This research indicates that there is the potential for small levels of profit to be made along the network chain; this needs to be proved by several pilot projects, comparing different geographical and project constraints.

Should it be proven that some external injection of financial incentive is required to make the recycling of flat glass financially sustainable, governments should be looking at schemes developed that currently support the network such as the “Valkglas Recycling” scheme in the Netherlands[24].

This scheme was originally developed as a voluntary manufacturer’s initiative set up to meet their corporate responsibilities to take back glass at the end of its life. Due to its success the programme was approved by the government as legally binding and implemented across the country.

The scheme collects 0.40 euro for each square metre of glass produced or imported into the Netherlands, which in turn goes to funding the collection and processing costs of end-of-life construction glass back to the glass manufacturing industry.

Locally, Zero Waste Scotland is currently engaged with the industry and is actively pursuing the development of a scheme to support flat glass recycling[25].

8.3.2 Environmental

The environmental benefits have been described above and it is clear those long-term benefits and sustainable practices are possible in the recycling of construction glass.

8.3.3 Social

An Environmental Services Association (ESA) report called “Going for Growth”[26] from 2013 indicated that 10,000 jobs could be created in the UK recycling sector by 2020.

The company CMS Windows based in Cumbernauld, north of Glasgow has shown increased use of local unskilled labour to dismantle and recycle uPVC and glass from domestic windows. This resulted in the increased employment of local people in a rural and deprived area of Glasgow[27].

Using unskilled labour is a successful business model that is also used by ‘Recycling Lives’ in Lancashire[28]. Hiring local unskilled people helps them to enter work, and enables the business to access grants to support the cost of training. Another business advantage is that it creates a local pool of talent to draw from.

8.4 DESIGN FOR RECYCLING

It is our responsibility as designers and engineers to consider circular economy principles and material selection from the very beginning of the design process of our projects. This will require a change in how we work, what materials we choose and how we influence our client's choices in material decisions.

It will also require research and innovation to find materials and methods of construction to enable recycling of all the major components. Changing how components are connected, to enable easier disassembly without damaging them, use dissolvable bonders and use of lime mortar in masonry construction, are just a couple of examples of a more circular approach to building design[29].

The glass design equivalents would be to design out the use of laminate glass units or ceramic frit, which both make glass recycling challenging or impossible right now. Ceramic fritted glass cannot be recycled, and the process of delamination crushes the glass in small particles, which cannot be used in the highest level of recycling - back into float glass.

This means we need to review the current trend of laminated double glazed units, which are often required to achieve the safety performance of the building façades. Alternatively, we can approach the challenge from the other side, and through research and technical development find a better way to delaminate glass - altering the interlayers or upgrading the delamination process.

To promote and actively influence the industry we also propose adding the requirement for glass recycling into specifications for refurbishment projects.

A summary of typical glass processes and their effect on the recyclability of the glass for consideration during the design process is outlined in the following table;

"It is our responsibility as designers and engineers to consider circular economy principles and material selection from the very beginning of the design process of our projects. This will require a change in how we work, what materials we choose and how we influence our client's choices in material decisions."

TABLE 3
Glass processing effect on recyclability

Glass process	Recyclable to float line?	Notes
Annealed glass	Yes	Readily recyclable
Cutting and edge processing	Yes	No effect on recyclability
Laminating	Limited	Current methodology for delaminating reduces quality. Requires improved delamination processes to ensure stays in closed cycle level. Current methodology means laminated glass goes to container glass or mineral wool.
Heat strengthen	Yes	No effect on recyclability
Toughened (or tempered)	Yes	No effect on recyclability
Heat soak tested	Yes	No effect on recyclability
Glass coating (hard and soft)	Yes	No effect on recyclability
Ceramic printing and fritting	No	Current methodology does not allow for recycling of ceramic printed glass
Insulated glass units	Yes	Requires removal of the spacer bars and edge seals, limitations on processing of individual panes as noted above
Low iron glass	Yes	Specifying low iron glass may require float manufacturers to reduce the recycled glass content to ensure a clear product is achieved. Further discussion with glass supplier on a project basis is required.

9. PRECEDENT PROJECTS

We know of very few precedent projects in the UK that show the viability of construction glass recycling. The following projects have been highlighted in our research.

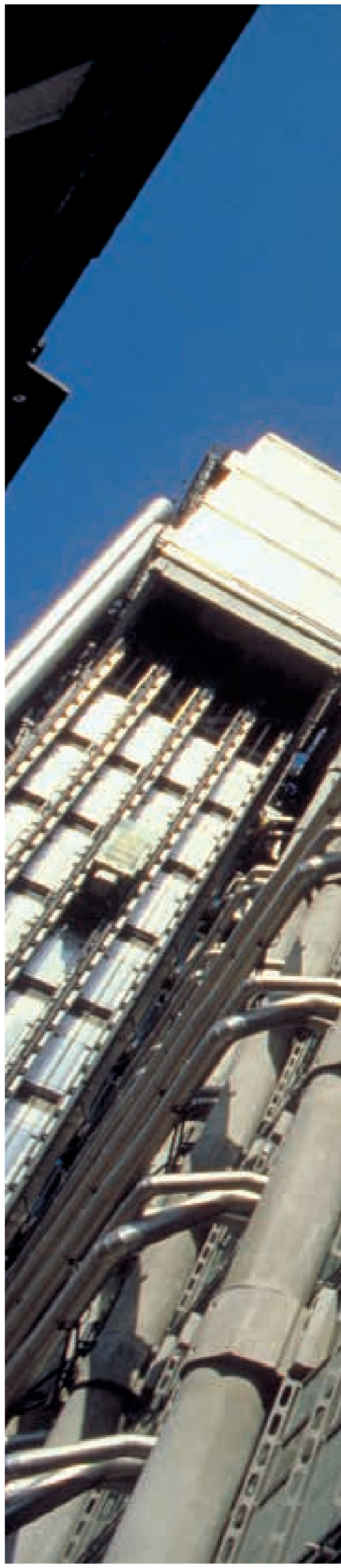


FIGURE 23
Lloyd's
© Arup

FIGURE 24

Verde SW1, London
© Grant Smith/Tishman Speyer

grant-smith.com

FIGURE 25

Left: CMS InnovationHub

Right: Graeme DeBrincat from Arup in their glass recycling
© Arup

9.1 LLOYD'S

In 2010, Lloyd's decided that it required more daylight and improved views from the iconic Richard Rogers designed building originally completed in 1987.

Some of the original rolled sparkle glass panes were replaced with clear flat glass and 123 tonnes of the original glass was removed from the building and sent back to Saint Gobain in Eggborough for remelt back to float glass [30, 31, 32, 33].

Additionally, some of the sparkle glass was reused, which scores even higher on the solid waste management scale[34]. The panels were cut into the new required size, and installed back or stored for any replacements required in the future. Some of the "off cuts" were used in furniture designs for the building, such as tops for coffee tables.

The work on Lloyd's demonstrates re-use and recycling of glass at the highest standard and with minimum environmental impact.

9.2 VERDE SW1

More recently and completed in 2016, Verde SW1 was a major refurbishment of a commercialoffice building in central London. The original glass removed from the building during the refurbishment led to 340 tonnes of glass being recycled into container glass[35].

Developer Tishman Speyer placed occupant comfort, health and wellbeing at the heart of renovations.

The starting point for the refurbishment was a carbon life cycle assessment (LCA) that analyzed the materials in the existing building and the refurbishment process. The LCA identified the existing glass façade as a key contributor to the carbon calculation.

As a result of the findings of the LCA, Tishman Speyer proposed that the old façade should be recycled back to glass to maximize carbon savings.

The process was then embedded into contracts and throughout the refurbishment program.

340 metric tons of façade glass was recycled; this saved a further 100tCO_2e in the downstream production of container glass.

Close collaboration with partners from the outset ensured that Tishman Speyer's sustainability principles were embedded in their processes: contractor, demolition contractor, recycler, LCA analyst.

Early and ongoing engagement with the glass reprocessing company was critical in the success of the project.

Embedding requirements in the process pre-tender ensured inclusion in the demolition contract.

Appointing a recycling champion to oversee the process was particularly important during the glass removal stage. This helped prevent contamination of the glass from the old façade.

10. PILOT PROJECT

A pilot project has been developed and is currently at tender stage, with a main contractor likely to be appointed imminently at time of writing. The Employer's Requirements façade and roof specification, developed by Arup, includes a requirement for the glass removed from the building to be recycled back to float glass manufacture.

10.1 INTRODUCTION

The Burrell Collection, designed by Gasson, Andresen and Meunier, opened to the public in 1983 to great acclaim; however, over the last decade it has unfortunately seen a steady deterioration of the building fabric and a decline in visitors.

The exterior of the building is primarily constructed of stone, glass, and stainless steel. One of the prime elements of the building is the glazed wall in the North Gallery, which looks onto the woodland.

This redevelopment, now known as the Burrell Renaissance Project, brings a unique opportunity to redisplay the collection and dramatically increase access to over 8,000 objects, which were donated to the City of Glasgow in 1944 by Sir William and Lady Burrell. This is also an opportunity to re-connect the public to the Collection by encouraging visitors to explore, socialise and enjoy re-imagined and enlivened interior spaces and improved external learning and event spaces.

The Burrell is located in Pollok Country Park, Glasgow. The building and collection is managed by Glasgow Life. The Burrell was granted Grade A listing by Historic Scotland in 2013. As a result, proposals for any alterations or specification of material and fittings must be to the same high standard as the original features.

The project will see some 3,120m^2 of double glazed insulated units in the vertical façade and pitched roof glazing systems being fully replaced with new. This equates to 110 tonnes of glass that will become available for re-use or recycling and must be diverted from landfill.

The public nature of this building and the desire to produce a highly sustainable and revitalised museum building has driven the decisions that will ensure all aspects of the refurbishment project are undertaken to ensure minimal environmental impact.

This high profile project will no doubt attract attention from many quarters and should it be possible to undertake the glass-recycling programme proposed, it will prove to be a great development for the Scottish construction industry and an exemplar project for the UK and Europe as a whole.

FIGURE 26

Burrell Collection in Pollok Country Park, Glasgow
© Helen Simonsson

FIGURE 27

Burrell Collection in Pollok Country Park, Glasgow
© Arup

FIGURE 28

Burrell Collection, North elevation
© Arup

Process	CO_2 produced (saved) tonnes
Deglaze and removal of glass units from framing members on site	negligible
Stack glass on stillages or pallets ready for collection	negligible
Collection and transportation to recycler facility	0.4382
Transportation of cullet to glass manufacturer	5.0281
Energy savings and emission reduction	(-33)
Total savings	(-27.53)

FIGURE 29

Pilot project cost and carbon calculation summary

10.2 PROJECT STUDY

Based on the glass quantities available from the pilot project, we have calculated potential carbon emissions from the process required to recycle the glass back into the furnace at a floatline in the Yorkshire region. These values are based on feedback from industry and will be verified during the pilot project for their accuracy.

The glass quantities to be removed from the building during refurbishment are 3,120 square metres and the value of 110 tonnes is based on double glazed units made up of two panes of 8mm thick glass.

A financial report will be prepared following the pilot project to understand the costs and savings along the various steps of the glass recycling process.

We have provided an estimate of the potential CO_2 reductions possible from this project alone.

Transportation from site to recycling facility is assumed to be 6 trips of 20 tonnes each by road, a total distance of 48km per round trip. Utilising the methodology of CO_2 emission calculation provided in “Guidelines for Measuring and Managing CO_2 Emissions from freight transport operations” by ECTA and CENFIC, 438.24 kg of CO_2 is produced in the transportation process[36].

Based on 4 journeys of 700km round trip, which assumes no backhaulage is used, this process produces just over 5 tonnes of CO_2 from the transportation. Where backhaulage is used additional cost and emission savings can be found.

The float glass manufacturer sees financial savings from reduced energy cost and reduced expenditure on raw materials. The reduced energy consumption saves in the order of 33 tonnes of CO_2 emissions in the process, far outweighing the CO_2 created in transportation of the cullet materials to the plant, resulting in an overall reduction of 27.53 tonnes of CO_2.

11. CONCLUSION & NEXT STEPS

This research shows that glass, as a 100% recyclable material, can be remelted an infinite number of times and that the construction glass industry has the potential to be a perfect example of a scalable circular economy in action.

Glass is an inert material that has the potential to be recycled in a closed-loop system indefinitely. Coupled with the short service life of insulating glass units (double and triple glazing) there appears to be a disparity between the materials potential and its current utilisation.

Using recycled glass to make new glass products generates significant energy and CO_2 savings, and contributes towards creating a circular economy.

The growth of a construction glass recycling industry requires a new network to develop. We have observed that this network is already organically growing in the central belt of Scotland and that the network indicated here can be expanded and duplicated around the UK, creating a sustainable industry that can supply the demand of high quality glass cullet to the glass float lines in northern England.

Arup has developed an understanding of the current recycling logistical structure and typical refurbishment construction process and supply chain. We have investigated the processes required to write a robust specification for the recycling of construction flat glass in refurbishment projects. To promote and actively influence the industry we propose adding the requirement for glass recycling into future façade refurbishment project specifications.

Designs and specifications for new façades should follow guidance to maximise the potential of glass to be recycled. It is our responsibility as designers and engineers to consider circular economy principles and material selection from the very beginning of the design process. This will require a change in how we work, what materials we choose and how we influence our client's choices in material decisions. It will require further research and innovation to find materials and methods of construction to enable recycling of all the major components.

11.1 PILOT PROJECT

We proposed to record the progress and results of a pilot project at The Burrell Renaissance. If successful, this project will serve as an exemplar of the potential and viability of construction glass closed-loop recycling.

The financial outcome, carbon reductions and logistical challenges will be compared against this report and a case study prepared for dissemination to record the challenges and lessons learnt during the process.

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Glass Technology Services	https://www.glass-ts.com/
Glass for Europe	http://www.glassforeurope.com/en/
FERVER	http://www.ferver.eu/
Zero Waste Scotland	http://www.zerowastescotland.org.uk/
CMS Scotland	https://www.cmswindows.com/
MKD32 Matthew Demmon	http://mkd32.co.uk/
Valklas Recycling	http://www.vlakglasrecycling.nl/
Ellen MacArthur Foundation	https://www.ellenmacarthurfoundation.org/about

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