GLASS

Research and Development Final Report

GLA-0015

A UK MARKET SURVEY FOR FOAM GLASS

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FOAM GLASS MARKET SURVEY

Executive Summary

The aim of this project was to identify whether or not there are opportunities to either develop or transfer a foam glass production process into UK for manufacturing construction products. This information would then be used to advise the Waste and Resources Action Programme (WRAP) where best to invest i.e. transfer existing technology into UK, develop UK technology or not to invest in the foam glass process. This was achieved by completing four investigations by BRE and Glass Technology services. These include a market survey on the strength and changing nature of the UK construction industry, a literature survey of existing foam glass processes and products used in other countries, an investment appraisal (whole life costs) of the foam glass process using data from an operational plant and a large-scale pilot plant, an assessment of the best practicable environmental option (BPEO) for introducing the foam glass process into UK, and an assessment of using an alternative microwave energy system for the process.

The key findings of the survey include:

- WRAP should consider the transfer and optimisation of an existing foam glass technology from Europe for the manufacture of foam glass products in UK. Financial assistance will be required.
- The UK market for construction products has seen significant growth in the last decade and is expected to continue this trend with major capital investment in schools, health and housing. Foam glass is suitable for a number of construction products e.g. loose fill, insulation, blocks and slabs, and has characteristics of low flammability, thermal stability, high chemical durability and contains no fibrous material. There are well established markets that foam glass products should be able to penetrate by 1% to 5% without disruption to jobs and local economies.
- Both the investment appraisal and the Best Practicable Environmental Option assessment undertaken in this project have shown that the ideal size of a processing plant will produce 225,000/m^3 of foam glass product requiring 50,000 tonnes of waste glass per annum. With this size of plant, the cost of foam glass products can be as low as £30/m^3 and still provide a discounted payback period of about 4 years with an internal rate of return (IRR) of 30%. Foam glass products generally range from £30/m^3 to £65/m^3 for loose foam glass aggregate and up to £200/m^3 for pre-shaped bricks, blocks, panels and insulation. The plant should be built within 100km of the main sources of glass waste which should be taken from the replacement window industry, end of life vehicles and cathode ray tubes. There is an economic benefit of using cullet from glass packaging waste, but this should only be used if it is heavily contaminated and not suitable for containers
- The use of continuous microwave radiation and exothermic reactions for heating the foam glass production process are currently not a viable option. Therefore the use of traditional forms of heating such as ovens should be used for the UK foam glass process.

Contents

From glass, to pellets to products (Geofil-bubbles)

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Aims and Objectives

This project aims to assess and advise WRAP on the market opportunities for foam glass construction products in the UK. To achieve this aim, four objectives were established:

- To undertake a detailed review of the UK construction market and to identify whether to transfer existing foam glass technologies into UK or to develop new energy saving technologies for UK.
- To undertake an investment appraisal of the foam glass process using whole life costs and savings to investment ratios.
- To undertake an investigation of the best practicable environmental option (BPEO) for introducing the foam glass process to UK that accounts for the conservation and protection of the environment.
- To prepare a consolidation report of the UK construction market, the various types of foam glass process, whole life costs and BPEO for introducing the foam glass process into UK.

This report presents the findings of a market survey, a literature survey, an Investment Appraisal (whole life costs), the BPEO modelling for both technical and alternative energy assessments.

In order to provide WRAP with appropriate recommendations, this report will also review three possible options for foam glass production. These are:

1. The viability of producing foam glass materials incorporating significant quantities of waste glass as a feedstock material via technology transfer into the UK market place of existing foam glass production technologies
2. The development of the foam glass production process to take advantages of new energy saving technologies that have emerged in recent years that have the potential to significantly reduce production costs whilst incorporating significant quantities of waste glass as a feedstock
3. Do nothing.

The assessment of the above options was undertaken by examining the following:

- The foam glass process
- Potential market for foam glass products
- Summary of existing foam glass technologies
- Waste glass quality and quantity
- Overall risks and market drivers
- Investment Appraisal including capital and operating costs
- Best Practicable Environmental Option
- Environmental assessment of foam glass products
- Alternative energy saving technologies

The results and recommendations of this study will be used by WRAP to consider investment opportunities for the foam glass process. If required, BRE and GTS will continue the development of a process protocol for foam glass recyclate in order to maximise application of this process to multiple construction products. This will include lab- and pilot-scale trials and fit for purpose tests to a select range of products. An initial proposal already submitted to WRAP will be considered for this role following the outcome of this report.

The Foam Glass Process

Overview

This chapter includes a brief review of the history and nature of the different types of foam glass process (continuous sheet, continuous blocks, continuous pellets) along with the mechanisms and feedstock required for foaming the products. Some initial drivers for encouraging the use of foamed glass are introduced. Details of foam glass manufacturers are included later in the report.

History of foam glass production

Foam glass, also referred to as cellular glass, has been commercially available since the 1930's. Originally it was manufactured from a specially formulated glass composition using virgin glass only. Currently, there are a number of foam glass production plants where they are using up to 98% post consumer waste glass in their product. The basic principle of foam glass manufacture is to generate a gas in glass at a temperature between 700 and 900°C. The gas expands thus producing a structure of cells to form a porous body. The foam glass can be either made from molten glass or sintered glass particles. The latter process requires ground glass to be mixed with a foaming agent, then on heating the foaming agent releases a gas and expands the molten glass mass.

There are numerous patents on foam glass production dating back to 1930's. Even though there are numerous patents there are only a few that have been adopted as a commercial process. It is not intended to report in detail the historical background to the current foam glass production methods. The patents that exist for commercial foam glass production are invariably so vague that it would be difficult to replicate the process without additional information. Therefore, most of the information on the different foam glass processes are from articles and publicity in the public domain and information from foam glass manufacturers.

The early products made in 1960's, which were blocks or preshaped articles, tended to use specially formulated glasses to form the foam glass such as alumino-borosilicate glass, either by a route from molten glass or mixing the glass components and a foaming agent, then firing. The main foam glass producers in Europe and North America now use a high percentage of processed post consumer glass in their products. Currently, there are three main product types of foam glass (Figure 1), these being:

- Loose foam glass aggregate - continuous production of sheets of foam glass that are then broken into loose foam glass aggregate and sized
- Blocks and shapes – generally continuous production of blocks and shapes in moulds that are then cut and shaped. Can also be manufactured by a batch process
- Pelletisation – continuous production of spherical pellets of foam glass that are then used in the manufacture of blocks, panels and slabs.

Foam glass is best suited as a rigid insulation material. Due to its excellent structural properties, it is suitable for use as insulation in roofs, walls and traffic areas such as flat roofs or floors, where other insulation products may be compressed resulting in an uneven surface and the loss of insulating properties. Foam glass has excellent fire resistant properties and its very low water absorption and water vapour transmission means that, unlike many other types of insulation, it tends to retain its insulating properties even when wet. It is also used as industrial insulation for a number of minor uses such as sandwich panels or is used as a product in extreme environmental conditions.

Loose foam glass aggregate

Blocks and shapes

Pelletisation

Figure 1 - Three main product types of foam glass.

Drivers for using foam glass

Foam glass has been manufactured for a number of years mainly in the USA and continental Europe as a lightweight high strength insulating material either as blocks and shapes or a loose replacement aggregate. The main driver for foam glass use has been the requirement of high-energy efficiency standards for building construction, both domestic and commercial. The UK has a binding obligation to reduce its carbon emissions under the Kyoto agreement and a large contributor to carbon emissions in the UK is the heating within domestic housing and commercial premises. The construction industry is directly affected by the Building Regulations Part L (England and Wales) and Part J (Scotland), which deals with energy conservation as these set down minimum performance standards for products and structures in terms of their U value. The basic building block of all these regulations is the U value. This is the rate of heat loss, expressed in watts per square metre per degree temperature difference (w/m^2K). The use of foam glass in the construction of housing and buildings could greatly reduce the energy consumption and hence the carbon dioxide emission of newly built housing and buildings.

In addition to the potential energy saving from the use of foam glass, there are other less obvious advantages of the material due to the lightweight nature of the material. These include design flexibility, construction productivity, reduced manual handling, lower transport costs, and lower foundation costs. Also it is rodent resistant, fire resistant, an effective sound absorber, non-toxic and non-water absorbent.

Foam glass as a building construction material is competing with insulating polymeric and fibre materials as it is a good insulator. However, foam glass also has inherent strength properties. Polymeric materials have poor fire resistance compared to foam glass. Foam glass characteristics of low flammability, thermal stability and high chemical durability are a distinct advantage over polymeric materials. Foam glass also has the advantage that it contains no fibrous material. Fibrous insulation materials such as fibre glass require special handling procedures to protect the user from inhalation of fibres and skin irritation.

The desirable properties of foam glass are high strength, low density, and low thermal conductivity. Generally these properties are achieved by having a large number of small, evenly sized bubbles, with thin walls in between. As the product is made of glass it is naturally inert in most environments with respect to biological, thermal, chemical and environmental degradation.

British Glass undertook an extensive research project[1] (between 1992 and 1995) to investigate the manufacture of foam glass blocks using post consumer waste container glass. This work concluded that it was possible to use coarsely ground waste glass to produce foam glass, but was not economically viable at that time due to a high energy requirement to manufacture and no demand for foam glass as an insulating material. However, with building regulations (Part L and Part J) specifying high levels of insulation and well developed foam glass processing technology, the manufacture of foam glass for the UK construction market may now be viable.

This report will review the possible technologies for manufacturing foam glass and the associated costs in the UK. Also the properties of foam glass in various applications will be reviewed.

Foam glass mechanism

The principle of the foam glass process, is that between 700 & 900°C the glass powder forms into a viscous liquid and then the foaming agent decomposes to form a gas that in turn forms bubbles. The glass needs to have sufficient viscosity not to allow the gas bubble to rise through the mass of the body but remains in position during the foaming heat cycle. If the temperature is too high the bubbles will rise and the body will collapse and not form a foam body[2]. The control of the heating rate is one of the most important factors in optimising the foam glass product. Rapid heating can cause the foam glass feedstock to crack, whilst slow heating will lead to early release of the gas from the foaming agent before the viscosity of the glass is low enough to allow the glass to expand.

A further complication is that the foam glass feedstock is relatively insulating due to a pack density of 80% and as the feedstock expands from the top surface this further insulates the materials below. Therefore, there is the potential to overheat the top

[1] M. Glendenning, Report on a series of trials to produce foam glass blocks, British Glass Members Report, 1995.
[2] E. Kreidl, Foam Glass, The Glass Industry, pp 304-318, Aug 1942.

surface in order to heat the bottom of the feedstock. This overheating can cause the top cells to collapse resulting in an inferior product.

The finely ground glass powder is mixed with the foaming agent which is the feedstock for the foaming furnace. Suitable foaming agents can be calcium sulphate ($CaSO_4$) or calcium carbonate ($CaCO_3$). It is reported[11] that the thermal conductivity will be lower if $CaSO_4$ is used, however $CaCO_3$ is easier to work with[3]. This is due to the production of sulphur gases from $CaSO_4$ during the foaming process, SO_2 has a lower thermal conductivity than CO_2. However, the formation of SO_2 requires more control as it is a noxious gas.

Gypsum is a readily available source of $CaSO_4$ and limestone is a readily available source of $CaCO_3$. If the air in the furnace at the foaming zone is replaced with either SO_2 or CO_2 then this will lower the thermal conductivity of the foam glass. Fly ash[4], which in itself is a waste mainly from coal-fired power stations, has been used as a foaming agent. The main constituents of fly ash are SiO_2, Al_2O_3, Fe_2O_3, CaO & SO_3. SO_3 is the active foaming agent evolving SO_2 at temperature to form the foam glass. However, fly ashes are waste materials from incinerators and therefore can contain toxic compounds and heavy metals.

Silicon carbide (SiC) is also a known and used[5,6] foaming agent that gives controlled and precise cell sizes. It is thought that SiC is the most commercially used foaming agent[7] for the reason of control and reproducibility. The SiC reacts with the SO_3 within the glass structure to form CO_2 & S. It is reported[8] that sugar will promote foaming, and as waste post consumer container glass will invariably have some sugar from the food it once held, this could be considered to be an advantage.

The foaming agent particle size affects the cell size[11], which will influence the performance and characteristics of the foam glass. When using gypsum a particle size between 110 and 160 microns and limestone 105 and 155 microns should be used to achieve a desired cell size. This in turn determines the density of the product. The lower the product density the lower the thermal conductivity (more thermally insulating). Slightly elevated atmospheric pressure (1.1 atmospheres) during firing is reported[11] to give a better degree of control of the foam formation. The smaller the cell size the higher compressive strength of the foam glass body. The strength is a function of the inverse square root of the cell size[9].

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[3] W. Lynsavage, Foam Glass, Ceramic Bulletin, Vol 30, No 7, pp21-22, 1951.
[4] G. Brusatin, G. Scarinci, L. Zampieri & P. Colombo, Foam glass from cullet, Glass Machinery & Accessories, 1, 2002.
[5] V.T. Slavyanskij & L.V. Aleksandrova, Reaction of glass and gas foaming agents during foaming, Steklo I Keramika, No11, pp 8-12, November 1966.
[6] G. Brusatin, G. Scarinci, L. Zampieri & P. Colombo, Foam glass from cullet, Proceeding International Congress on Glass, Vol 2, pp 17-18, 2001.
[7] T.E. Frydenlund & R. Aaboe, Use of waste materials for lightweight fills, www.gjenbruksprosjektet.net/filemanager/download/9/Hasopor-paper-3h.PDF
[8] H. Hojaji, Development of foam glass structural insulation derived from fly ash, Mat. Res. Soc. Proc, Vol 136, pp185-206, 1989.
[9] J. Morgan, J. Wood & R. Bradt, Cell size effects on the strength of foamed glass, Materials Science and Engineering, 47, pp 37-42, 1981.

Processes for producing loose foam glass aggregate

Continuous sheet process

Due to commercial confidentially and limited information in the public domain there is little detailed information regarding the process of foam glass manufacture. The continuous process[10] describes where a mixture of finely ground glass and forming agent is placed on a moving belt, which is fed into a furnace and heated to the foaming temperature between 700 and 900°C. The particle size range[11] is between 100 and 700 microns. Waste glass from a processor (either container and/or flat glass) is likely to be in the size range between 5 and 20 mm. Therefore, this would need to be reduced in particle size down to 100 microns using a two stage process likely to include a hammer mill (down to 1 to 2 mm) then a rod or ball mill (down to 100 microns). WRAP is currently in the process of reviewing and maybe supporting the development of technology that is capable of reducing the particle size of the waste glass for high value applications. Therefore, there could be new technology available for this process that may be more economic than the grinding technology described. Figure 2 shows the processing flow from the waste glass to the foam glass manufacture[11] for a typical foam glass production method.

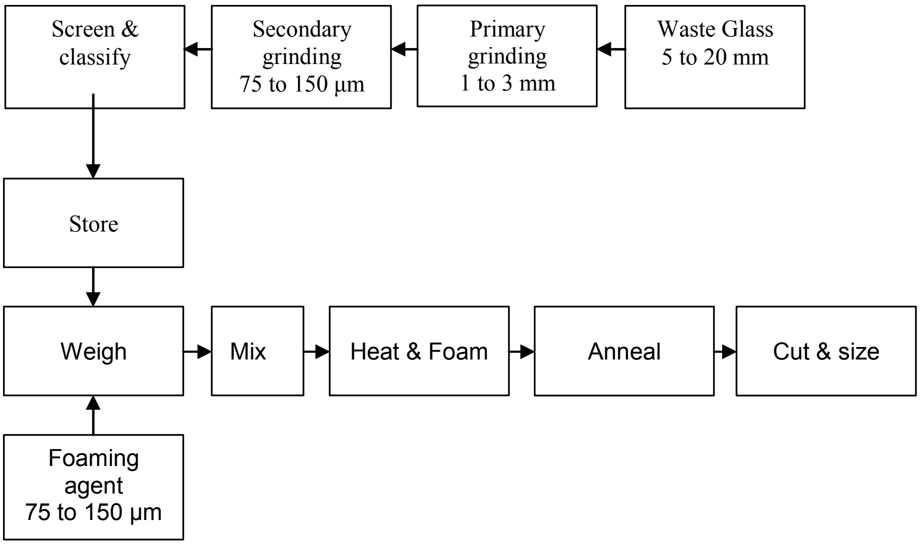

Figure 2 - Process route for foam glass production.

For a continuous manufacture the feedstock will be continuously fed onto a moving belt that passes through the furnace[12] (Figure 3). The feedstock will pass through the foaming zone, between 800°C and 1100°C. It is necessary for this to be a rapid heat zone to activate the foaming of the feedstock and subsequent required viscosity of the glass. The extracted heat from the cooling zone can be used for the preheat zone, hence, conserving heat.

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[10] S. Kraemer, A. Seidl, R. Mayer, L. Streibl, Apparatus and process for the continuous production of foamed glass and foamed ceramic, US Patent 3,473,904, October 1969 – Informative patent on continuous kiln for firing the foam glass.
[11] D. Solomon & M. Ros, Foamed Glass Manufacture, US Patent 5,516,351, May 1996 – Informative patent on the use of foaming agents and percentage to use for desired properties.
[12] J. Malesak, Method and apparatus for continuously manufacturing foam glass, US Patent 3,607,170, Sept 1971.

The foam glass product will be a sheet of a width up to 2 m depending on the size of the furnace and a thickness up to 100 mm. After it has been formed and cooled the slabs of foam glass can be broken up to form loose aggregate. The product can be graded into different particle ranges depending on the application.

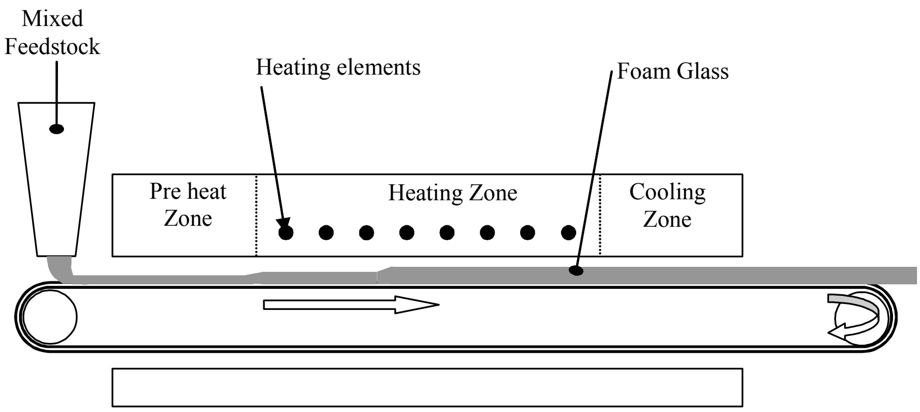


Figure 3 - Continuous furnace for the production of foam glass.

The feedstock can either be dry or wet, however, it is believed that the wet route will not produce closed cells and hence result in lower thermal insulation compared to completely closed cells made by the dry feedstock route.

Continuous process for foam glass blocks and shapes

The manufacturing technique for larger blocks and shapes up to sizes in the order of 1200 x 600 x 160 mm may involve a different process. Due to commercial confidentially the process employed by such companies as Pittsburgh Corning and other companies that license the technology is not known. However, a process for continual manufacture of blocks is described in a US patent[13,14], citing a technique whereby moulds containing the foam glass feedstock are passed through a furnace. This is a very similar concept to the previously described technique, except that the foam is manufactured in individual blocks rather than a continuous sheet. It will be necessary to have an annealing zone after the foaming zone. The annealing zone will allow the internal strain to be reduced and controlled, hence, forming a stable foam glass product.

The formation of foam glass blocks is essentially a batch-based version of the continuous process. From previous work carried out by GTS[1], it is known that problems arise with heat transfer as the blocks become larger. This is essentially because the feedstock and the product are both insulating and with a large body there is potential for the core never to achieve the sintering temperature before the outside starts to collapse. The foam glass formed in moulds can be cut and if necessary machined to the required shape. Pittsburgh Corning has patented[15] a process whereby foam glass is manufactured by the means of a fluidised bed. Gas is

[13] D. D'Eustachio & H. Johnson, Process for making cellular materials, US Patent 3,441,396, Apr 1969.
[14] K. Schymura, Apparatus for producing a foamed-glass or foamed-ceramic strip, US Patent 4,289,521, Sep 1981.
[15] C. Smolenski, Process for making cellular glass nodules by the means of a fluidised bed, EP Patent 0,294,046, May 1988.

passed through the glass powder as it is sintered to produce the foam glass. It is not known if this method is currently used.

Foam glass pellets

The production of foam glass pellets is manufactured in a different way. The finely ground glass and the foaming agent are formed into spheres and then fed into a rotary furnace, whereby the foam action takes place to form spheres of foam glass (Figure 4). As the spheres pass through the furnace they are annealed and cooled.

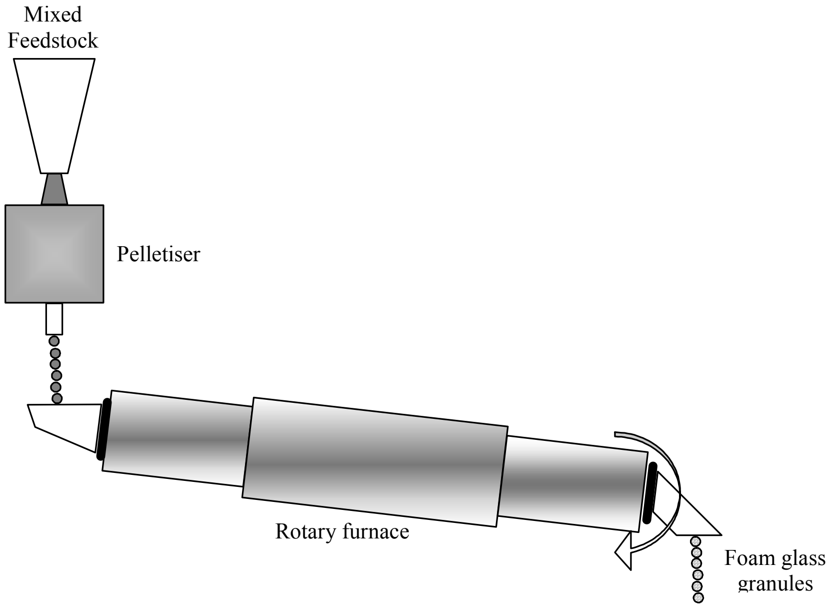


Figure 4 - Continuous production of foam glass granules using a rotary furnace.

Ceramic foam products

Ceramic foam[16] is made by making a slurry of finely ground ceramic particles (<10 microns), a foaming agent and a setting polymer. The slurry is whisked to entrap air and is poured into a mould and the foam body sets at room temperature to form a solid body. It is then fired to sinter the ceramic particles together to form a strong porous ceramic body. However, this processing route would not be suitable for large production of foam glass as it is relatively expensive and tends to form an open cell structure that lends itself to applications of filtration rather than insulation. This method could be adapted for foam glass manufacture of specialised products such as filters. However, it is envisaged that there would be strong competition from existing products in a relatively small market.

Foam glass production is now a well-established process with at least five companies in Europe offering a range of foam glass products to meet the requirement of the end application. This report will analyse the potential market for foam glass production in the UK and examine the economic and environmental impact.

[16] R. Smith & J. Binner, Processing and applications of foam ceramics, Ceramic Technology International, pp 48-51, 1994.

Construction Markets for Foam Glass Products

Overview

This chapter looks at the potential future markets for foam glass construction products by reviewing existing markets. The structure and success of the construction industry in the last ten years is used as an indicator that the economic growth of the industry will continue into future years. The chapter includes a brief review of concrete and clay products suitable for the foam glass process and suggests how foam glass products can capitalise by a 1%-5% penetration of existing markets or compete with the net growth of imported products.

Future economic growth trends

Data included in this chapter will show that there is sufficient confidence to predict that growth in the construction industry in the last decade is set to continue for future years. However, there are various external factors to the construction industry that can encourage or discourage growth and/or decline. These factors can be global in terms of predicted and actual world economic growth forecasts (CEBR 1.72%-2.71%, OECD 1%-3%, Eurozone 1.6%-2.9%, 2001-2003 respectively), or more local whereby the strength or weakness of the Euro against the pound impacting on UK export competitiveness.[17] There are other issues which can have significant impact on economic growth and the most immediate concern is the escalation of activities in the Middle East. These will play a role in the eventual market opportunities for foam glass products.

A recent survey[17] commissioned by BRE reported on future trends for the UK construction sector in terms of economies (Global, Europe, UK), UK markets, construction materials (imports & exports) and construction sectors (e.g housing, commercial and public). In general, the UK economic outlook is positive with overall growth set to rise from 2.5% to 2.75% by 2003[18]. A stronger Euro, inflation well under control and stable interest rates at 4% has helped consumer confidence, encouraged investment and kept unemployment low (5.2%). Future increases in government spending for Health (£65.4bn to £105.6bn 2002-2008), Transport (£7.7bn to £11.6bn 2002-2006) and Education (£45bn to £58bn 2002-2006) will all be reflected in the construction industry as building stock, infrastructure and facilities are replaced, refurbished or increased. Various forecasters provide similar short-term growth forecasts in UK construction output including CPA (3.7% 2002-2003), CFR (3.8%-2.2% 2002-2004), CEBR (4.75%-3.93% 2002-2003) and RICS (0.8%-1.4% 2002-2003).

Structure of the British construction industry

The following pages show the previous, current and predicted structure of the construction industry in England, Scotland and Wales, otherwise Great Britain. The majority of information has been taken from *The Construction Statistics Annual 2002*

[17] Leading Edge, Construction Sectors & Building Materials 2002-2011, BRE Confidential report, 2002
[18] http://www.dti.gov.uk/construction/main.htm

(DTI)[19], but also from other publications including *The Construction Industry Mass Balance* (Viridis)[20], *Future Perfect* (Biffa) and *Strategic Waste Management Assessments* (Environment Agency)[21].

There has been considerable change in the construction industry since the UK stock market crash in 1989. As a major investor in building stock and employment, the construction industry suffered significant losses and many construction contractors went out of business or moved to other countries/sectors. This has had some impact on available trade skills but has also enabled new skills, technologies and working practices to be introduced. Added to this is a need to be leaner, more productive and efficient (Egan etc), the industry is seeking opportunities to make it more attractive to UK and Overseas investors.

This growth is demonstrated in Table 1, which shows the value of construction output (GB and Overseas) in the last decade. This is significant evidence of the strength and gradual, sustained growth for all major sectors of the industry. Overall, UK construction has increased (52%) from approximately £47.4 billion to £72 billion in the last decade. Commendably, the Overseas sector of the UK market has grown (97%) from £2.3 billion to £4.6 billion. These are firm indicators that the industry is ripe for investment and capable of accepting new products and markets.

	Housing	Infrastructure	Non-Housing / Non-Infrastructure	All Repair & Maintenance	**Total Construction Great Britain**	Total Construction Overseas
YEAR	**£ Million**					
1991	5,778	5,904	15,695	20,012	**47,389**	2,317
1992	6,071	5,538	12,828	19,298	**43,735**	2,459
1993	6,618	5,427	11,205	19,548	**42,798**	2,945
1994	7,407	5,075	12,304	21,084	**45,870**	3,380
1995	7,128	5,594	13,669	22,550	**48,941**	3,970
1996	7,004	6,311	14,432	24,222	**51,969**	4,695
1997	7,971	6,301	15,505	25,488	**55,265**	4,300
1998	8,423	6,170	17,743	26,691	**59,027**	4,258
1999	8,407	6,187	20,874	27,389	**62,857**	3,464
2000	9,977	6,441	21,122	29,086	**66,626**	3,889
2001	10,219	7,146	22,467	32,159	**71,991**	4,574

Table 1 - Value of Construction Output by British Contractors 1991-2001[22]

Table 1, also shows the sustained growth (77%) of the UK housing market from approximately £5.8 billion to £10.2 billion. This growth tracks growth in all other sectors and can be used as an indicator of overall growth. The housing market is predicted to continue growth in response to high demand and low supply for housing. Housing is also one of the key opportunities for foam glass products e.g. bricks, blocks, tiles, concrete and insulation panels.

Volumes and values of select products

There are literally thousands of available products to the construction industry ranging from material type (concrete, timber, stone) to product type (brick, block, tile). It is believed that foam glass can be used for a range of available products. However,

[19] http://www2.dti.gov.uk/construction/stats/csa.htm
[20] Viridis and CIRIA, Mass Balance of the Construction Industry, 2002
[21] http://www.environment-agency.gov.uk/subjects/waste/
[22] http://www.dti.gov.uk/construction/main.htm

for the purposes of this project it is necessary to concentrate on currently available products that have a potential to be made using the foam glass process.

Table 2 shows that the high volume markets are crushed rock, ready mix concrete, sands and gravels which can be 10 or 20 times more than some of the medium volume markets such as clay bricks, ceramic tiles and mortars. In some cases the high volume markets can be 500-1000 times greater than the small volume markets such as clay tiles and clay blocks and chimney pots.

	Clay Bricks	Concrete Building Blocks & Bricks	Unbound Crushed Rock	Sands	Ready Mix Concrete	Tiles & Flagstones	Fibre Cement Products	Cement
1998	5,691	15,808	84,081	50,213	53,089	9,353	105	15,914
	Mortars	Prefabricated building components	Concrete Pipes	Gravels	Ceramic Tiles & Flags	Ceramic Sanitary, Pipes & Fittings	Clay Tiles	Clay Blocks & Pots
1998	1,959	7,307	1,187	37,058	4,244	128	163	66

Table 2 - Volume (000 tonnes) of materials supply in Great Britain[23]

Volume is not necessarily the most important indicator for any assessment of markets. Table 3 provides an economic value of select materials supply in Great Britain. The value of products and the overall market share is of interest and can sometimes be quite paradoxical. For example, although the supply of crushed rock is in decline it is also one on the most valuable materials available to the construction sector both in versatility and overall value £1.56 billion in 2000. Yet it is also a low-value material in comparison with some of the other materials being analysed in this project e.g. the cement market is almost the same value at £1.19 billion in 2000 but is one-tenth the volume of crushed rock.

	Bricks	Concrete Building Blocks	Crushed Rock	Sand & Gravel	Ready Mix Concrete	Cement
	£000s	£000s	£000s	£000s	£000s	£000s
1992	520,740	546,072	1,727,604	1,066,776	1,521,317	994,140
1993	563,760	599,512	1,794,912	1,073,640	1,521,683	997,290
1994	627,300	690,464	1,941,084	1,172,064	1,679,925	1,134,000
1995	527,400	620,328	1,810,056	1,075,872	1,587,984	1,072,260
1996	526,680	611,024	1,594,728	983,964	1,530,548	1,152,720
1997	549,360	656,336	1,605,444	1,036,392	1,635,676	1,166,850
1998	535,140	675,888	1,580,592	1,031,616	1,683,735	1,180,170
1999	543,780	687,544	1,591,176	1,058,508	1,725,273	1,159,650
2000	520,560	708,232	1,563,684	1,070,808	1,688,130	1,192,860
2001	508,500	708,072		1,165,692	1,685,566	1,127,790

Table 3 - Value of materials supply in Great Britain[24]

There is also a need to consider that materials such as sands, crushed rock and cement are not always the final product and will be used for further products and

23 Viridis and CIRIA, Mass Balance of the Construction Industry, 2002
24 http://www.dti.gov.uk/construction/main.htm

applications. Table 5 reproduced from information gathered by the CIRIA/Viridis construction mass balance show the market size for products in 1998.

Year 1998	Market size	1% Penetration	5% Penetration
Material Group	Tonnes		
Aggregates & Quarry products	125,871,381	1,258,714	6,293,569
Wood	9,240,600	92,406	462,030
Finishes, Coatings & Adhesives	1,477,213	14,772	73,861
Fabricated metal products	3,937,593	39,376	196,880
Cabling, Wiring & Lighting	189,619	1,896	9,481
Glass	1,415,436	14,154	70,772
Plastic	1,402,382	14,024	70,119
Ceramic products	4,313,253	43,133	215,663
Cement, Concrete & Plaster Products	97,991,921	979,919	4,899,596
Stone & Mineral products	43,630,764	436,308	2,181,538
Bricks & clay products	5,979,410	59,794	298,971
TOTAL	**295,449,572**	**2,954,496**	**14,772,479**

Table 5 - UK Mass Balance (tonnes) of Construction Products in 1998[25]

Imports and exports of select products

Consideration should also be given to the import and export markets for construction products to/ from Great Britain. There are thousands of individual products imported and exported from Great Britain, only a very limited number have been included in this report to represent those products that have the greatest potential to be made using the foam glass process. All data in this section came solely from the DTI *Construction Statistics Annual 2002* although they have been reproduced in a different format. Table 6 shows overall (including select products) materials and components that were imported or exported to/ from Great Britain and the overall balance of that trade. These figures reflect figures in earlier sections of this report, mainly that there has been a considerable growth in the construction sector the previous decade.

ALL MATERIALS & COMPONENTS	Imports of all Building Materials & Components	Exports of all Building Materials & Components	Balance of all Building Materials & Components
	£Million	£Million	£Million
1992	4,037	2,305	-1,732
1993	4,071	2,651	-1,420
1994	4,762	3,025	-1,737
1995	4,989	3,524	-1,465
1996	5,386	3,803	-1,583
1997	5,577	3,805	-1,772
1998	5,628	3,761	-1,867
1999	5,758	3,583	-2,175
2000	6,379	3,521	-2,858
2001	6,545	3,580	-2,965

Table 6 - Imports and Exports of All Materials and Components 1992-2001[26]

[25] Viridis and CIRIA, Mass Balance of the Construction Industry, 2002
[26] http://www.dti.gov.uk/construction/main.htm

Table 6 shows that imports have grown (62%) from approximately £4.01 billion to £6.55 billion and exports have grown (55%) from £2.31 billion to £3.58 billion whilst the net balance of trade has been negative (-71%) from £-1.73 billion to £-2.97 billion. However, whilst there has been an overall growth in construction output, materials supply, materials imported and materials exported, it has not been possible for UK manufacturing markets to capitalise on this opportunity. This is most likely due to cost of the product rather than the inability of UK manufacturers to produce the products.

Tables 7-16 (Appendix 1) show the overall trends for imports, exports and net balance of trade for a select range of products that could be manufactured using the foam glass process. A simple matrix (Table 7, Appendix 2) has been devised to assess the market position of these select construction materials and products based on the available data from DTI[27]. Where the product is net imported to the country, it would seem that there is an opportunity to produce more of this product in the UK, especially where the market is expanding for imports. This includes aggregates, clay bricks, glazed tiles, unglazed ceramic tiles and ceramic sanitary ware. The percentage growth would also indicate if there was a potential for UK to capitalise on this opportunity, especially where the growth was considerable and where the UK manufacturing market could compete with overseas manufacturing for this growth in imports e.g. clay bricks (771% growth) and unglazed ceramic tiles (896% growth).

When looking at an indication of the market value of these products, glazed ceramic tiles have clearly the highest with £224.8 million followed by ceramic sanitary ware at £94.3 million and aggregates at £68.1 million. Yet consideration needs to be given to the current production levels in the UK, the competition for the products and how the products differ in their manufacture and raw materials.

Construction products suitable for the foam glass process

Product variability

This project is interested in the variable product opportunities for the foam glass process not only for the high-grade (up-cycle) applications but also the medium-grade (recycling) and low-grade (down-cycle) applications. In effect, the foam glass process can be applied to any product whether of high-quality and value such as a flame retardant filler (£500 - £1000/ tonne) or a low-quality product and value such as backfill material (£12-£15/ tonne)[28]. It is important to note that market values change in relation to supply and demand as well as a range of other factors beyond the control of this study.

The markets for foam glass in the UK have historically been limited by the economics of energy consumption and expensive technology of the foam glass process. But the production of similar type products using primary aggregates and industrial by-products are well established e.g. pulverised fuel ash (pfa), incinerator bottom ash (iba) and foundry bottom ash (fba). This is because both pfa and fba are from waste sources and are also pozollanic which together reduce the overall cost of the production process. Similar industries could utilise the flat glass waste and foam

[27] http://www.dti.gov.uk/construction/main.htm
[28] Personal communication, WRAP meeting at British Glass, 2002

glass process to replace current or develop new products. Similarly, it is expected that established waste transfer, management and processing facilities will equally diversify and collect, transfer and process waste flat glass into a ground material suitable for the foam glass process. This, along with growing environmental taxation for primary extraction, will encourage a more favourable economic climate for the foam glass process so that it can compete with more traditional processes.

There are many construction products that could be suitable for the foam glass process but this report has focused mainly on concrete and clay products as these appear to be the most likely opportunities. Mostly this is because they are growing markets, have already proved their ability to include waste materials (e.g. pfa, iba etc) but also the high value of the markets. However, the likelihood of adopting the foam glass process in composite products using a combination of material groups (e.g. wood-concrete, PVCu-concrete) should not be overlooked. The following pages briefly review the major markets for both concrete and clay based products.

Current concrete products

Concrete is one material that has demonstrated suitable properties for accepting blends of traditional, secondary and bi-product wastes into its manufacture. There is a whole range of established and potential markets where primary aggregates can be partially or wholly replaced by suitable recyclate. There is also a range of established and potential processes to manufacture these products e.g. extrusion, casts, presses, in-situ and foam. An example of these processes and one that has seen sustained growth in the UK is the precast process which is providing products to a growing pre-fabrication and modular type construction process. The different types of precast concrete products produced by the members of the British Precast Concrete Federation include:

Foundation Units & Piles	Staircases & Stair Units
Retaining, Revetment & Crib Walls	Roof Tiles
Sea & River Defence Units	Cladding & Structural Wall Units
Pipes & Drainage	Frames, Beams & Columns
Tunnel Linings	Multi-storey Carparks
Box Culverts	Grandstands & Terracing
Manholes & Inspection Chambers	Specialised Building Systems
Water Treatment & Storage Tanks	Agricultural Products
Kerbs & Flags	Fencing
Paving (Block and Decorative)	Ducts, Conduits & Markers
Vehicle Safety Barriers	Garden Products
Concrete Bricks	Lighting Columns & Poles
Cast Stone Architectural Units	Road Furniture & Bollards
Lintels, Sills & Copings	Bridge Beams & Gantries
Beam & Block floors	Railway Sleepers
Hollowcore & Composite floors	Walling/masonry Blocks

The largest market share of the concrete precast industry is taken up by (in order):

1. Masonry blocks
2. Paving slabs and blocks
3. Roof tiles
4. Pipes and associated products
5. Floor units

Concrete can either be cast on site (in-situ) or can be cast in a factory and then delivered to site ready to be installed (precast). The precast concrete process therefore lends itself to the foam glass process as both require an element of casting products for later construction or fabrication. Like other precast concrete products, foam glass products could also be deconstructed and reused on a different structure or recycled again preferably into high-grade applications. The concrete precast industry has annual sales in the UK of £1.6 billion and employs over 20,000 people[29].

There are no current UK or EU standards relating to the specific use of flat glass waste into foam glass products. Significant guidance does exist on the use of crushed concrete, brick and other inert materials (glass) as aggregate in new concrete (e.g. BRE Digest 433 and DETR Quality Control for Recycled Aggregates 1998). No specific standard tests have been developed in the UK for the assessment of concrete elements made from foam glass. However, many standard tests exist to assess the strength, quality and durability of reinforced concrete and precast products which can be used to provide an assessment of the condition and the potential life-span of a foam glass product. Relevant standards and specifications for concrete are performance based (rather than material specific) and currently do not exclude the use of recyclate as a concrete constituent.

Current clay products

The Romans introduced the process of fired clay bricks and hydraulic mortar to Europe and this basic principle of building a stable bonded stack of handleable pieces has stayed with us for centuries. The variety and availability of bricks and blocks has increased, more and more building techniques have been developed and a whole range of fixtures and fittings have been created to speed up the process of construction. Buildings are rarely built using bricks and blocks alone – there is usually concrete or timber. There are six main clay products assessed by this report; bricks, stone, blocks, paving, slates, and tiles.

<u>Bricks</u>.

Generally 337.5mm long by 65mm high with a maximum depth of 102.5mm. The standard UK brick is only 215mm in length. A European common standard for bricks is currently being negotiated in Brussels. Bricks are produced from clay, calcium silicate, sand-lime and flint-lime. There are many types of brick described as solid, perforated, hollow, cellular and frogged. Bricks are used to maintain the structural integrity of the building, to decorate features internally and externally or as a cladding material to an inner concrete, timber or steel frame.

<u>Stone.</u>

In the South of England , it is an expensive material to build with due to the limited availability of materials and transportation costs. In the North of England it is used in preference to clay bricks, mostly as an outer skin of a cavity wall construction.

<u>Blocks.</u>

Any brick that is larger than the general size is defined as a block. The standard size for blocks is 440mm long by 215mm high with a depth of 100mm. These can be the

[29] Personal communication, Christopher Goodier, Concrete Centre, BRE

same material as brick or made from concrete. They are used in their own right as outer walling and rendered or, in the case of the recycled aggregate thermalite, as an inner skin to a brick and block cavity wall construction.

Paving.

Paving is generally made from concrete. Stone is still used but is a more expensive alternative and therefore rarely used in modern housing estates. There has been a recent trend in the use of block paviers for car parks, petrol forecourts and undercrofts.

Slates.

Traditionally slates were used predominantly in the West country and Midlands as a roofing material on a low pitched roof. Later periods saw slates in more widely spread areas, concrete tiles were more popular and cheaper in most areas.

Tiles.

Traditionally those houses that were not thatched were tiled with clay tiles. These became almost the only roofing material for many decades in most of the country. The advent of speed building and the invention of concrete made a huge difference. Now concrete tiles are predominantly used in new build.

In Britain the most popular building method is concrete foundations and floor, concrete block inner skin with a cavity wall and brick and cement mortar outer skin. There is no official standard that controls the quality of reused or recycled bricks and generally suppliers of these materials work under the unofficial standard 'one good face, one good end'. Reputable firms that supply recycled bricks can attain ISO accreditation under ISO9002 if they set up a Quality Management System of their own to class the bricks for example, premier quality, average quality and below quality. This type of system allows clients to know what to expect and gives potential for customer satisfaction.

Foam glass properties, applications and potential markets

Given the information in this chapter, it is possible to indicate the potential markets for foam glass products in UK. This is not limited to the following tables but it is likely that any foam glass process will naturally choose markets that are easy to penetrate, do not require too much technological development, have been established in other countries and are available in large volumes. Table 18 shows a list of foam glass products currently being manufactured in Europe and USA as identified by Glass Technology Services in this report. Table 19 shows the market size of traditional UK concrete /clay products and the foam glass potential in UK in terms of 1% and 5% penetration of these traditional markets. It also includes low and high values for traditional materials, these figures were extracted from the Franklin & Andrews 2003 UK Building Costs Blackbook. Unfortunately, it is difficult to translate tonnages into overall product costs as similar products are often different sizes and densities. Hence the need to include low and high values.

It is of interest that a 1% penetration of traditional markets would result in the production of 2,360,000 tonnes of foam glass products. A 1% penetration of bricks and blocks alone is worth more than 800,000 tonnes of product. By 2006 in UK, there could potentially be an annual supply of 500,000 tonnes of post consumer container glass, 120,000 tonnes of flat glass from the domestic replacement window sector and 266,000 tonnes of flat glass from the demolition sector[30]. Foam glass production also has the potential to use contaminated (masonry, ceramics, gravel) glass and a wide range of unwanted waste glasses such as mercury lamps, laminated glass and cathode ray tubes (CRT) from televisions and computer monitors. The use of contaminated waste glass could impact on the quality of the recycled product unless the contaminant is locked-up within a product e.g. the coated foam glass prill being produced by Geofil Ltd. and discussed later in this report. However, it is important to recognise that foam glass is only one of the markets that will be sourcing waste glass and will need to compete with alternative glass recycling markets, not least re-melt.

Neither of the two Tables 18 and 19 take into consideration the import and export markets discussed in previous pages of this report. It is therefore safe to predict that the UK construction products markets, whether for home use, imports or exports, is in a healthy position and is ripe for investing into a foam glass process. This will make better use of our waste glass resources, especially those that are of high-quality and currently not being utilised, as well as create jobs, reduce environmental impact and provide opportunity for product development.

Current Foam Glass Products in Europe & USA	
Product Group	Various Applications
Blocks, Concrete, Mortars & Insulation	Precast concrete panels Concrete floors, roofs and walls Foundation units & piles Kerbs & flags Block paving Concrete bricks Piping and valve insulation Storage vessel wall insulation Chilled water systems insulation Floors & roof insulation Ground insulation Underground piping insulation.
Loose aggregates	Ground stabilisation on soft ground Floors & roofs insulation Backfill insulation Ground insulation Foundation piles Water drainage applications.

Table 18 – Foam glass products currently being produced in various European countries and USA

[30] BRE, 2003 Waste Flat Glass from the Demolition and Replacement Window Industries, WRAP

Traditional Concrete /Clay Products in UK		Value of Traditional Products *			Foam Glass Potential in UK	
Applications	Market size (tonnes)	Measure	Low value	High value	Foam Glass 1% penetration (tonnes)	Foam Glass 5% penetration (tonnes)
Aerated concrete blocks (pfa)	638,000	m2	£8.97	£25.57	6,380	31,900
Ready mixed concrete	53,089,000	m3	£62.40	£101.50	530,890	2,654,450
Worked stone	451,000	m2	£595.58	£1,076.92	4,510	22,550
Concrete bricks	5,691,000	m2	£31.32	£60.00	56,910	284,550
Clay blocks	32,000	m2	£8.97	£60.00	320	1,600
Non-aerated blocks (fba)	956,000	m2	£11.22	£24.47	9,560	47,800
Building blocks & bricks	15,808,000	m2	£8.97	£60.00	158,080	790,400
Pre-fabricated components	7,307,000	m3	£9.00	£60.00	73,070	365,350
Clay building blocks	5,690,000	m2	£8.97	£60.00	56,900	284,500
Ceramic sanitary fixtures	57,000	each	£94.60	£323.40	570	2,850
Ceramic sinks	46,300	each	£74.55	£92.63	463	2,315
Ceramic tiles & flagstones	4,244,000	m2	£27.32	£49.59	42,440	212,200
Bricks & ceramics (pfa)	10,000	m2	£27.32	£49.59	100	500
Non-aerated blocks (pfa)	54,000	m2	£11.22	£24.47	540	2,700
Concrete pipes	1,187,000	m2	£31.32	£60.00	11,870	59,350
Tiles & flagstones	9,353,000	m2	£12.05	£44.43	93,530	467,650
Clay tiles	163,000	m2	£23.79	£39.87	1,630	8,150
Chimney pots	34,000	each	£23.65	£58.50	340	1,700
Clay roofing tiles	163,391	m2	£36.15	£78.80	1,634	8,170
Stone kerbstones	92,265	m2	£50.06	£88.57	923	4,613
Worked slate	118,532	m2	£53.01	£63.50	1,185	5,927
Glass fibre insulation	204,465	m2	£3.67	£5.43	2,045	10,223
TOTAL	**105,388,953**				**1,053,890**	**5,269,448**
Traditional Aggregate Products in UK		**Value of Traditional Products**			**Foam Glass Potential in UK**	
Railway ballast	2,500,000	m3	£11.00	£29.30	25,000	125,000
General fill (stone)	49,000,000	m3	£11.00	£29.30	490,000	2,450,000
Roadstone (coated & uncoated)	35,400,000	m3	£11.00	£29.30	354,000	1,770,000
Asphalt (gravel & stone)	27,005,000	m3	£11.00	£29.30	270,050	1,350,250
General fill (fba)	44,000	m3	£11.00	£29.30	440	2,200
Concrete aggregates	16,500,000	m3	£11.00	£29.30	165,000	825,000
General fill (pfa)	143,000	m3	£11.00	£29.30	1,430	7,150
Structural fill (pfa)	197,000	m3	£11.00	£29.30	1,970	9,850
Lightweight aggregates (pfa)	145,000	m3	£11.00	£29.30	1,450	7,250
Lightweight aggregates (fba)	120,000	m3	£11.00	£29.30	1,200	6,000
TOTAL	**131,054,000**				**1,310,540**	**6,552,700**

* Source Franklin & Andrews 2003 UK Building Costs Blackbook

Table 19 – Volumes and values of traditional concrete, clay and aggregate markets in the UK and the foam glass potential at 1% and 5% penetration of existing markets.[31] [32]

(pfa = pulverised fuel ash; fba = foundry bottom ash)

[31] Viridis and CIRIA, Mass Balance of the Construction Industry, 2002

[32] http://www.dti.gov.uk/construction/main.htm

Current Foam Glass Manufacturing

Overview

This section of the report reviews the current manufacturers and methods of production for foam glass in Europe and USA. Due to commercial confidentiality many of the companies approached were not willing to provide detailed information about their process. Therefore, it was not possible to give a direct comparison of the different foaming techniques and a commercial assessment. There are a number of institutions and universities that have or are undertaking pilot scale investigations into foam glass production. However, due to the lack of information or the willingness of the respondents to release information these were not investigated or reported.

Selection of companies producing foam glass products

The following section includes a selection of companies that are producing foam glass products using a range of processes.

Pittsburgh Corning, UK

Pittsburgh Corning has been manufacturing foam glass for a number of years and has a well-established market in the USA and continental Europe. Their foam glass product is known as FOAMGLAS® and is manufactured in Europe at Tessenderlo, Belgium, Schmiedefeld, Germany and Klasterec nad Ohri, Czech Republic, as well as the USA. At present there is no manufacturing facility in the UK.

Due to commercial confidentially no information on the production process was given by Pittsburgh Corning (UK) Limited. They did confirm that they are currently utilising 66% of post consumer waste glass in their products. However, they would not disclose their glass quality requirement for post consumer waste glass for use in foam glass production. The product technical data sheets reported the composition as an alumino-silicate, which implies that there must be an additional material that modifies the foam glass composition to take account of the waste glass composition.

They produce a range of products from pipe lagging to insulation blocks, with blocks measuring up to 600 x 1200 mm and thickness between 40 & 160 mm. All the products produced by Pittsburgh Corning are pre-shaped. Their foam glass is used in numerous applications, including above ground and underground piping, vessels, structures, and tank foundations. With the advantage that under the most severe moisture conditions, foam glass insulation does not absorb water, lose insulating effectiveness, or deteriorate. It is also inert, non-combustible, lightweight, easy to cut, and strong and stable over a temperature range of -260°C to +485°C. Pittsburgh Corning also produces a wide range of board products such as wallboards and floorboards for building construction.

Cell-u-Foam, USA

Cell-U-Foam Corporation is a USA based company, a subsidiary of ACS Industries Inc., who manufacture pre-shaped foam glass insulation. They produce under licence from Pittsburgh Corning, therefore, their range of products and product specifications are very similar. They have tried to manufacture foam glass insulation from processed waste glass (the source was not disclosed) but found that the consistency of the glass was not suitable for their process. The product literature states that the foam glass composition is 100% with no binder but it has not been possible to substantiate this further. Cell-u-Foam commented that in the US their only competition is Pittsburgh Corning and in the US market there is over capacity for this very specialised product.

Due to strict confidentially this company was unwilling to discuss any of their process technology. Therefore, it is not possible to report on the process used and the associated costs. Cell-u-foam produce a product known as 'Ultra-CUF', which is the brand name for their foam glass product. They produce a range of products from pipe lagging to block insulation, with blocks measuring up to 450 x 600 mm and thickness between 38 & 165 mm (Figure 5). Again similar to Pittsburgh Corning products, all the Cell-U-Foam products are pre-shaped. Ultra-CUF is used in a broad range of insulation applications, including:

- Piping and vessels for chemicals and refining
- Storage tank walls and bases
- Chilled water systems
- Roofing
- Commercial and industrial buildings
- Underground piping.

Figure 5 - Cell-u-Foam foam glass products

Misapor AG, Switzerland

Misapor AG based in Switzerland was founded in 1986 marketing a foam glass product for the construction industry. As part of this research, Misapor allowed a site visit to their new product facility (Figure 6) in Dagmersellen, Switzerland. Their established plant at Surava processes 10,000 tonnes per annum of waste glass. Misapor has embarked on an extensive expansion plan.

Misapor are planning to commission new foam glass manufacturing plants before 2006 to meet demand driven by new German building regulations that stipulate high insulation properties for new buildings. It is believed that similar to Part L and Part J building regulations in UK, there will be an increasing demand for foam glass or similar insulating materials throughout Europe.

Figure 6 - Misapor new foam glass production plant in Dagmersellen, Switzerland.

The process developed by Misapor allows the use of mixed container and waste flat glass of a low quality to be used in the process. Also, contaminants such as borosilicate glass, CRT glass, ceramics etc. can be tolerated. Misapor has developed their foam glass plants next to existing glass processors, they take the glass that is not suitable for remelt back into containers. As the glass they use has no commercial value, they receive it free of charge since the glass processor is not permitted to landfill glass in Switzerland.

Figure 7 shows the foam glass exiting the furnace, it is then broken up to the required particle size and used for various applications such as floor insulation (Figure 8). Figure 9 shows the course grade of loose aggregate and the foam glass pore structure respectively.

Misapor were willing to provide information on the capital and operating cost for a foam glass manufacturing plant in the UK. This costing was used as the basis for the life cycle costing of using foam glass as a substitute material for traditional aggregate. Misapor manufactures loose foam aggregate with a particle size ranging from 50-75 mm down to 5-10 mm. The larger particle sizes are used in:

- Ground insulation
- Ground stabilisation
- Foundation piles

- Roof insulation
- Sport grounds
- Swimming pool ground insulation
- Ice rink insulation.


Figures 7 and 8 - Foam glass exiting the furnace and being used for a loose aggregate floor insulation

A unique advantage of foam glass aggregate is its lightweight nature. Misapor report that it is so lightweight that helicopter transport to remote locations is viable. Another example would be the use of the material for ground stabilisation of a remote track or pathway. Misapor have also developed a drainage system[33], whereby, filling water permeable textile bags with foam glass makes a water drainage conduit system. This replaces traditional drainage methods that may use perforated piping which can be prone to blockage in high-silt areas near to melt streams or flood plains.

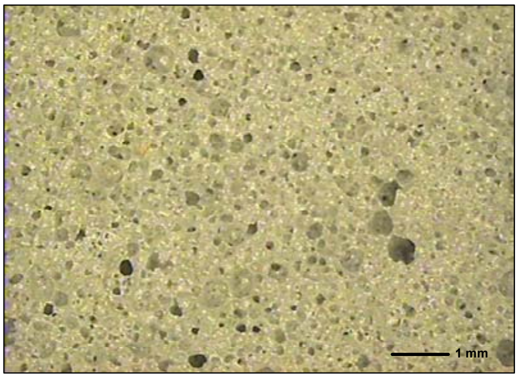


Figure 9 - Misapor's large loose aggregate foam glass and pore structure.

Lightweight structural concrete

In addition to providing a loose fill foam glass aggregate, Misapor has developed a structural lightweight concrete product[34,35] known as 'Alwac'. It uses graded foam glass (particle size between 5-10 mm) to totally replace the natural aggregate in concrete. Figure 10 show the two grades of foam glass gravel that is currently being used by Misapor in lightweight insulating concrete.

[33] D. Basura & D. Engi, Infiltration drainage fitting or filtration drainage conduit, International Patent WO 01/07720 A1, February 2001.
[34] D. Basura & D. Engi, Lightweight Concrete, International Patent WO 00/63132, October 2000.
[35] D. Basura & D. Engi, Castable composition for paving slabs etc, European Patent 1,044,938, October 2000.

The concrete has been tested by various institutions in Switzerland with no observed alkaline-silica reaction (ASR). It is believed that the firing during the foaming stage depletes the glass surface of alkalines and reduces it susceptibility to ASR. Misapor has had the product tested to SIA162/1, a Swiss construction standard for concrete products undertaken by 'Institut für Materialprüfung'. The lightweight concrete has been certified as a suitable material for structural construction purposes. This lightweight structural concrete has distinct advantages over traditional concrete, namely:

- Thermally insulating
- Lightweightness allows longer spans, more design opportunities
- Easier manual handing, use small lifting devices rather than cranes for assembling structures from precast concrete
- Shorter construction time
- Overall reduction of labour and plant costs
- Lower transportation cost.

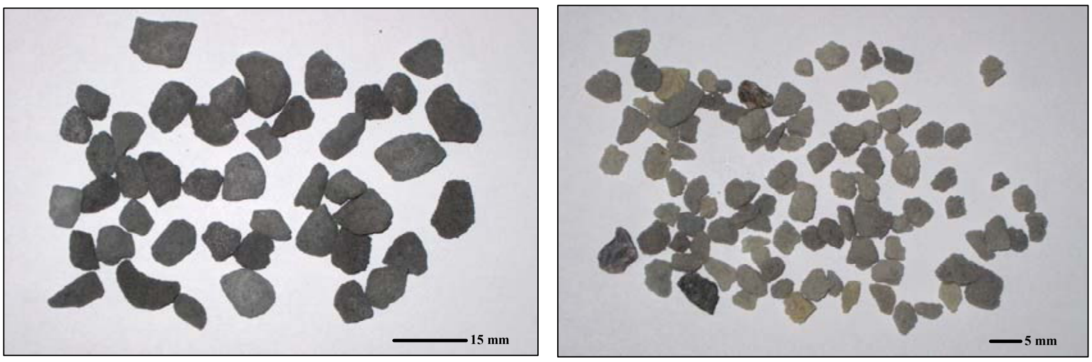


Figure 10 - Medium and Small sized loose aggregate foam glass.

Misapor commercially manufacture lightweight structural concrete for domestic and commercial building in and around Switzerland. During a visit to Misapor, a building designed by the Swiss Architect Jacques Herzog (the architect for the Tate Modern), using lightweight structural concrete was seen. This architect is using Misapor lightweight concrete to enable him to undertaken more adventurous designs such as larger unsupported floors and larger unsupported overhangs to meet the Swiss building specifications.

Construction built to Swiss building specifications will typically require a minimum thickness of 45 cm of cast concrete with 10 cm of insulation material to meet the specification. This typical construction has 'thermal bridges' across the insulation. Using Misapor lightweight concrete, architects can construct a concrete building with 30 cm walls without the need for additional insulation. Figure 11 shows a building constructed using Misapor lightweight concrete.

Figure 11 - A concrete building built using Misapor lightweight concrete.

Geofil, Hungary

Geofil have been manufacturing a range of pellets (Geofil-bubbles) from various types of glass wastes including significant quantities of contaminants such as labels and bottle tops. The large scale pilot plant shown in Figure 12, is where Geofil have been conducting multiple tests on the variability in size and nature of the pellet and have to-date completed more than 80 types of pellet for a number of applications. The results of the laboratory and mode of failure tests on some of the products have demonstrated compressive strengths up to 58 N/mm^2.

Figure 12 – The Geofil pilot plant in Tatabanya, Hungary.

Geofil have successfully produced a number of trial products (test products not commercial production) using the above pilot plant and a source of industrial waste glass containing organic and inorganic contaminants. These products include blocks, panels, tiles, renders and concrete (Figure 13). The products are constructed using the Geofil-bubbles, a blowing agent, a melting point reducer and viscosity modifying agents to form a lightweight artificial gravel with a diameter of 2-25 mm.

Figure 13 – Various trial products developed by Geofil using Geofil-bubbles.

Hasopor AG, Norway

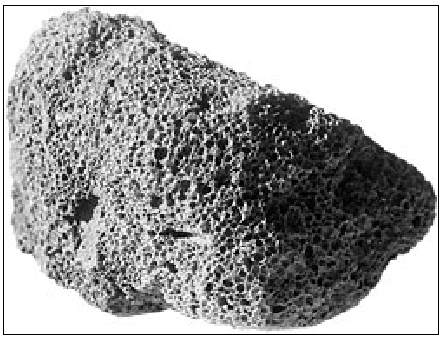
Misapor has licensed technology to Hasopor AG (part of the Hasgroup) who have foam glass manufacturing plants in Norway and Germany producing 40,000m^3 per annum and 80,000m^3 per annum respectively. Hasopor are currently reviewing the market for a second foam glass plant in southern Norway planned for construction in 2004. Hasopor produce a similar product of similar properties to Misapor. The Hasgroup core business is recycling technology for a number of different waste streams. Hasopor can use vitrified waste from their waste vitrification plant and incorporate it into foam glass. Hasopor is able to recycle 99% of OSRAM ‘end-of-life’ products by incorporating them into foam glass.

Millcell AG, Switzerland

Millcell is a company based in Switzerland that manufactures foam glass of a similar type to that of Misapor, a loose foam glass replacement aggregate with a range of particle sizes depending on the application. Millcell manufacture between 40,000 m^3 and 60,000 m^3 per annum of foam glass, using waste glass predominantly from container glass waste. There is limited technical information available in the public domain[36,37] on the process and technology used. Due to commercial confidentially Millcell were not willing to provide detailed information on their process. However, information that was available indicated that the feedstock is passed through a furnace on a moving belt as shown in Figure 3, and than broken up to the require

[36] O. Vieli, Foamed glass granules, US Patent 4,332,908, June 1982.
[37] O. Vieli, Granulated foamed glass and process for production thereof, US Patent 4,332,907, June 1982.

size after exiting the furnace. Figure 14 shows Millcell continuous foam glass production, they produce a blanket of foam glass. This is then broken up to be used as lightweight loose aggregate or in lightweight concrete applications[38]. Figure 15 shows a typical Millcell foam glass particle prior to further crushing and sizing.

Figures 14 and 15 - Millcell foam glass continuous production and loose aggregate particle [38]

Liaver, Germany

Liaver, part of the Liapor Group, have been manufacturing expanded clay granules since the late 1960's for the construction industry. They also produce expanded glass granules. They utilise waste container glass, mix it with a binder to form pellets (granules) and then sinter in a rotary furnace between 750 and 900°C, to produce porous granular grains with a closed surface structure. The glass granule product has under gone numerous tests at the University of Hanover and Weimar University of Architecture and Buildings, as follows:

- Alkali stability and alkaline-silica reactivity
- Use in lightweight mortar DIN 4226-2
- Heat conductivity of granules and mortar to DIN 52612

The Liaver product has a number of applications for example:

- Mortar for brickwork
- Construction and repair of flat roof
- Floors
- Plasterboard
- Precast concrete panels.

Liaver glass granules are used to produce insulating board products. The glass granules are coated with a sintering agent and then sintered to produce a board resulting in each individual granule being fused by a narrow neck to the adjacent granule. The board can be used in the following applications:

- Noise control – noise absorbent panels (REAPOR®)[39]
- Thermal protection – additional insulation
- Fire protection – fire protection panels
- High temperature insulation – lining of hot gas chimneys
- Construction of vehicles – crash absorber

[38] O. Vieli, Foamed glass granules for lightweight concrete, European Patent 10,069 A, June 1982.
[39] H. Gödeke & H. Fuchs, REAPOR – Sintered open-pore glass foam as a high strength sound absorber, Glasstech. Ber. Glass Sci. Technol., 71, No 9, pp 282 to 284, 1998.

- Biomedical technology (unlikely to use waste glass – absorbable implants.

All of the above applications replace traditional fibre products with the advantage of additional strength both compressive and flexural.

Overall properties of foam glass

Glass Technology services also completed a detailed market survey of various companies across Europe and the USA that are manufacturing foam glass products. Similarly, those companies that had patents on products or who had undertaken trials on the processing of foam glass products. This has identified a number of properties associated with foam glass products which commonly include:

Lightweight, longer spans	Inert
Rigid	Rodent and insect resistant
High strength	Bacteria resistant
Thermally insulating	Easy to handle
Sound insulating	Quicker construction time
Frost resistance	Low transport cost
Non-flammable	Easier to cut and drill
Flame resistant	Low water absorption
Non toxic	Easy to combine with concrete

Comparable results

Table 20 has consolidated as much of the comparable data available. This chapter has focused mostly on Misapor because they were the only company prepared to release significant amounts of data. Table 20 reflects this quite well. Similar to Liaver, Geofil-bubbles is a comparable product because it uses a rotary furnace rather than a horizontal continuous furnace used by Millcell and Misapor. They each have their limitations and benefits in the production of foam glass either as a flat slab or as a prill, ball or bubble.

Table 20 - Product properties of a selection of products from various foam glass manufacturers. Due to vast array of products offered by the individual manufacturers, only a limited selection is shown to indicate the range of properties of foam glass. This Table is neither comprehensive nor complete.

Properties	Pittsburgh Corning	Pittsburgh Corning	Cell-u-Foam	Misapor	Millcell	Liaver	Liaver	Geofil-bubbles
	Wallboard Block[40]	Foamglas F Block[40]	Ultra-CUF 1031 Block[41]	Loose aggregate 10 to 50mm[42]	Loose aggregate[43]	Glass Granules 2 to 4mm[44]	Reapor sound insulation[44]	Glass Granules 2 to 25mm[45]
Compressive strength	0.4 N/mm^2	1.6 N/mm^2	0.7 N/mm^2	6 N/mm^2			0.7 to 0.9 N/mm^2	0.3 to 58 N/mm^2
Flexural strength	0.3 N/mm^2	1.0 N/mm^2	0.55 N/mm^2					2.8 – 9.1 N/mm^2
Flexural modulus of elasticity	600 N/mm^2	1500 N/mm^2						
Co-efficient of thermal expansion	9.0 x 10^{-6}/K	9.0 x 10^{-6}/K	8.6 x 10^{-6}/K					
Thermal conductivity	0.039W/m.K @ 10°C	0.048W/m.K @ 10°C	0.045W/m.K @ 10°C	0.080W/m.K	0.080W/m.K		0.078W/m.K	

40 Pittsburgh Corning UK Ltd, Technical data sheet.
41 Cell-u-foam Co, Technical data sheet, http://www.cuf.com/dwnload/datasheets.pdf
42 Misapor Ltd, Specification Booklet
43 Millcell AG, Technical data sheet, http://www.millcell.ch/devis/devis.html
44 Liaver GmbH, http://www.liapor.com/einfo_liapor.htm
45 Geofil-bubbles Kft, Technical information via a personal communication

Properties	Pittsburgh Corning	Pittsburgh Corning	Cell-u-Foam	Misapor	Millcell	Liaver	Liaver	Geofil-bubbles
	Wallboard Block[40]	Foamglas F Block[40]	Ultra-CUF 1031 Block[41]	Loose aggregate 10 to 50mm[42]	Loose aggregate[43]	Glass Granules 2 to 4mm[44]	Reapor sound insulation[44]	Glass Granules 2 to 25mm[45]
Specific heat	0.84 kJ/kg.K	0.84 kJ/kg.K	0.83 kJ/kg.K					
Thermal diffusivity	4.4 x $10^{-7}m^2/s$ @ 0°C	3.5 x $10^{-7}m^2/s$ @ 0°C	4.9 x $10^{-7}m^2/s$ @ 0°C					
Product density	105 kg/m^3	165 kg/m^3	128 kg/m^3	225 kg/m^3	100 to 300 kg/m^3	290 kg/m^3	300 to 500 kg/m^3	450 to 1850 kg/m^3
Bulk density						190 kg/m^3		250 to 1100 kg/m^3
Porosity				$10^6/cm^3$		85 – 86 %		14 – 50 v%
Water absorption	0	0	0			50 – 60 m%		0,1 – 55 m%
Hygroscopicity	0	0	0	0				
Permeability	0	0	0	0				
Capillarity	0	0	0					
Surface water adhesion				70 l/m^3				
Fire	Non combustible	Non combustible	Non combustible	V1 (DIN A1)				Non combustible
Toxic fumes	None	None	None	None				None

Properties	Pittsburgh Corning	Pittsburgh Corning	Cell-u-Foam	Misapor	Millcell	Liaver	Liaver	Geofil-bubbles
	Wallboard Block[40]	Foamglas F Block[40]	Ultra-CUF 1031 Block[41]	Loose aggregate 10 to 50mm[42]	Loose aggregate[43]	Glass Granules 2 to 4mm[44]	Reapor sound insulation[44]	Glass Granules 2 to 25mm[45]
Dimensional stability	Perfect	Perfect	Perfect					Perfect
Sound transmission loss @ normal frequency	28 dB/100 mm	28 dB/100 mm	28 dB/100 mm				>0.6 (DIN 52215)	42 dB/120 mm
Tipping angle				45°				

Table 20 - Product properties of a selection of products from various foam glass manufacturers. Due to vast array of products offered by the individual manufacturers, only a limited selection is shown to indicate the range of properties of foam glass. This Table is neither comprehensive nor complete.

Investment Appraisal of the Foam Glass Processes

Overview

This chapter presents the results of an investment appraisal of the foam glass process costs, including investment costs to purchase land and machinery, as well as the on-going maintenance, operation and production costs. The study has investigated various scenarios, allowing for small, medium and large scale production and assumed three different incomes from the sale of the product.

Introduction

It is intended that this chapter will provide a clear analysis of the economics of undertaking foam glass production in the UK, and selling the products in the domestic market. It details the procedure undertaken to perform the analysis, reports the findings in tabular and graphical format and ends with some concluding remarks on the analysis. The analysis takes into account:

- Investment costs, including initial capital, capital replacement
- Operating costs
- Sensitivity analysis (one at a time sensitivity and a probabilistic Monte Carlo Simulation)
- Analysis of economies of scale achieved by increasing the size of the plant (Savings to Investment)
- Investigation of different scenarios varying the price earned of the foam glass and size and capacity of the production plant.

Development of the financial model

Setting the study period

The study period is the time over which the analysis is considered. It has to be sufficiently long to ensure that a correct assessment of the long-run economic performance can be made. The study period chosen for this assessment is 25 years, which is considered a long enough time scale for the investor to assess the long term economic benefits that may be achieved.

Identified scenarios

The same study period has been used for all scenarios. The analysis has assumed that the Base Case scenario (the expected cost and estimated service lives) is for the production of 45,000/m^3 of foam glass product (10,000 tonnes of waste glass) per annum. Two other scenarios are also considered:

1. Production of 112,000/m^3 foam glass output (25,000 tonnes waste glass)
2. Production of 225,000/m^3 foam glass output (50,000 tonnes waste glass)

These scenarios have different investment and operational costs associated with size of plant and production output. Cost assumptions are detailed in the main body of this report.

Cost items considered

Using information and data provided by Glass Technology Services (GTS), or obtained by BRE (and agreed by GTS), a financial model was developed to calculate the investment costs to set up a factory, and the operational and maintenance costs to allow the production of foam glass in the UK. The model adopts the HM Treasury methodology and accepted accountancy rules for predicting the present value of future income streams, and the approach also supports the new ISO 15686 part 1 - service life planning. The investment costs considered in the analysis consisted of:

- Purchase of property
- Construction of building
- Glass preparation machinery
- Glass powder preparation machinery
- Volume blowing furnaces
- Transportation engineering
- Electro-technology
- Engineering work
- Assembly and shipment
- Evaluation + 1 year exclusively negotiation option
- Various (tools, EDP, furniture, vehicles)

The initial capital purchased for this production will have an Estimated Service Life (ESL) or the estimated time after installation during which a building or its parts meets or exceeds the performance requirements. If the service life of an element is less than the study period, a replacement of this item is necessary. The model will assume planned replacements of component parts when the life expectancy is less than the study period. The model assumes that the items in Table 21 will need replacing during the study period.

Replacement of Major Capital Items	**Estimated Service Life (ESL)**
Glass preparation	5
Glass powder preparation	5
Volume blowing furnaces (3 lines)	10
Transporting engineering	10
Various (e.g. tools, furniture, vehicles)	10

Table 21 – Estimated service life in years of mayor capital items

The operating costs considered in the analysis consisted of:

Materials	**Maintenance**
Cullet consumption and price	Decorations
Packaging Recovery Note (PRN)	Fabric
Foam agent consumption and price	Services
Electricity	Plant Maintenance
Water	
	Staff
Occupancy	Plant manager
Cleaning	Shift workers
Utilities	
Administrative Costs	**License**
	License & support

Plant income / revenue

The price of foam glass production generally has a range from £30/ to £60/m^3 for loose fill aggregate and £200/m^3 for a finished product (insulated floor panel)[46]. The financial analysis has been performed for the Base Case for all three of these scenarios and the results reported in the main body of this report.

It is assumed that the expected benefit from this production would be the sale of finished, or part finished building components which will have a market value. The market value has been assumed to be the selling price of the next best substitute product (the opportunity cost). We have researched the prices of these substitutes to test whether the expected benefits assumed in this model are reasonable assumptions.

Financial criteria

The analysis requires that year on year cash flows are discounted to reflect the time value of money. A discount rate of 10% has been applied in the Base Case, using the following formula (Equation 1):

$$X/\ (1+r)^n$$

When

X= input value

r = rate of interest or discount rate

n = number of years

Equation 1 - Discount equation to allow for the time value of money (Treasury 1997)

The year on year cash flows (periodic money streams that are expected to continue in the future) are discounted to account for the fact that these monies will be worth less in the future than they are today. When the monies are discounted they are expressed as present values. In order to compute present values, it is necessary to discount future costs (and benefits). Discounting reflects inflation. As a result of

[46] Personal communication, Katherine Adams, BRE

discounting, benefits and costs are worth more if they are experienced sooner. The higher the discount rate, the lower the present value of future cash flows. More information is available on this in the Green Book (Treasury 1997), Appraisal and Evaluation in Central Government, HM Treasury.

Sensitivity analysis

Sensitivity analysis accounts for variable costs, fluctuations in prices and price /cost volatility. For this project sensitivity analysis has been carried out to assess which of the uncertain input values would have the greatest impact on the appraisal if they were to vary in price from the expected value. A *one at a time* sensitivity analysis involves changing one of the input values about which there is uncertainty. This was carried out for each input parameter by changing one input value with an assumed pessimistic and then an optimistic value and repeating the analysis. The advantage of performing such an analysis is that it allows the decision maker to assess which of the input parameter has the greatest impact on the evaluation and what the results would be if one of the parameters took on a different value. A variety of *one at a time* sensitivity analyses have been carried out. Changing one cost variant and analysing the response to this change when other inputs are kept constant can reveal those cost assumptions that would significantly alter the Base Case model.

Variation in cost of input parameters

Price variability of components may have a significant impact on the assessment study. Sensitivity analyses have been carried out to assess which parameters have the greatest impact on the whole life cost (WLC) study and what the WLC would be if one of the input parameters took on a different value.

Variation in ESL of major capital replacements

Sensitivity analyses to investigate the significance to the investment appraisal if the replacement components were to be replaced more frequently or less frequently than the Base Case.

Financial calculations

For each scenario a series of simple, discounted and supplementary financial calculations have been made (Figure 16). In this analysis the Savings to Investment Ratio (SIR) considers what the potential savings would be from an additional investment which increased the production capacity of the plant from 45 000/m^3 p.a. to 112 000/m^3 p.a. and 225 000/m^3 p.a.

Investment Appraisal - UK Foam Glass Production

Financial calulations for a handling capacity of 10 000 tons/ p.a.

Heading	Description	Formula
Simple financial calculations		
Cumulative project costs	Sum of initial costs plus operational costs. Costs are totalled for all years	Sum of all costs detailed in the Initial and Operational Cost Assessment worksheets (Ic + Oc1 + Oc2 … + Ocn)
New costs	Sum of initial costs plus operational costs - Existing costs. Costs are totalled for all years	Sum of all costs detailed in the Initial and Operational Cost Assessment worksheets - Existing costs
Financial benefit	Sum of increased revenue and decreased costs from the Benefits workbook	
Cumulative project benefits	Total expected benefits accumulated	Sum Eb (Expected benefit) (Eb1 + Eb2 … + Ebn)
Cumulative net cost	The cumulative costs minus the cumulative benefit for each year	(Ic + Sum Oc) - (Eb1 + Eb2 … + Ebn)
Discounted cash flow analysis		
Discounting	Year on year cash flows (periodic money streams that are expected to continue in the future) are discounted to account for the fact that these monies will be worth less in the future than they are today	X/ (1+r)n When X= input value r = rate of interest or discount rate n = number of years
Discounted cumulative project costs	Sum of initial costs plus operational costs discounted annually at a chosen discount rate	Sum of all costs detailed in the Initial and Operational Cost Assessment worksheets discounted
Discounted new costs	Sum of initial costs plus operational costs - Existing costs. Costs are totalled for all years and discounted annually at the chosen discount rate	Sum of all costs detailed in the Initial and Operational Cost Assessment worksheets - Existing costs discounted
Discounted cumulative project benefits	Sum of increased revenue and decreased costs from the Benefits workbook discounted	
Discounted cumulative net cost (NPV)	The cumulative costs minus the cumulative benefit for each year discounted	(Ic + Sum Oc) - (Ib + Sum Ob)/ (1+r)^n
Supplementary economic measures		
Savings to Investment ratio (SIR)	ratio of cost savings to additional investment costs	Net benefits/New costs
Internal rate of Return (IRR)	The discount rate at which the present value of the future cash flows of an investment equal the cost of the investment.	It is found by adjusting the discount rate to find which rate return a NPV of 0

Figure 16 – Investment Appraisal for UK foam glass production of 45,000 m^3 of product

Base Case Scenario

The Base Case chosen for this study is for the manufacture of 45,000/m^3 of foam glass products per annum including 10,000 tonnes of waste glass. The Base Case has assumed that the expected benefit (value of product) from the factory would be £60/m^3 of foam glass equating to £2.7 million per year.

From this table one can see the present value of the costs, benefits and NPV for each year in the 25 year study. The analysis has assumed a 10% discount rate. It can be seen that the NPV over the 25 year study has been forecasted to be £5.6 million (average £0.22 million per annum). This information is shown in Figure 17 below.

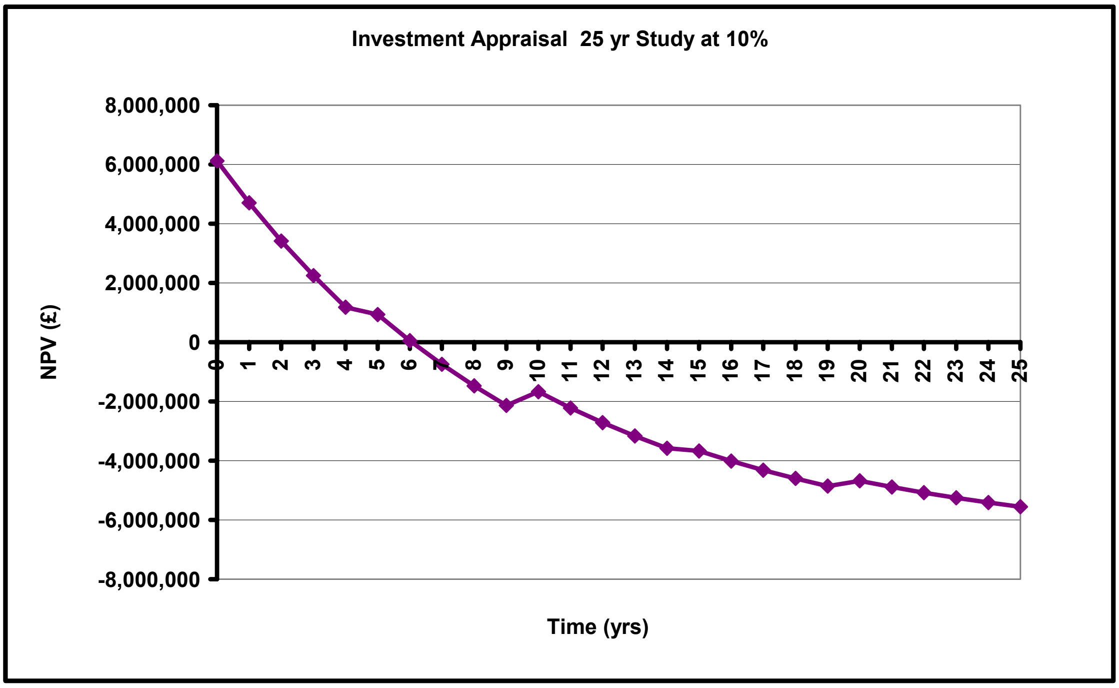


Figure 17 — Base Case Cumulative NPV (discounted 10%) over 25 yrs

From Figure 17 we can see that the discounted payback period (the length of time needed to recoup the capital investment) is about 6 years.

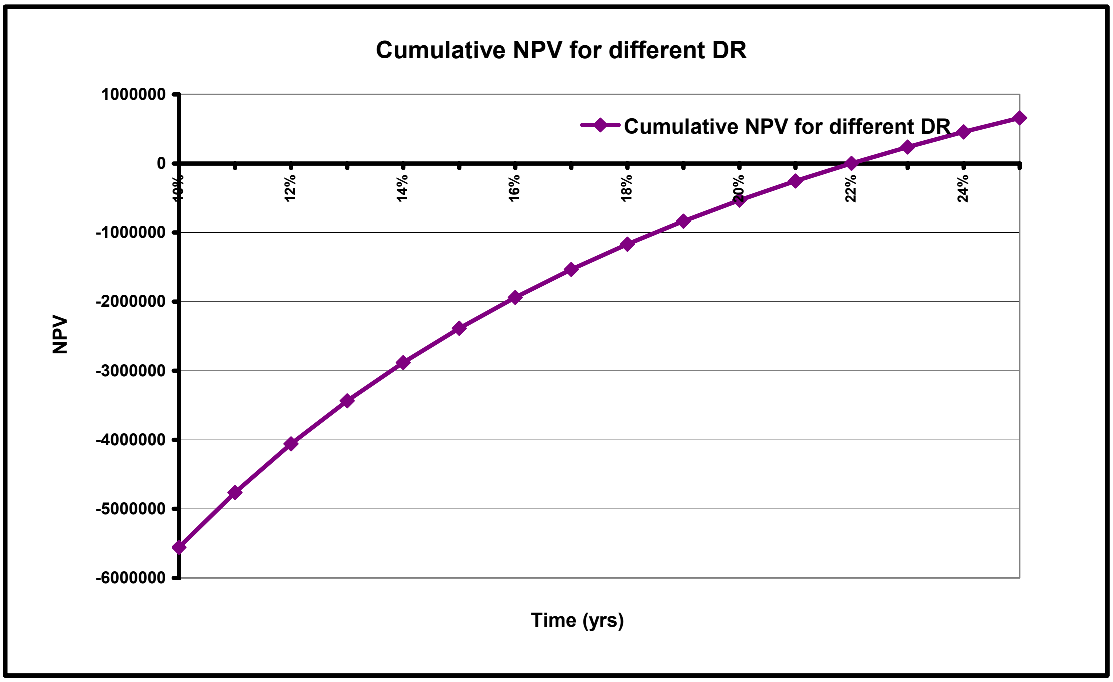


Figure 18 — Base Case Internal Rate of Return over 25 years

The internal rate of return (the discount rate at which the present value of the future cash flows of the investment is equal to the cost of the investment, and therefore has an NPV of zero) is around 22% (Figure 18).

The sensitivity analysis investigates the significant assumptions placed on the model. This analysis is intended to identify the critical input values made in the model The process undertaken to perform this analysis was to increase and decrease the value of each input parameter by a fixed amount, or percentage, and re-compute the NPV. It is presented below in tornado diagrams for ease of interpretation. The input variables that have the greatest effect on the NPV forecast can be identified by the width of the tornado bar.

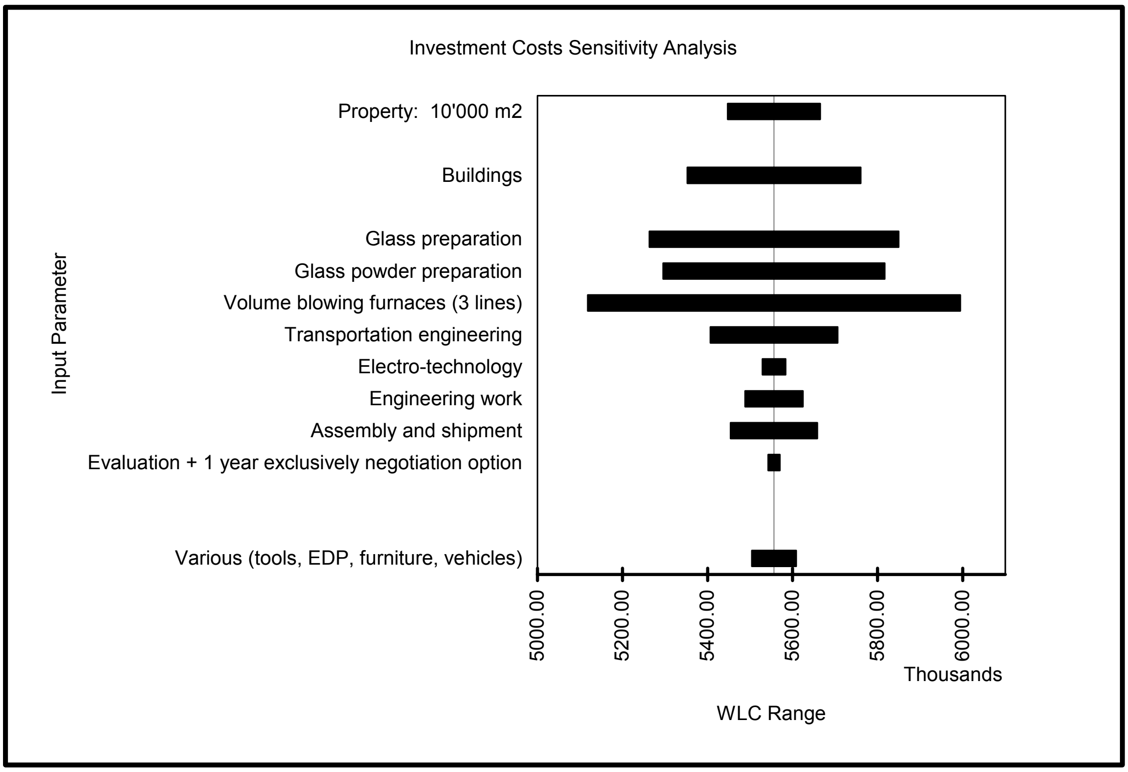


Figure 19 — Base Case Sensitivity Analysis Investment Costs

From the Tornado diagram (Figure 19), we can see that the significant cost assumption is the cost of the volume blowing furnaces. When this cost was varied by plus or minus 20%, the NPV forecast changed to £5.1 million and £6.0 million respectively. It is possible to see the significant cost items given the range of bars in the graph above.

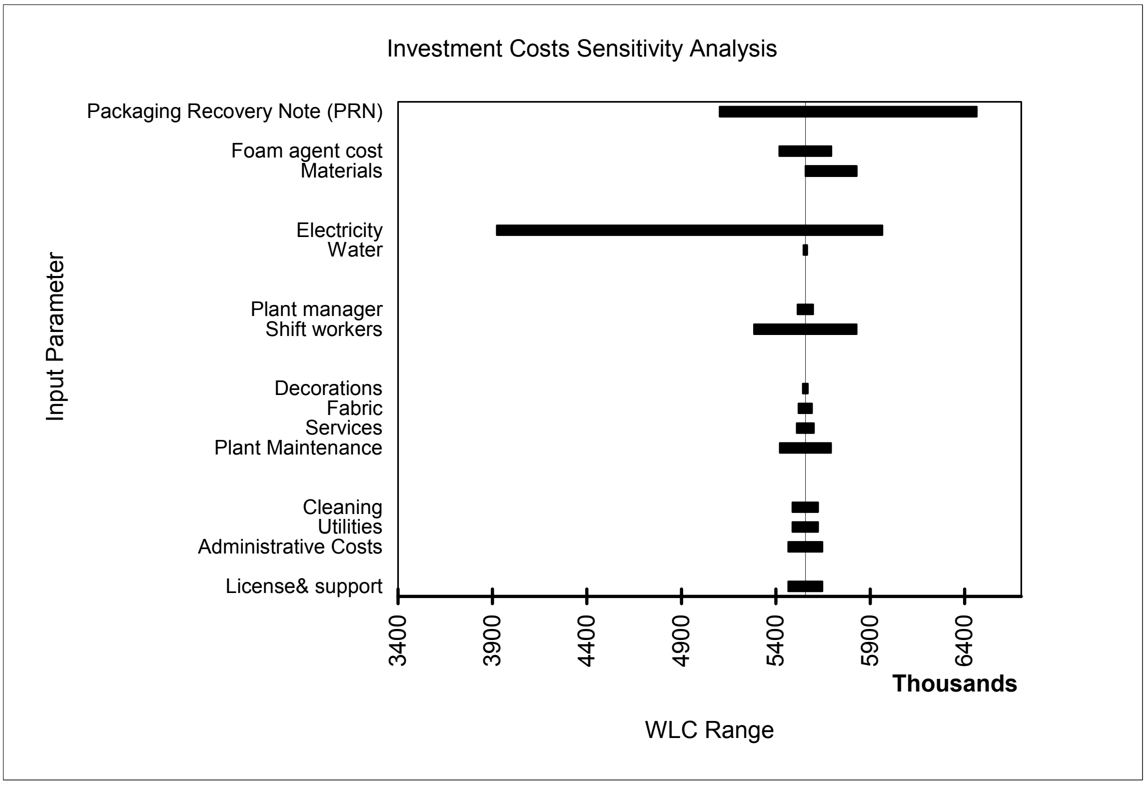


Figure 20 — Base Case Sensitivity Analysis Operational Costs

For the operational costs the most significant item is the cost of electricity (Figure 20). If electricity costs as much as 9p per Kw/h, it reduces the NPV to about £3.9 million. If the Packaging Recovery Note (PRN) received is £25 per tonne the NPV forecast improves to approximately £6.5 million.

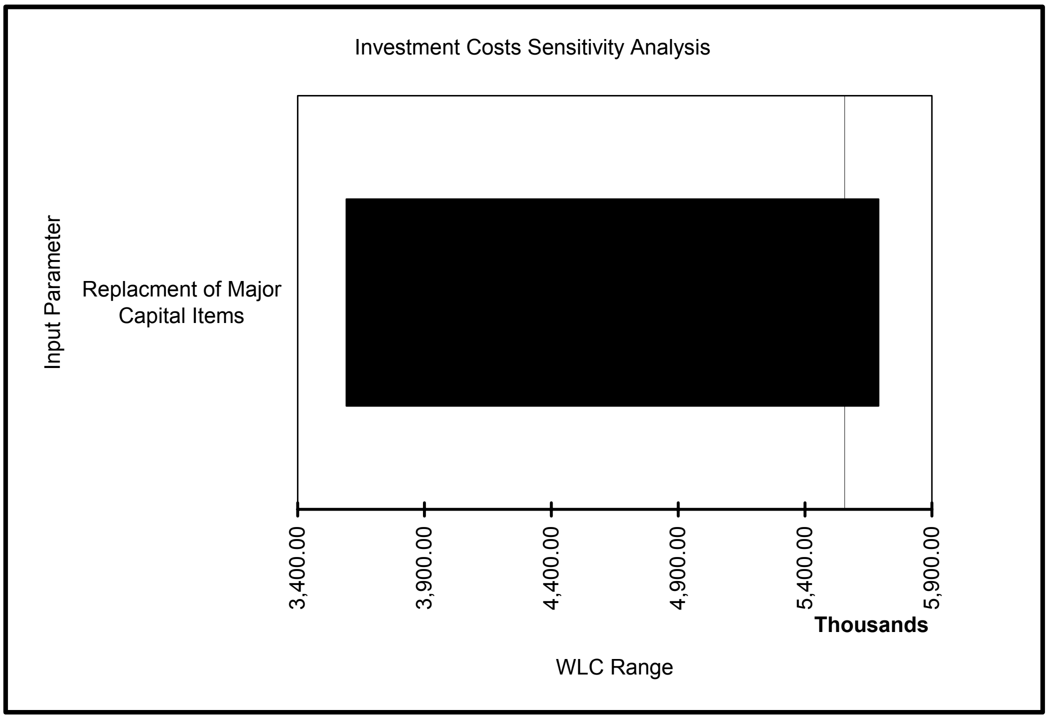


Figure 21 — Base Case Sensitivity Analysis Variance in replacement frequency

The Tornado diagram in Figure 24 examines what the NPV would be if, over the 25 year study period, the Estimated Service Lives took on the pessimistic and optimistic values. We can see from the Tornado diagram that they would be £3.6 million and £5.7 million respectively. It is important to note that this analysis has disregarded the financial consequence of any residual values - the realisable value of the assets after costs associated with the sale at the end of the study period. In this pessimistic example we find that most of the replacement components occurs in year 24 and can be assumed to have a relatively high residual value.

Sensitivity analysis on expected benefits

The model considers what the effect will be on the Investment Appraisal if the expected benefit was to take on a different value. We have identified an upper and lower extreme for the expected benefit at £30/m^3 and £200/m^3.

Base Case — expected benefit £30/m^3

This information has been shown graphically in Figure 22 below.

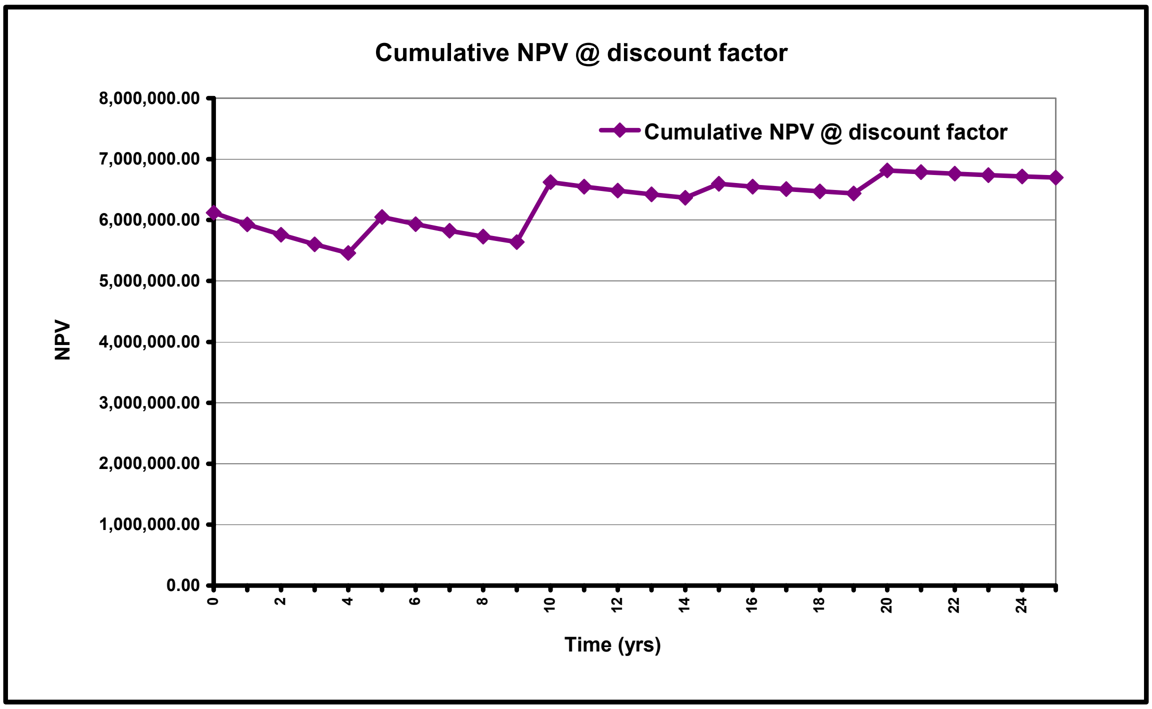


Figure 22 — Expected benefits £30/m^3 Cumulative NPV (discounted 10%) over 25 yrs

The Investment Appraisal above assumes the expected benefit to be £30/m^3 rather than the expected £60/m^3. The effect of this on the analysis is that the plant fails to payback over the 25 year study, not earning enough income to cover the initial investment required to set up the factory. Over the 25 year study the initial investment required was £6.1 million. The cumulative NPV is £7.0 million, implying that it would cost a further £0.9 million over 25 years to run the plant if the expected benefit was £30/m^3.

Base Case — expected benefit £200/m^3

The Base Case calculations have assumed the expected benefit to be £200/m^3 rather than the expected £60/m^3. This information has been shown graphically in Figures 23 and 24 below.

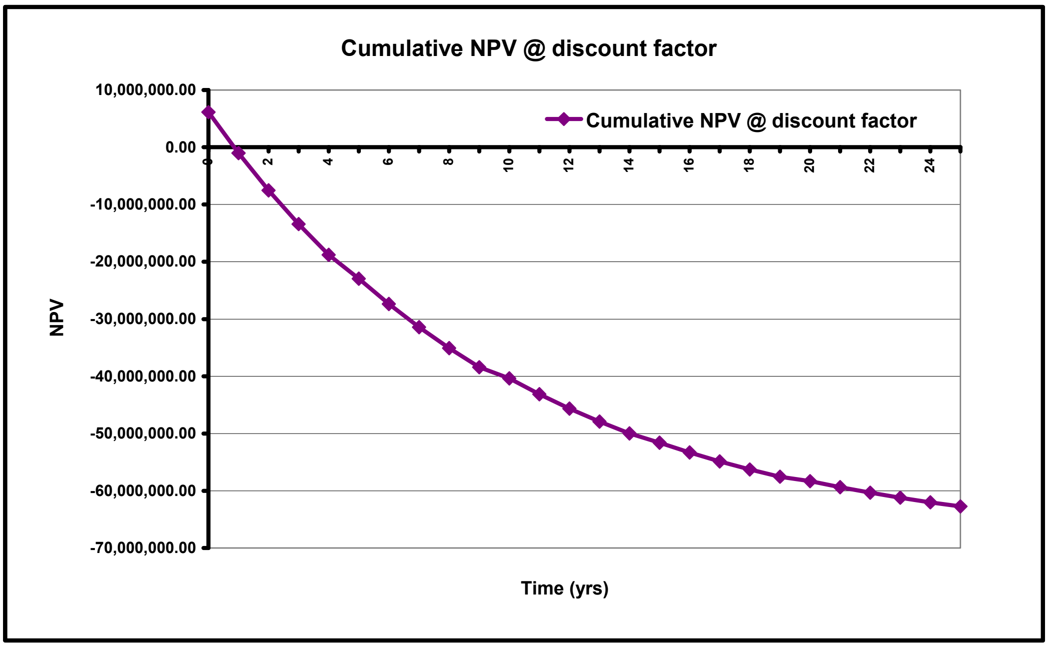


Figure 23 — Expected benefits £200/m^3 Cumulative NPV (discounted 10%) over 25 yrs

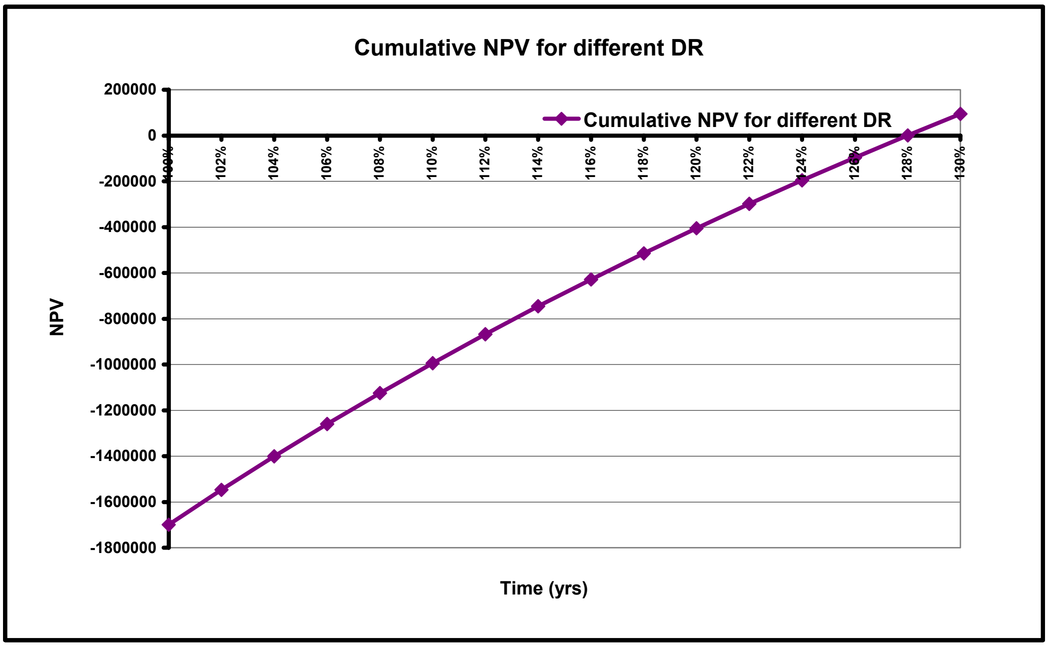


Figure 24 - Internal Rate of Return £200/m^3

The Figures above show that if the expected benefit was £200/m^3, the analysis will look more favourable. The payback period is approximately 1 year and has an Internal Rate of Return (IRR) of 128%.

Base Case - Monte Carlo simulation

The result of the Monte Carlo simulation are summarised in the cumulative distribution graph in Figure 25. The simulation suggests that, for this Base Case, there is a 50% chance of achieving a NPV of £5,708,041. The expected NPV forecasted in the Base Case model was £5,556,286. The simulation suggests that there is a 46% chance of achieving this value or less. From the simulation we can conclude that we can be 95% certain that the NPV will not be lower than £3.9 million and 95% certain it will not exceed £7.6 million. This can be seen in the cumulative distribution curve in Figure 26 below.

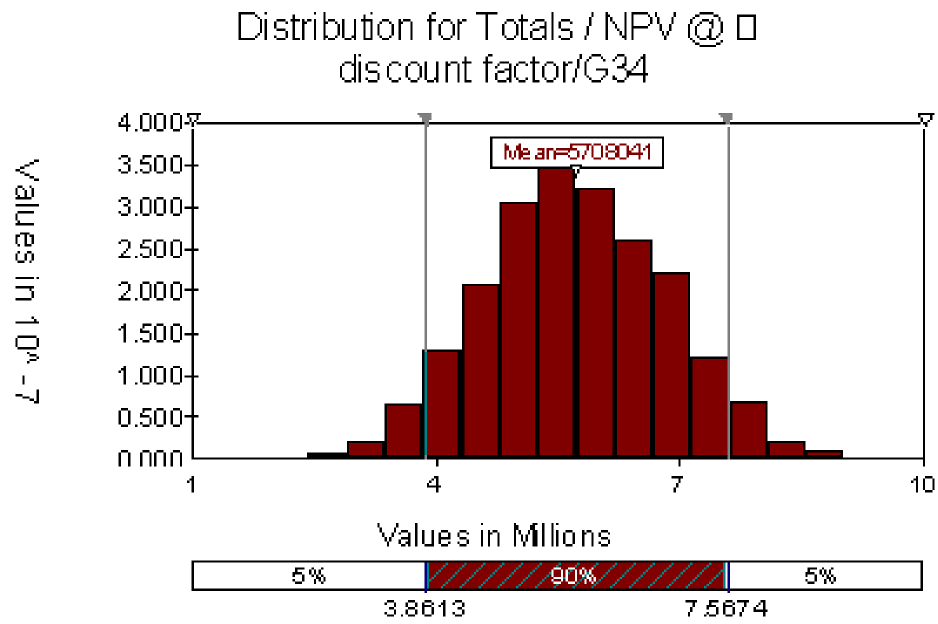


Figure 25 — Base Case summary statistics from Monte Carlo Simulation

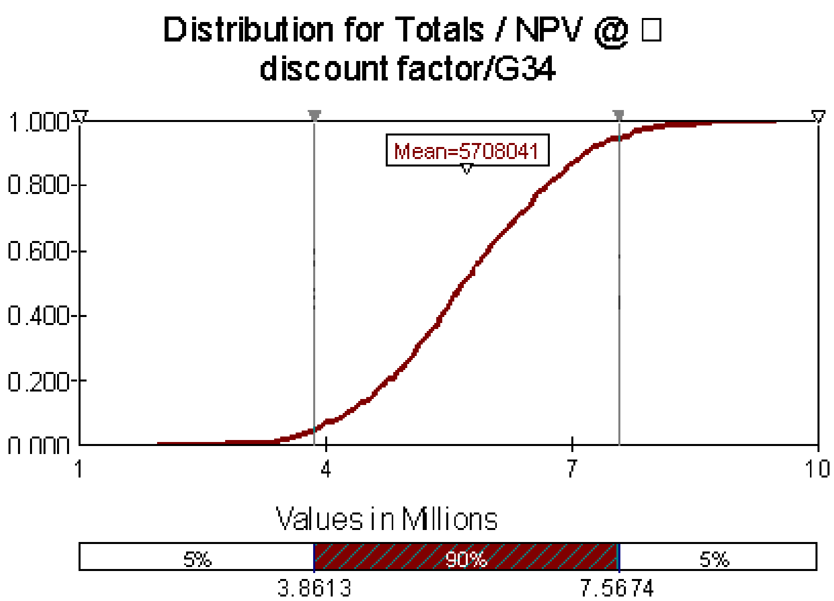


Figure 26 — Base Case Monte Carlo Simulation Cumulative Frequency graph

Production 112,000/m^3 of foam glass output per annum

The comparative manufacture of 112,000/m^3 of foam glass products per annum including 25,000 tonnes of waste glass was assessed. Figures 27 to 28 illustrate that the investment would payback in approximately 2 years, and has an IRR of approximately 53%.

Production 225,000/m^3 of foam glass output per annum

The comparative manufacture of 225,000/m^3 of foam glass products per annum including 50,000 tonnes of waste glass was assessed. Utilising the summary financial analysis for production of 225,000/m^3 of foam glass output per annum (supplied to the project confidentially), Figures 29 to 30 illustrate that the investment would payback in 1.5 years, and has an IRR of approximately 76%.

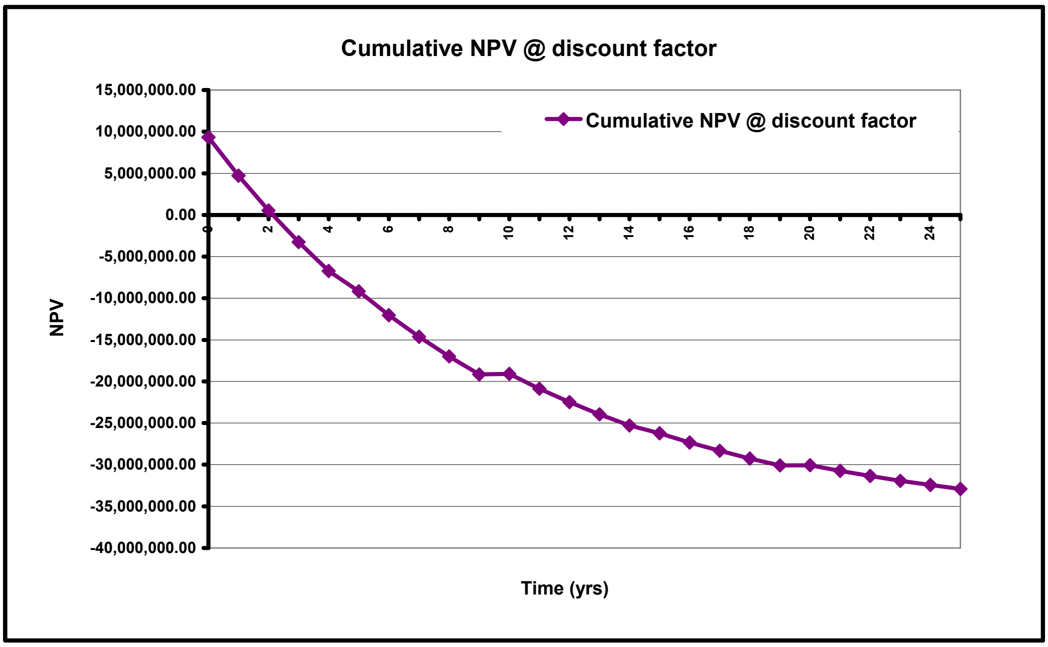


Figure 27 - Production 112,000/m^3 of foam glass output per annum
Cumulative NPV (discounted 10%) over 25 yrs

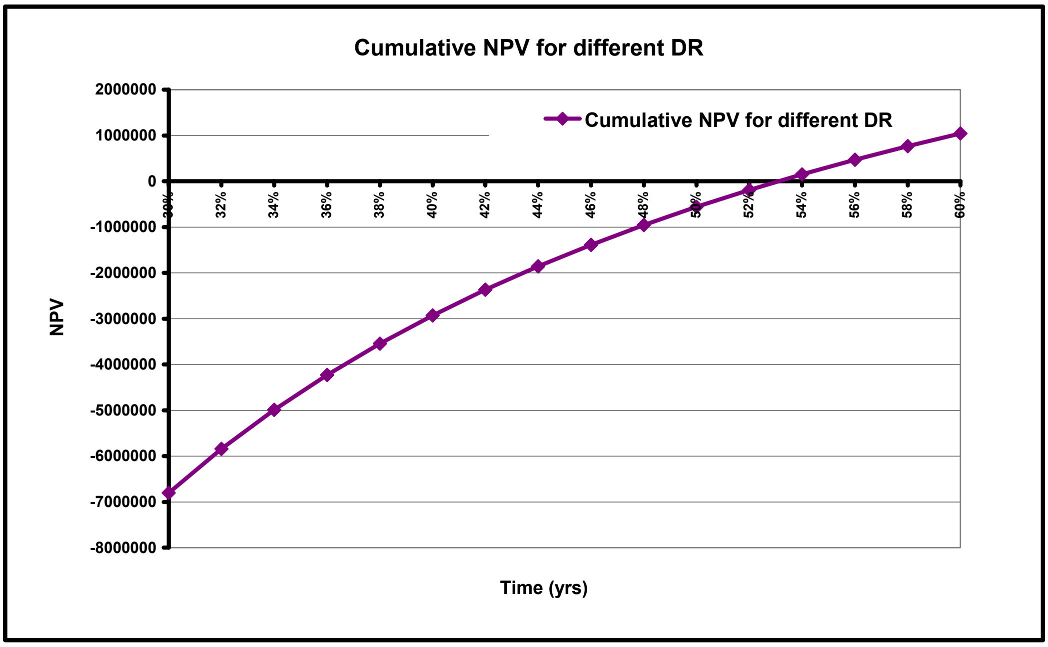


Figure 28 - Production 112,00/m^3 of foam glass output per annum
Internal Rate of return over 25 years

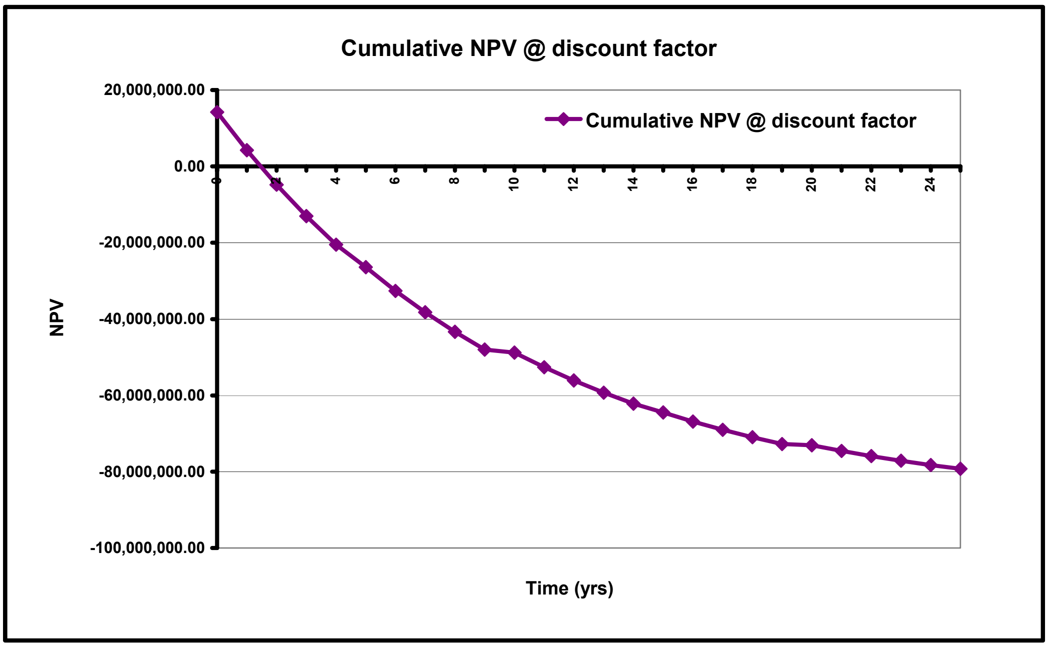


Figure 29 - Production 225,000/m^3 of foam glass output per annum
Cumulative NPV (discounted 10%) over 25 yrs

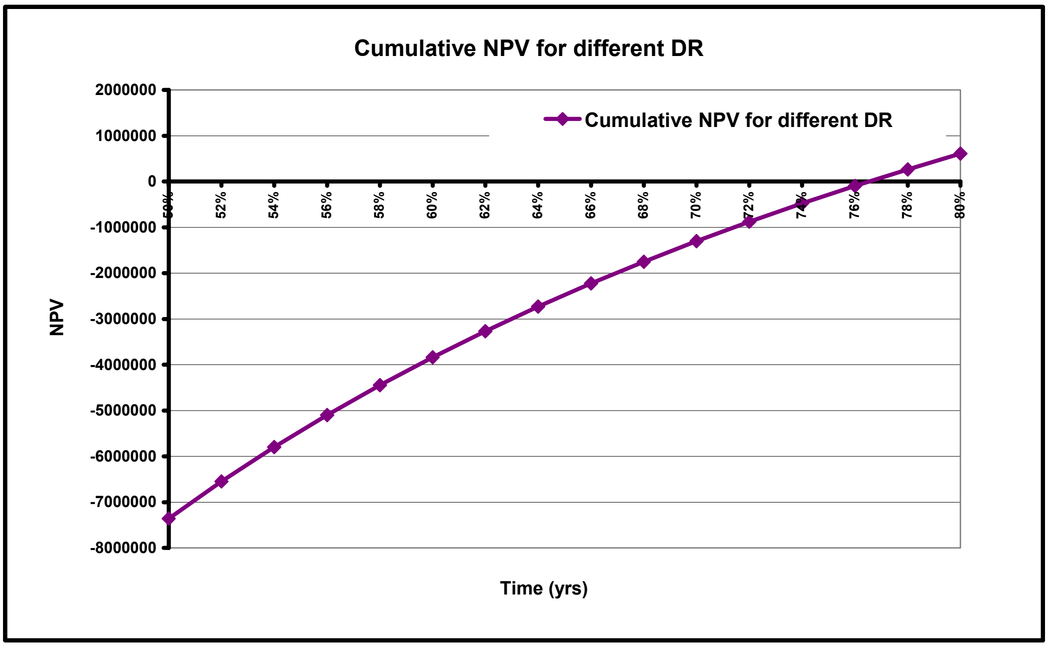


Figure 30 - Production 225,000/m^3 of foam glass output per annum
Internal Rate of Return over 25 years

Savings to investment analysis

In Appendix 14 there is a complete breakdown of the investment appraisal. The results of the investment appraisal for the production of 112,000 m^3 and 225,000 m^3 production plant can be compared as a savings to investment ration shown below.

Savings to Investment ratio (SIR)

Plant Output	**14 000**	**112 000**	**225 000**
Discounted cumulative project costs	18,951,721.50	27,305,276.64	41,663,846.52
Discounted cumulative project benefits	24,508,008.05	61,270,020.12	122,540,040.25
		14 000 : 112 000	**14 000 : 225 000**
Additional Cost		8,353,555.14	22,712,125.03
Additional Saving		36,762,012.07	98,032,032.20
SIR		**4.4**	**4.3**

The model has shown that for the 112,000 m^3 size plant an additional investment of £8.4 million would lead to an additional benefit of £36.8 million. The SIR for this additional investment is approximately 4:1.

The model has shown that for the 225,000 m^3 size plant an additional investment of £22.7 million would lead to an additional benefit of £98.0 million. The SIR for this additional investment is approximately 4:1. This means that for every additional unit of investment the savings earned from these economies of scale would be approximately four times greater.

Given the relatively high benefit of the additional investment for the larger sized plants, we have investigated what the effect would be on assuming the lower forecast for the expected benefit of £30/m^3. The analysis has been carried out only for the 225,000 m^3 capacity plant given the similarity in the SIR for both cases

From the SIR results above, one can see the present value of the costs, benefits and NPV for each year in the 25 year study. The analysis has assumed a 10% discount rate. It can be seen that the NPV over the 25 year study has been forecasted to be £19.6 million. This information has been shown graphically in Figures 31 and 32. From these graphs we can see that the discounted payback period is about 4 years with an internal rate of return (IRR) of around 30%.

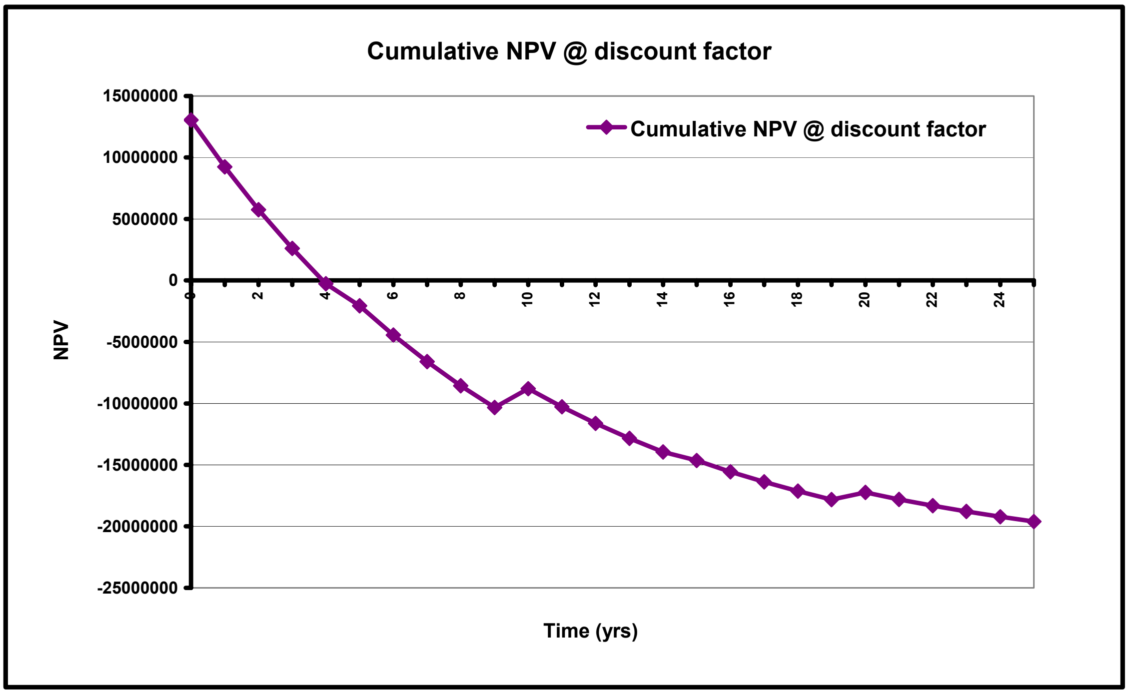


Figure 31 - Production 225,000/m^3 of foam glass output per annum, £30/m^3
Investment Appraisal Cumulative NPV over 25 years

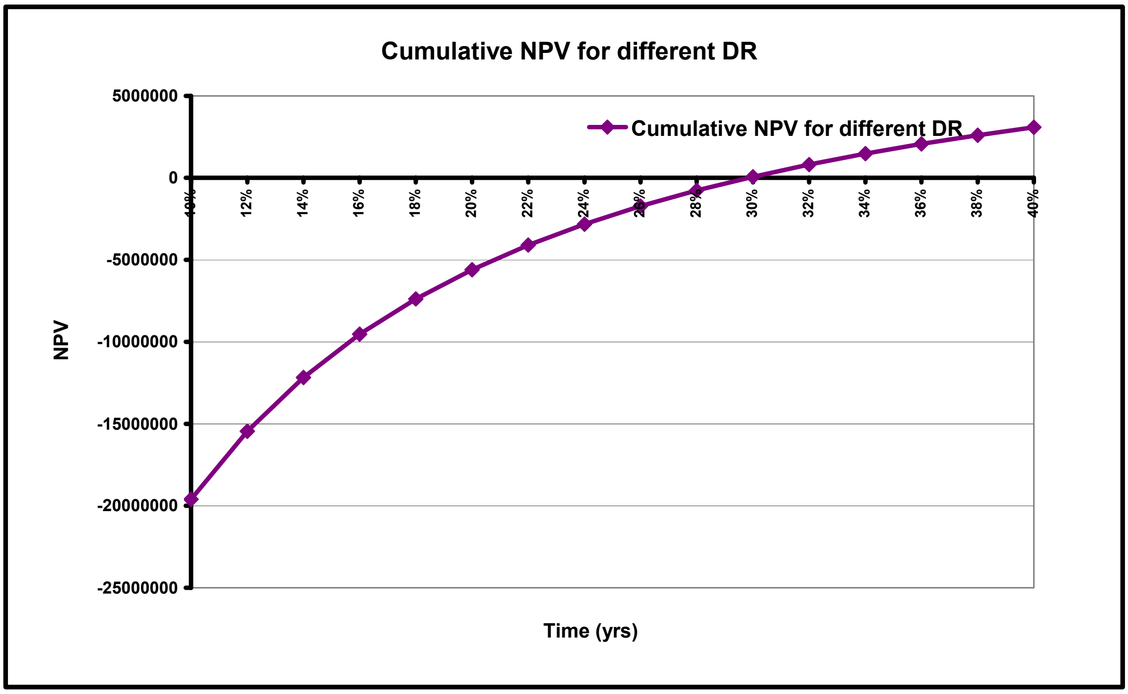


Figure 32 - Production 225,000/m^3 of foam glass output per annum, £30/m^3
Investment Appraisal IRR over 25 years

Best Practicable Environmental Option for Foam Glass

Overview

This chapter identifies the Best Practicable Environmental Option (BPEO) for glass waste utilised in a foam glass production process compared to traditional recycling for glass, use in aggregates and also disposal. The BPEO is a concept often used by the Government and local authorities to aid decision making in the management of various types of waste. The BPEO can be defined as an outcome of a decision making process, which established for a given set of objectives, the option that provides the most benefits or the least damage to the environment, at an acceptable cost. The concept of the BPEO means that local environment, social and economic preferences will be important in any decision for the management of waste glass. The BPEO may be different for the same type of waste originating in differing locations. This chapter outlines the various stages undertaken in the determining the BPEO, including a baseline assessment which examines key legislation, sources, types and quantities of waste glass and the economics for reprocessing waste glass. The scoping exercise undertakes a detailed analysis of the various management routes for waste glass at present, assigning a value in terms of low, medium or high significance. Legal constrints may rule out some options, whilst technical and economic constraints make others less acceptable. The BPEO assessment concentrates on 4 scenarios for the use of waste glass and these are then ranked using a number of criteria. For each scenario, the environmental impacts, including transport are identified in broad terms. Finally, the BPEO is defined for the use of waste glass, at certain tonnages for the production of foam glass.

The BPEO model

The BPEO model has been developed for identifying options for certain types of construction waste, including glass, under a DTI project[47]. The model analyses criteria for legislation, technical, economic, social and environmental considerations in terms of the management route for waste streams. It does not analyse the potential benefits of products and therefore an element of Life Cycle Assessment for products, known as Eco-profiling is presented in the following chapter.

For the BPEO model to be fully effective, a certain amount of data is required and assumptions have to be made. The model follows a number of stages as outlined in Figure 33. The model allows a comparison of using glass waste in foam glass production in the UK with other uses and disposal for glass waste. It also gives a comparison of using 3 sizes of a foam glass production plant, with the input of waste glass vary accordingly. This creates a number of scenarios which are then ranked using a predetermined set of criteria, producing a crude environmental score. Key data requirements are:

- Sources of waste glass, including transportation options
- Inputs in terms of energy, resources, labour
- Outputs in terms of products and emissions
- Quality and end-use of the products

[47] Katherine Adams, Closing the resource loop, DTI project, unpublished 2001-2003

At each stage of the process the system boundary defines the scope of the study and the inputs and outputs at each stage are analysed in terms of the consumption of energy, water, raw materials and chemicals. Potential emissions to air, water and soil are analysed. The following sections discuss the stages of the model in relation to waste glass and its use in foam glass manufacture.

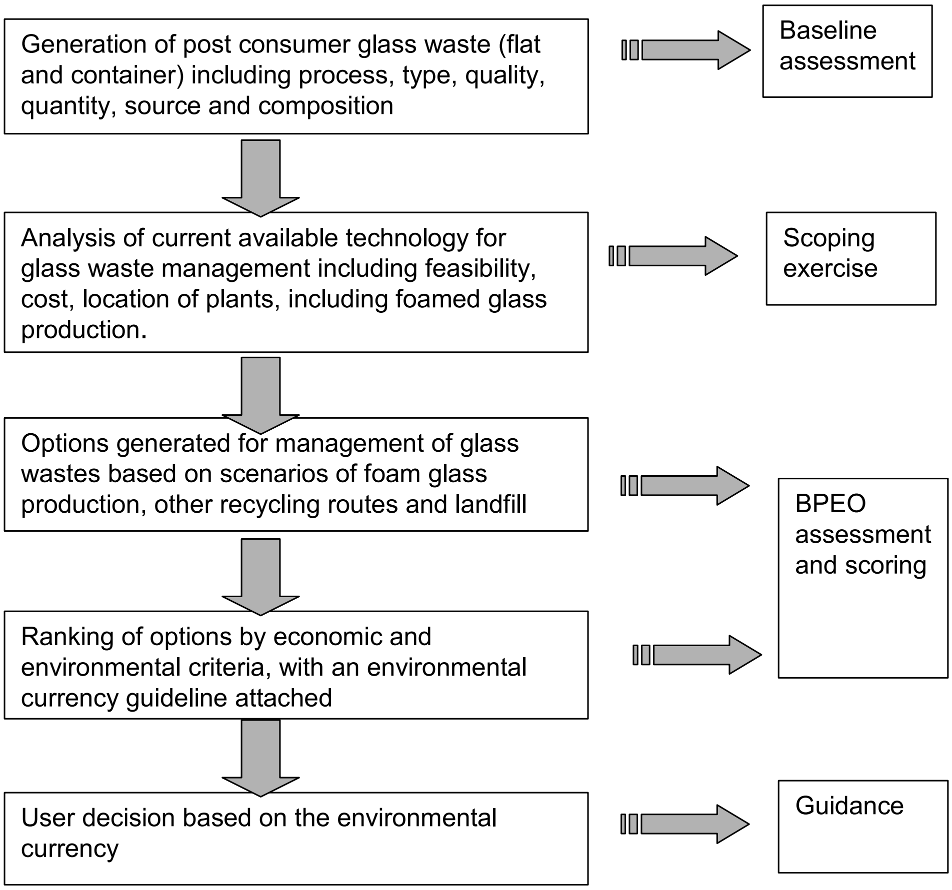


Figure 33 - The BPEO model for waste glass routes

BPEO Stage 1 - baseline assessment

The baseline assessment, analyses data available for current waste glass arisings in the UK and discusses the legislation and economic drivers for the management of it via foam glass production and other reprocessing methods. This ensures that the use of waste glass in a foam glass production is a viable option, which can then be analysed further. The baseline assessment includes:

- Legislation drivers for the waste glass management
- Type of waste glass including composition
- Quality of waste glass including contamination levels
- Quantity of waste glass
- Source of waste glass
- Economics of waste glass management

Legislation and regulation

Legislation

Legislation plays a key role in influencing the current and future management of glass waste. The source of waste glass, management and associated cost will be influenced by a number of regulations. Three, key pieces of legislation have been chosen here to demonstrate some of the drivers to increasing the recovery and recycling of glass wastes. The Packaging Regulations have targets for the recycling of glass containers and have a Packaging Recovery Note (PRN) value attached. Waste glass from waste electrical and electronic equipment (WEEE) and from end of life vehicles (ELV) will have recycling targets associated to them, making these waste streams more economically attractive.

Packaging

The packaging targets for 2002 set under the Packaging Regulations 1997, for obligated UK businesses are 59% recovery, with a 19% minimum for recycling of each packaging material, including glass. The targets have remained the same for 2003, with the Government focusing on setting up necessary collection systems to ensure that the UK can meet its awaited targets from the EU Directive. Priority attention has been given to the issue of achieving more recovery and recycling from the household waste stream. The decision to maintain the 2002 targets through to 2003 has had a negative effect on PRN's with prices dropping to £10 as of April 2003.

The UK failed in its obligation to recover 50% of material by June 2001. The UK recycled 42% of its packaging waste in 2001, with glass accounting for approximately 736,000 tonnes (16%) shown in Table 22[48]. Glass accounted for 10.81% of the UK's PRN's including Packaging Export Recovery Notes (PERN's) in 2001.

[48] http://www.letsrecycle.com/glass/index.jsp

	UK reprocessing [1]	Exported for reprocessing [2]	Reprocessing for which no PRN/PERN issued [3]	PRN & PERN carried forward to 2002 [4]	Tonnes accepted for recovering & recycling, UK (total of [1] and [2])
Paper	(a) 1,851,505	179,439	25,895	83,064	2,030,944
Glass	696,578	39,016	17,036	29,273	735,594
Aluminium	25,869	3,161	1	821	29,030
Steel	141,343	136,736	3,051	8,365	278,079
Plastics	203,149	66,813	6,077	10,506	269,962
Wood	573,951		4,985	23,742	573,951
Alternative Evidence	(b) 30,741				30,741
Total recycling	3,492,395				3,917,560
EfW (c)	(d) 513,939		913	24,986	513,939
Total	4,037,075	425,165	(e) 57,958	180,757	4,462,240

(a) paper total includes 659 tonnes composting
(b) alternative evidence produced as evidence of compliance
(c) Energy from Waste (EfW) broken down as follows: Clinical incineration 4,060; Municipal Soild Waste 479,169; Refuse Derived Fuel 12,958;
(d) EfW 17,752 - Total: 513,939 tonnes
(e) of which 5,000 tonnes is exported

Table 22 - Recovery and Recycling Undertaken in 2001 (tonnes)[49]

The European target the UK must reach is 60% recycling by 2006, with differentiated minimums for each packaging material - 60% for glass. However, the European Parliament is currently amending the Packaging Waste Directive, seeking to move the target date from 2006 to 2008 as some Member States may achieve the present 2006 target early. It is believed that a final European Parliament vote on the amended regulations will take place towards the end of June or early July 2003. Currently, the European Council of Ministers and the European Parliament do not agree on a set of amended targets. The two sides are proposing the following targets as shown by Table 23. The Government believes that increasing the recycling target to 75%, the UK would need a £1 billion investment in its infrastructure over five years in order to achieve full compliance.

[49] http://www.letsrecycle.com/glass/index.jsp

	European Parliament position	Council of Ministers position
Recovery	60 - 75%	60%
Recycling	65%	55 - 80%
Material specific Recycling:		
Glass	60%	60%
Paper/Board	55%	60%
Metals	50%	50%
Plastics	20%	22.50%
Wood	15%	15%
Target date	31-Dec-06	31-Dec-08

Table 23: Proposed Changes to the EU Directive on Packaging Waste[50]

Waste electrical and electronic equipment (WEEE)

Glass makes up around 6% by weight of WEEE[51] with a large proportion of this being cathode ray tubes (CRT). Two or three types of glass are used in a typical CRT. The glass at the back of the CRT has a high lead content, with up to 25% by weight being lead oxide[52]. The plate glass at the front is coated with phosphorescent luminophores as a fluorescent coating. The technology exists in the UK to recover CRT's, however, this is a relatively new development requiring a specialised plant. It requires the separation of the different types of glass, stripping off any coatings, and finding applications for the leaded glass. The compositional range of glass used by different manufacturers is a barrier to the use of a large amount of waste glass in new CRT's.

The WEEE Directive 2002/96/EC will require the collection and recovery of a minimum of 70-75% by an average weight of an appliance, with recycling between 50-65% by average weight depending on the appliance. This has yet to be transposed into UK law and it is currently unclear if a regulatory or a market instrumental approach will be utilised, but current levels of recycling of CRT's will have to improve dramatically. CRT's can be used as the waste glass feedstock for foam glass production.

End of life vehicles (ELV)

Glass represents approximately 2.9% of the material in a car (by weight), mostly in the form of flat glass[53]. The ELV Directive (2000/53/EC) aims to increase the rate of reuse and recovery to 85% by average weight per vehicle and year by 2006, and to 95% by 2015. This therefore will require increased recycling of non-metal parts of cars making glass a prime candidate. Glass in cars can be difficult to remove without

[50] http://www.letsrecycle.com/glass/index.jsp
[51] Industry Council for Electronic Equipment Recycling (ICER), UK Status Report on waste from electrical and electronic equipment, ICER London, 2000
[52] Industry Council for Electronic Equipment Recycling (ICER), UK Status Report on waste from electrical and electronic equipment, ICER London, 2000
[53] Automotive Consortium on Recycling and Disposal (ACORD), 1999. Automotive Consortium on Recycling and Disposal Second Annual Report Summer 1999 Reporting on 1998 Performance. Society of MotorManufacturers and Traders, London

breakage and the tint within windows can cause contamination. The use of ELV waste glass in foam glass production is appropriate.

Type and generation of glass waste

Sources of waste glass for current foam glass production in Europe have utilised cullet from glass packaging, due to the value associated with it under the EU Packaging Regulations. It is presumed though that flat glass waste arisings, with an estimated 90,000 tonnes from the window replacement sector growing to 160,000 tonnes by 2010[54] could be used for foam glass production, although no value in the form of Packaging Recovery Notes (PRN) are associated with this waste material, making container glass a more attractive proposition.

A recent report published by WRAP identified that the UK produces approximately 4 million tonnes/year of glass waste, with only 915,000 tonnes collected and recycled, therefore there is significant scope for increasing glass recycling[55]. Since 2000 the UK as a whole has increased recycling and recovery of glass by 20%. Although an inert substance, glass represents a lost opportunity for saving resources and landfill space. There are several types of glass produced in the UK and the wastes arising, collection and recycling rates are indicated in Table 24.

Type	**Waste Arisings (tonnes/year)**	**Collection (tonnes/year)**	**Recycling Rate (%)**
Container	2.3 – 2.5 million	715,000	30
Flat (motor vehicles, construction and demolition)	1.5 – 2 million	200,000	13
Fibre	50,000	0	0
Lighting	1,300	0	0
Cathode Ray Tubes	41,000	0	0
Other (e.g. domestic and catering tableware)	60,000	0	0
TOTAL	**4,061,000**	**915,000**	

Table 24: Glass Waste Arisings, Collection and Recycling Rates[56]

The composition of the type of waste glass will vary slightly depending on the source and application of the glass. For foam glass manufacture, container and flat glass have been used and tests have also been conducted on cathode ray tube waste and the composition of the glass did not cause any significant impact on the foam glass manufacturing process and the quality of the final product.[57][58]. Therefore it is assumed that the composition of the glass waste is not a barrier when sourcing cullet for foam glass production.

Quality of glass waste

The Geofil-bubbles foam glass process can accept glass contaminated with labels and tops as it is locked away within the bubble matrix and coated to prevent ASR or

[54] BRE, Waste Flat Glass from the Demolition and Replacement Window Industries, WRAP, 2003
[55] Enviros, Recycled Glass Market Study and Standards Review, WRAP, 2002
[56] Enviros, Recycled Glass Market Study and Standards Review, WRAP, 2002
[57] http://www.permonline.ru/~termoec/
[58] Personal communication and site visit, Geofil-bubbles pilot plant in Budapest, Hungary

leaching[59].The quality of glass waste required for foam glass production is low with a wide range of acceptable contaminants e.g. paper, bottle caps, stones. This places foam glass manufacture in an advantageous position when compared to traditional glass recycling whereby the glass is recycled back into containers, which cannot tolerate certain contaminants, including pottery, crystal glass and Pyrex cookware.

It is also necessary to remove ferrous and non-ferrous metals and other contaminants for container bottle recycling. To overcome this barrier, the glass reprocessors are investing in advanced sorting equipment and efficient collection systems. Increasingly more glass is being recycled into low value applications such as glasphalt and as aggregates, but which accept high volumes of cullet. These applications can accept low quality grades of glass that can be highly contaminated.

Post consumer flat glass waste is not fed back into the flat glass process as the specification for flat glass manufacture is very strict[60]. The chemical composition is extremely important, and therefore the composition of the recycled glass must match the composition of the material in the furnace. In order to ensure this, the flat glass manufacturers will use only waste glass scrap which arises from their own processing plants or possibly from glaziers using their product. It is presumed that if flat glass is used as a feedstock for the foam glass manufacture, then again a high level of contamination can be accepted, however, certain fittings and fixtures may have to be removed.

Quantity and source of glass waste

The scenarios being tested by the BPEO model will consider the utilisation of waste glass in foam glass production at:

- 10,000 tonnes per annum
- 25,000 tonnes per annum
- 50,000 tonnes per annum

Table 24, on the previous page indicates that for the types of glass waste arising, container and flat glass wastes are the most appropriate in tonnage to address the needs of foam glass production. However, effective collection systems will need to be put in place, (especially for flat glass waste) in order to obtain security of supply. For container glass, local authorities are increasing the collection of this waste through bring bottle banks and kerbside collection schemes. As there is a PRN value attached to container glass, various applications for using this waste will be competing for the material, if not enough of the glass waste is collected (currently nearly 30% is collected) to satisfy all markets.

A key aspect for the sourcing of the waste glass is the distance travelled from point of origin to the foam glass factory and the means of transportation. Ideally, waste glass should be sourced from the local and regional area to fulfil the proximity principle[61], and either transported directly to the factory or stockpiled in a central area, without the need for a glass reprocessor. The glass can either be crushed and ground at the foam glass factory or prior to the factory gates. This enables the foam glass plant to be located close to the source of the waste glass, compared to other waste

[59] Personal communication and site visit, Geofil-bubble pilot plant in Budapest, Hungary
[60] BRE, Waste Flat Glass from the Demolition and Replacement Window Industries, WRAP, 2003
[61] Proximity Principle – This states that a waste material should be reused, recycled or reprocessed as close as practicably possible to the point of generation.

management processes that require the glass to be reprocessed by glass reprocessors which are located predominately in the north of the UK. This will therefore limit the considerable distances, usually by road, that glass waste has to travel to be reprocessed and the associated environmental and economic impacts.

The foam glass process seems ideally suited to accepting glass loads which are too heavily contaminated for use in other applications. The foam glass process is also suitable for accepting post consumer flat glass waste and ELV waste glass which at present have limited end market applications and are not covered by already established collection and recycling systems.

Economics

The cost of cullet will affect the competitiveness of the foam glass production and products. The costs of waste glass vary depending on the type, source, quality, amount and location. The costs available can be divided into costs for cullet container glass and flat glass. Table 25 illustrates the prices for tonnages of waste container glass delivered to a reprocessor, who will then clean and sort the glass ready for use. The glass price shows the sum that will be paid at the weighbridge by the reprocessors. This will also be the likely cost for the waste glass (cullet glass) to the foam glass industry.

Type of glass	**February 2003 (£)**	**March 2003 (£)**
Brown	20-25	20-25
Clear	25-30	22-38
Green	15-22	14-20
Mixed (colour)	12-18	10-15

Table 25 - Glass containers (delivered to a collector) £ per tonne[62]

The main source of container glass cullet is from local authorities collected through bottle banks, who face a charge of between £0-£20 per tonne as of February and March 2003 (Table 26). Local authorities may then have a value for the glass deducted from the charge resulting in a reduced overall charge/profit to the authority. The market for recycled materials is notoriously unstable and there are often fluctuations in price. Factors influencing this include changes in the cost of raw material, changes in the demand for glass packaged products or changes in the level of imports. Transportation costs are a key element in sourcing the glass waste and can represent a significant part of the total reprocessing cost. A recent study estimates that the recycling chain of kerbside to stockpile to reprocessor for glass would cost in the region of £120 to £160 per tonne[63]. This cost appears rather high but local authorities have a statutory duty to recycle, with the possibility that haulers are benefiting from fully or partially loaded return journeys. For processing costs, these will vary dependant upon location, the tonnage throughput and the degree of automation. Average costs are detailed in Table 26. There is little data on the cost of

[62] http://www.letsrecycle.com/glass/index.jsp
[63] National Society for Clean Air (NSCA), Relative Impacts of Transport Emissions in Recycling, NSCA, Brighton, 2002

flat glass waste. BRE's study on flat glass from the replacement and demolition sector for WRAP[64] has gained some cost information (Table 26).

Source	£ per tonne
Glass collection/handling costs (from bottlebanks) [62]	0-20
Segregated skip for flat glass [60]	0-130
Revenue for flat glass per skip [60]	0 -20
Stockpiling [59]	9
Materials Reclamation Facility [59]	70
Glass crushing [59]	2
PRN Revenue	10.25

Table 26 - Glass collection/handling costs (average £ per tonne)

BPEO Stage 2 - scoping exercise

The scoping exercise addresses the various waste management options for waste glass and ranks them in terms of significance. To test the feasibility of using waste glass in the foam glass production process it is necessary to understand the current and future markets, prices and trends for waste glass. The glass manufacturing industry itself is the primary and most obvious market for recycled glass, representing a closed-loop recycling option, where glass can be recycled time and time again without any loss of quality. The foam glass sector will be competing for waste glass from a number of different applications as shown in Table 27.

[64] BRE, Waste Flat Glass from the Demolition and Replacement Window Industries, WRAP, 2003

	Year (000's tonnes)			
Application	**2000**	**2002**	**2004**	**2006**
Containers – Green	227	240	260	280
Containers – Amber	65	120	180	230
Containers –Clear	218	280	340	420
Containers – Recycled Flat	60	50	40	30
Fibre Glass	50	50	60	70
Flat Glass	50	60	65	70
Other Glass	10	10	10	10
Aggregates – Concrete	0	15	40	70
Aggregates – General Fill	10	30	70	100
Aggregates – Bound road base course	10	50	100	200
Aggregates – Decorative	4	5	7	7
Water filtration – Drinking water	0	0	10	50
Water filtration – Waste	1	2	10	50
Abrasives	0	3	10	25
Fluxing Agent for Bricks and Cement	0	0.5	30	150
Art/craft	0.02	0.05	0.1	0.3
TOTAL	**705**	**916**	**1,232**	**1,762**

Table 27: Estimated Growth for Recycled Glass[65]

Waste management of glass

Being of mineral origin, glass is categorised as an inert waste and landfilling it does not lead to methane or leachate generation, although it does occupy a valuable void space and is a waste of resource. The raw materials used in the manufacture of glass are relatively abundant and cheap. However, the quarrying of these materials does lead to extensive environmental degradation and the manufacturing process consumes enormous amounts of energy and water. There is also the Aggregates Levy set at £1.60 per tonne for primary aggregates which gives rise to an economic impact of using raw materials.

The argument against recycling many materials (including glass) is that the energy used to transport the material by both the recycling consumer and for collection and transit to the reprocessing plant offset any benefits accrued by the actual recycling process. In the case of glass, recent studies[66] have shown that transportation loads do not outweigh load savings resulting from recycling. Glass is already one of the most successfully recycled components of the municipal solid waste (MSW) stream, with a vast network of bottle banks in place (22,000 sites), although only 25% of all waste glass available is recycled. In the EU, this proportion is currently 58% (7.5 million tonnes/annum). The increase in glass recovery is a result of a number of factors:

- Technical feasibility of recycling glass
- Economic advantage of recycling it
- Commitment of glass industry and construction product manufacturers to accept post-consumer material

[65] Enviros, Recycled Glass Market Study and Standards Review, WRAP, 2002
[66] Hansard Written Answers Text 20th March 2003 Website: http://www.parliament.the-stationery office.co.uk/pa/cm200203/cmhansrd/cm030320/text/30320w04.htm, Vol 401, No 67

- Investment and development of technology to process this glass

Recycling Markets

The traditional process of glass recycling is based on the product being remelted back into container glass. More information on recycling waste glass into containers is in Appendix 16. Upon arrival at a reprocessing centre or warehouse, loads of waste glass are visually inspected to ensure they meet the appropriate quality standard. Loads that are deemed to contain an unacceptably high proportion of contaminants are rejected at this point and are usually landfilled or used as an aggregate, a low value application. In order for the UK to increase its recycling activity, every type of end market must be developed and capacity increased overall for glass waste. Table 28 outlines the main markets including size and potential for waste glass currently, including the possibility of foam glass production. To encourage the recycling of glass, other markets for glass have recently been developed including glass being used by the aggregates industry as a road building material, in decorative products and as a water filtration medium. These alternative markets for recycled glass include markets which can utilise all types and colours of glass and, where possible, create a demand close to source. This is apparent for the waste glass required for foam glass production. The use of cullet in the construction industry has risen due to the launch of the Aggregates Levy. This should alleviate the processing costs for waste glass compared to costs for primary aggregates.

The key to any recycling activities is the cost of recycling compared to the cost of the alternatives. The least expensive product to produce is construction aggregate by crushing the glass to a suitable size, followed by use as a lasting material. More advanced building materials such as brick and block will command higher market values. These products need to be produced in large quantities (as with the foam glass production) to get the unit cost of production down to a level which will compare favourably with other products. Another key consideration is the number of inert landfills proposed under the Landfill Regulations, currently 382. These will require a supply of inert materials, such as glass. If low gate prices are offered for certain types of glass, then more competition for glass albeit landfill will become apparent.

Table 28 - Markets for Waste Glass

Application	Description	Replacement Product	Advantages	Disadvantages	Waste Glass	Potential size of market (tonnes/year) in 2004
Foam glass	Use of waste glass with a foaming agent to produce foam glass, a product with high insulation values	Bricks, blocks, concrete, insulation, aggregates	Strong bulk and material density. Good thermal, fire and sound insulation properties. High volume usage	Competition with cementitious foamed plastic products. Energy intensive process	Mixed, coloured and contaminated glass	10,000 25,000 50,000
Container glass	Manufacture of containers using reprocessed flat and container glass	Glass (virgin)	Raw material cost reduction, energy savings, furnace life and reduced CO_2 emissions	Contamination issues, colour specification	Colour separated, contaminants need to be removed	820,000
Flat glass	Manufacture of flat glass using recycled flat glass including float and rolled plate	Glass (virgin)	Energy and cost savings, increased furnace life.	High quality requirements, dedicated cullet processing facility	Very high quality- from downstream processing plants	65,000
Aggregate	Crushed glass can be blended with aggregate for use in unbound compacted layer of aggregate used beneath road surfaces	Crushed rock and aggregate	Similar or lower cost. Resistant to load under compression and impact. Good drainage properties. High volume usage.	Engineering specification can be material specific. Other recycled materials available.	Mixed, coloured and contaminated glass	70,000
Constituent in concrete	Glass cullet can be used to substitute some of the aggregates used in concrete production	Crushed rock and aggregate, gravel. Partial	Low cost and decorative colour. Finely ground glass suppresses alkali	Can cause reduction in mechanical strength due to ASR. Specification barriers	Coloured glass. Low contaminants. Fine glass	40,000

		replacement of Portland cement and pozzolans such as fly ash	silica reactivity (ASR)		powder	
Glasphalt	Up to 30% by weight of crushed glass can be mixed with aggregate and bitumen to produce the layer of asphalt below the road surface	Crushed rock aggregate	Similar or lower cost. Enhanced visibility. Lower bulk density, low absorption of moisture, relatively hard and relatively non-variable, high volume	Glass can be de-bonded from the surface. Increased glare. Potential damage to vehicles, low value	Any coloured glass, mixed, high level of contaminants	100,000
Abrasive	Due to the angular nature of finely crushed glass, it can be used as a sand replacement in shot blasting.	Silica sand, steel shot/grit, copper and nickel slag	Competitively priced, effective performance with angular particles. Improved safety, with low heavy metal content. Low bulk density Does not cause silicosis.	Alternative materials are inexpensive	Any colour glass. Minimum contaminants	10,000
Filtration medium	Glass is ideal for use where good drainage is required, as moisture passes through glass better than sand. Cullet can also be used for water filtration in place of sand.	Silica sand and anthracite	Low cost. Resists bacterial growth	Use needs to be approved	Highly processed green and amber glass. Clear glass cannot be used	20,000
Flux/binder in ceramics	Finely ground glass can act as a ‘flux; and bond	Mineral fluxes such as clays	Low softening temperature.	Price of glass and grinding capacity	Any colour glass.	30,000

and bricks	to clay		Reduced firing time and fuel consumption		Minimum contaminants. Finely ground glass	
Decorative products	The cullet is normally colour separated and used in landscaping applications, for example in gardens, or blended with other materials to produce products such as floor and wall tiles.	Crushed rock and aggregate/gravel	Decorative colours, Similar or lower cost. Resistant to load under compression and impact. Good drainage properties. High value	Small volume usage, impurities need removal	Usually colour separated, low contaminants	7,000
Insulation	Glass cullet can be used for insulation fibre manufacturers up to a level of 40% e.g. glass wool.	Glass (virgin)	Reduced cost, increased furnace life	Specifications for continuous reinforcement fibre are too stringent and cannot be met by post-consumer glass without major investment	Flat glass cullet preferred. Colour is not critical. Low contamination levels including organic contamination	60,000

Scoping matrix

The scoping matrix analyses current technology for glass waste management including the glass waste quality, the amount of processing required, value of the product, the technical viability of the process, the market size and the environmental impact, in order to compare the use of waste glass in foam glass production compared to other reprocessing methods. (Table 29). The impact for each waste management method is categorised as a low, medium or high, with a score attached, as shown by the key in Table 30. The total score is then presented for each waste management option, the higher the score the better the waste management option in terms of the criteria used.

Table 29 - Scoping Matrix for waste glass management routes, including foam glass production

Application	Quality of Recyclate	Processing Required	Value of End Product	Technical	Potential Market Size	Environmental Impact of Production Process	TOTAL
Foam glass	Low	Medium	High	Medium	Medium	Medium	14
Container glass	Medium	High	Medium	High	High	Medium	15
Flat glass	High	High	High	Medium	Medium	Medium	13
Aggregate	Low	Low	Low	Medium	High	Low	13
Constituent in concrete	Low	High	Low	Medium	Medium	Low	14
Glasphalt	Low	Low	Low	High	High	Low	14
Abrasive	Medium	Medium	High	High	Low	Low	13
Filtration medium	High	Medium	High	Medium	Low	Low	10
Flux/binder in ceramics	Medium	High	High	Low	Low	Medium	12
Flux/binder in bricks	Medium	High	Medium	Medium	Medium	Medium	13
Decorative products	Medium	Medium	High	High	Low	Low	14
Insulation	Medium	Medium	High	Medium	Medium	Medium	13

The use of waste glass for container glass has the highest score, largely due to the market size and technical feasibility of this waste management option. Waste glass for use in foam glass production is ranked equally with the reprocessing methods as a constituent in concrete, glasphalt and decorative products. The key aspects for using waste glass in a foam glass production process is that low quality is acceptable, medium processing is required, the value of the end product is high, the technical feasibility is medium, as is the market size and the environmental impact of the process. Therefore, when comparing the utilisation of waste glass in the foam glass manufacturing process to other reprocessing methods, the scoping matrix identifies that it is a viable option.

Attribute	**Key**	**Scoring**
Quality of Recyclate	Low – contaminated, mixed Medium – colour separated, low contaminants High – separated, no contaminants	3 2 1
Processing Required	Low – minimum processing e.g. crushing Medium – some level of processing e.g. sorting High – large amount of processing e.g. grinding	1 2 3
Value of end product	Low - <£10/tonne Medium - <£10-50/tonne High - >£50/tonne	1 2 3
Technical	Low – unproven Medium – trial stage, technology transfer High – proven	1 2 3
Market Size	Low – <10,000 tonnes/annum Medium - <50,000 tonnes/annum High - >50,000 tonnes/annum	1 2 3
Environmental Impact	Low – no significant impact of process Medium – some impacts of process High – significant impact from process	3 2 1

Table 30 – Key and Score for the impact of waste management methods used in the scoping exercise

BPEO Stage 3 – assessment and scoring

Methodology

This stage is key in determining the BPEO for utilising glass waste in the foam glass manufacture process. This is determined by a number of criteria, but the key factor will be environmental impacts, as cost implications are already being analysed in the investment appraisal section. The detail of data available for this analysis has been limited, therefore assumptions based on similar processes have been made (see Appendix 17). The environmental data is analysed using a life cycle assessment approach and impacts are given based on established mechanisms. The model used is the IWM-2 model by Forbes *et al* [67]. This is based on municipal solid waste and has been used to develop scenarios for bring bottle collection systems for recycling into glass containers. One of the potential benefits of using waste glass for foam

[67] McDougall F., White P., Franke M & Hindle P., Integrated Solid Waste Management: a Life Cycle Inventory, Blackwell Science, Oxford, 2001

glass production is the usage of all types of glass. However, LCA data is limited with regards to flat glass and other types of glass in terms of waste management routes and therefore only container glass waste has been analysed.

The data gained from the foam glass process has been analysed and compared to the IWM-2 model data for container glass recycling. The collection, transportation and sorting systems remain the same. Other criteria include legislation (predominately waste and environmental legislation), cost (cost of waste and product) and technical issues (predominately standards and specifications). The majority of this other criteria is qualitative and plays an informing role for the scenarios. The scenarios are ranked using the environmental impact data and also cost data, with a crude score given. Table 31 outlines the data requirements for the BPEO model.

The foam glass production process

The waste glass would have to undergo collection, possibly pre-sorting, crushing and grinding before being fed into the foam glass production process. Figure 34 shows the current foam glass production process being utilised by Misapor. Waste glass currently used in the process is glass from the municipal waste stream i.e. containers which therefore attract the PRN value. The waste glass can be mixed, with no requirement for colour separation and contaminants can be apparent such as ceramics, stoneware and porcelain. Bottle caps and labels do not represent a problem. Flat glass from windows, end of life vehicles and cathode ray tubes can also be used. Glasses and contaminants which represent a problem to glass reprocessors and associated recycling schemes, do not in the case of foam glass production, which is major advantage to this potential recycling application. Transportation of the glass cullet to the production plant is a major consideration in terms of environmental impact and cost.

The furnace for the foam glass is electrically heated and data has been based on carbon dioxide emissions from gas and coal fired power stations. There is no production of carbon dioxide from the furnaces on site. There is a small generation of carbon dioxide from the foaming agent. Energy intensive processes, such as foam glass production which uses electricity, cause relatively large carbon dioxide emissions. It is anticipated that energy efficiency and innovation could be incorporated into the design stage, such as the use of lower temperatures. The major environmental effect of the process is the electricity generated for the furnace process. The milling and grinding of the powders is undertaken dry, therefore there is no water usage, other than for general factory usage. The manufacturing plant operates 24 hours a day for 7 days a week with 20 employees. There is automatic production, with manpower required at the supply of raw materials stage and the shipping of final product.

The BPEO assessment has concentrated on a full dataset from the Misapor process. Other processes are currently in pilot stage for producing foam glass products. One such process is Geofil-bubbles whereby the product is a lightweight aggregate in various sizes and composition. Homogenisation is undertaken with a blowing agent and then granulation occurs, which is then heat cured and coated. Both processes have elements of heating within them, and it is assumed that these will generate similar emissions.

Aspect	Main Parameters	Characteristics
Energy balance	Transport Process characteristics	Mode – road, rail, water Vehicle size and type Distance travelled Route Fuel efficiency Inputs – energy use/requirements Outputs – e.g. electricity generation
Resource Use	Primary Resources Secondary resources/products	Materials for processes Land requirements Infrastructure requirements Recycling products Land reclamation opportunities Land diversion/avoidance
Emissions	Air Water Land	Global warming potential Acidification NOx (from transportation) Avoided emissions from energy recovery Particulate emissions/dust Dioxins VOCs/odours Pollution potential Quantity/composition of solid residues
Economics		Capital costs Operational and maintenance costs Monitoring and aftercare Decommissioning Markets for recycled products Impact on local economy Affordability
Social		Employment Making producers responsible Skills base Public acceptability Social implications Cultural heritage Accidental risks
Compliance		Compliance with legislation and policies
Practicability		Practical deliverability Technical feasibility Flexibility Making best use of existing facilities and expertise

Table 31 - Data requirements for the BPEO Assessment for foam glass manufacture

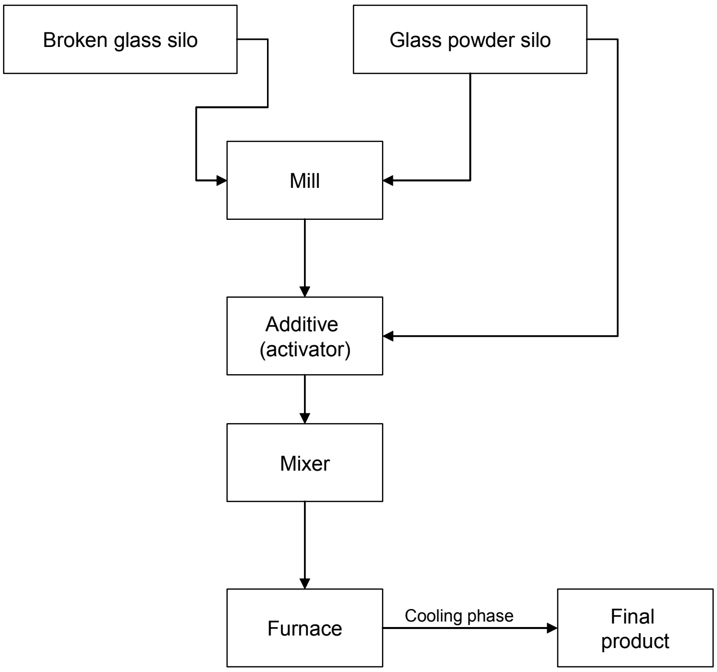


Figure 34: The Foam Glass Production Process

BPEO Scenarios

The following scenarios have been analysed using LCA data from the IWM-2 model and the BPEO model.

- **Scenario 1 -** Recycling of container glass (from bring sites collection) into new container manufacture at 10,000, 25,000 and 50,000 tonnes/year
- **Scenario 2 –** Recycling of container glass (from bring sites collection) into foam glass products at 10,000, 25,000 and 50,0000 tonnes/year
- **Scenario 3 –** Recycling of container glass (from bring sites collection) into aggregates at 10,000, 25,000 and 50,000 tonnes/year
- **Scenario 4 –** Landfill of waste glass at 10,000, 25,000 and 50,000 tonnes/year

The use of waste container glass for foam glass production has been compared to the use of waste container glass back into containers as this is the reprocessing method whereby most of the environmental data has been identified. Also compared is the use of waste container glass into aggregates as this is becoming a feasible and common option. The assessment concentrates on the four scenarios identified above and also on the differing input volumes of waste glass into the foam glass manufacturing plant. The global warming potential in tonnes has been depicted to identify the environmental impact of each scenario at the given tonnages (Figures 35-37). The sorting, collection and transportation systems remain the same for all scenarios, enabling the end use applications to be compared.

The vast majority of emissions from the reprocessing of glass come from the melting of the glass, rather than the crushing of glass. For instance emissions for CO_2 are calculated as 350,000 grams per tonne of glass recycled back into container glass and at 1,000 grams per tonne of glass for crushing. For foam glass manufacture, the emissions for CO_2 are 43,000 grams per tonne of waste glass. The global warming potential is highest for Scenario 1 (container manufacture) for all tonnage levels, followed by foam glass manufacture (Scenario 2) and then landfill (Scenario 4). The use of container glass in aggregates produces very little CO2 emissions as the energy use is minimal.

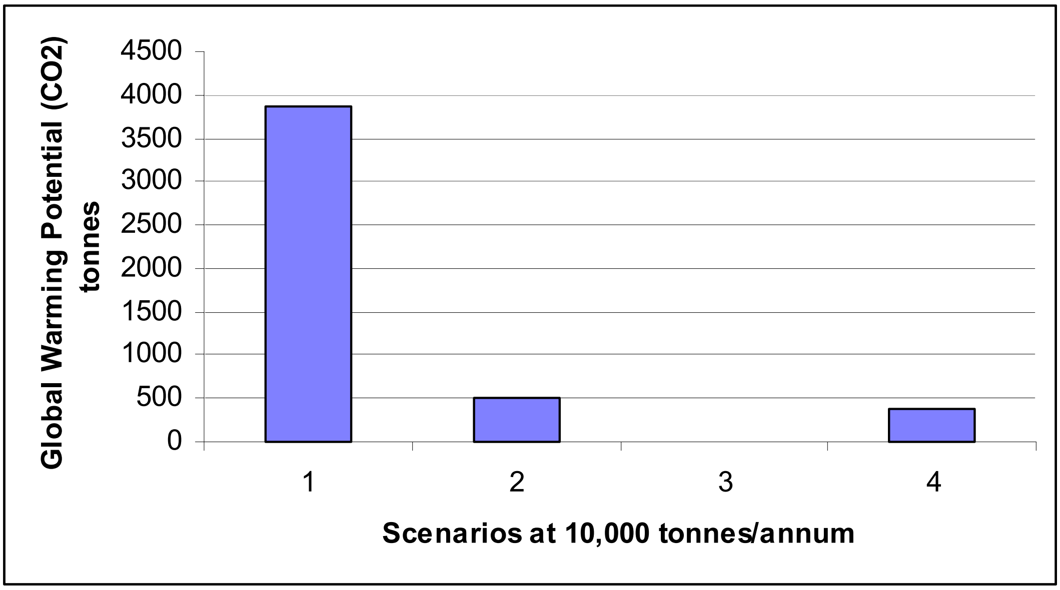


Figure 35 - Global Warming Potential for 4 Scenarios at 10,000 tonnes/annum (tonnes)

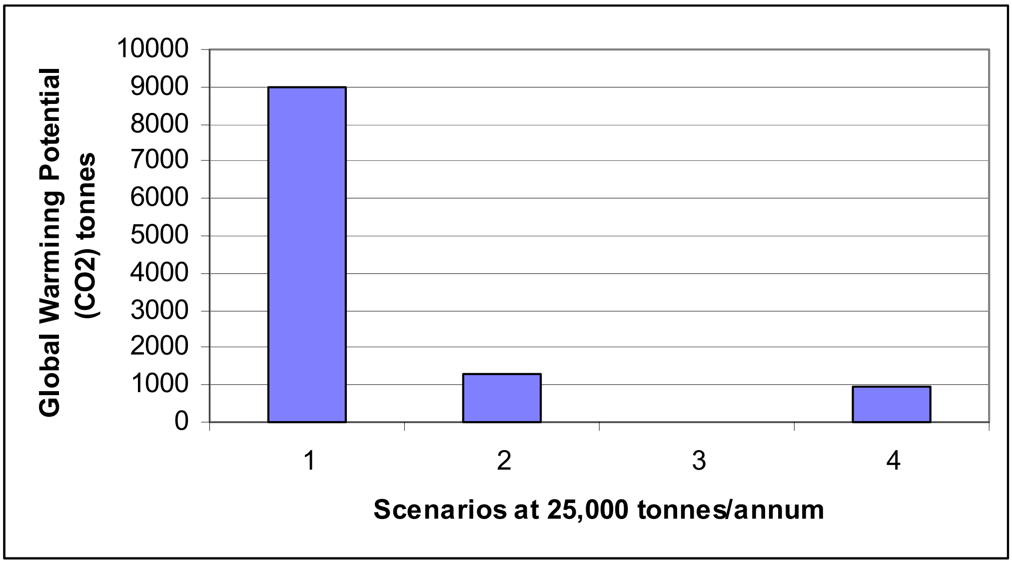


Figure 36: Global Warming Potential for 4 Scenarios at 25,000 tonnes/annum (tonnes)

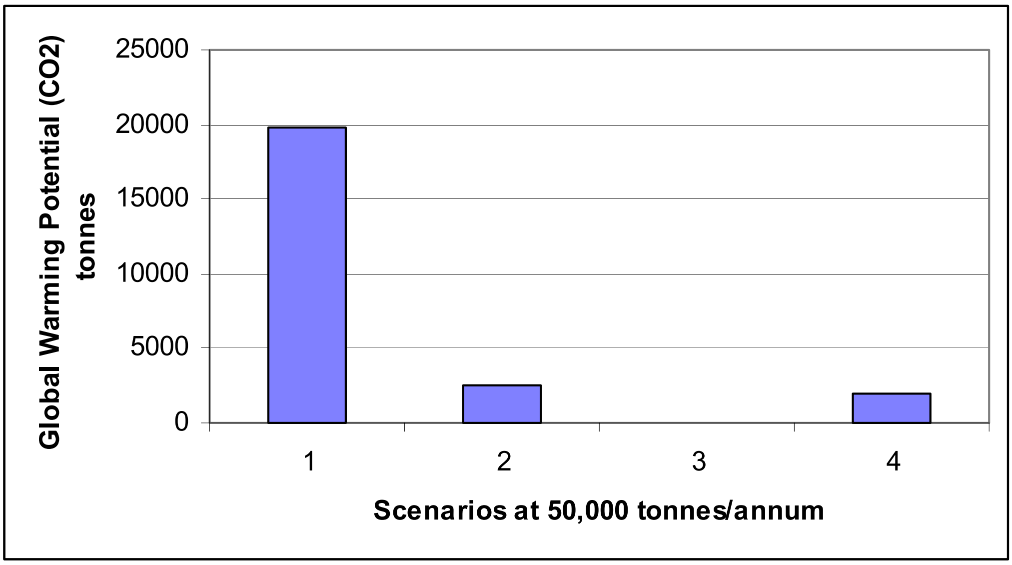


Figure 37 - Global Warming Potential for 4 Scenarios at 50,000 tonnes/annum (tonnes)

When comparing the energy consumption for the 3 scenarios (10,000 tonnes/year, 25,000 tonnes/year and 50,000 tonnes/year) for foam glass production (Figure 38), the production plant at 50,000 tonnes/annum (Scenario 3) has the most net benefit, followed by 25,000 tonnes/annum (Scenario 2). This is due to more waste container glass being recycled, representing a net benefit in energy usage, displacing the need for the quarrying and processing of virgin material.

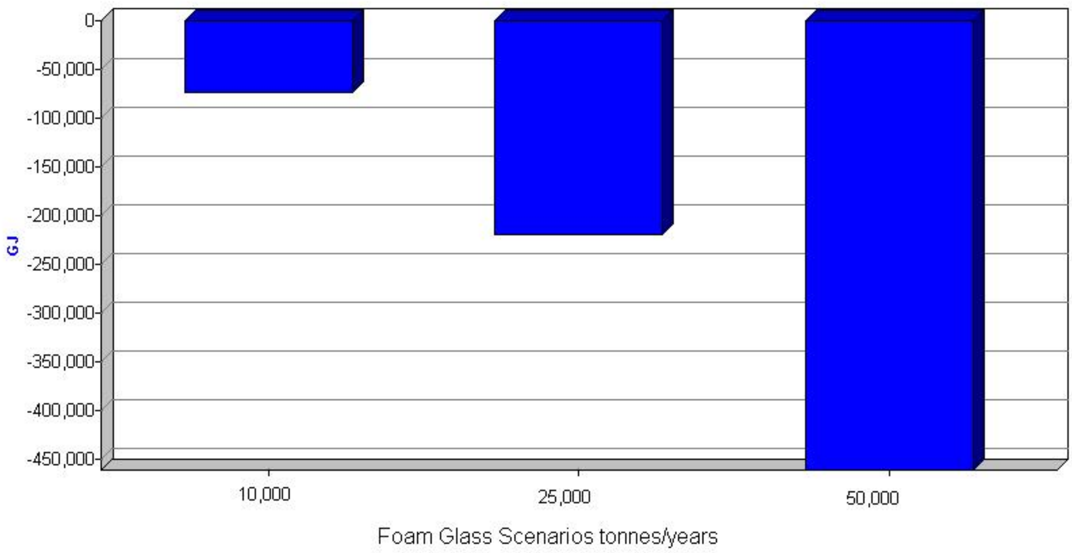


Figure 38: Energy usage for the Foam Glass Scenarios (Giga Joules)

Figure 39 shows the production of nitrous oxides (NOx) for the foam glass scenarios, transportation being the major source, predominantly from the collection and transfer to the foam glass plant. The amount of NOx produced increases with the amount of waste glass used in the process, as more cullet has to be transported. As transportation is such a key issue for the BPEO, the foam glass plant needs to be located as near as possible to the source of the waste glass, ideally within a 100km radius. It should be noted that emissions of NOx will reduce with the introduction of cleaner vehicles and fuels.

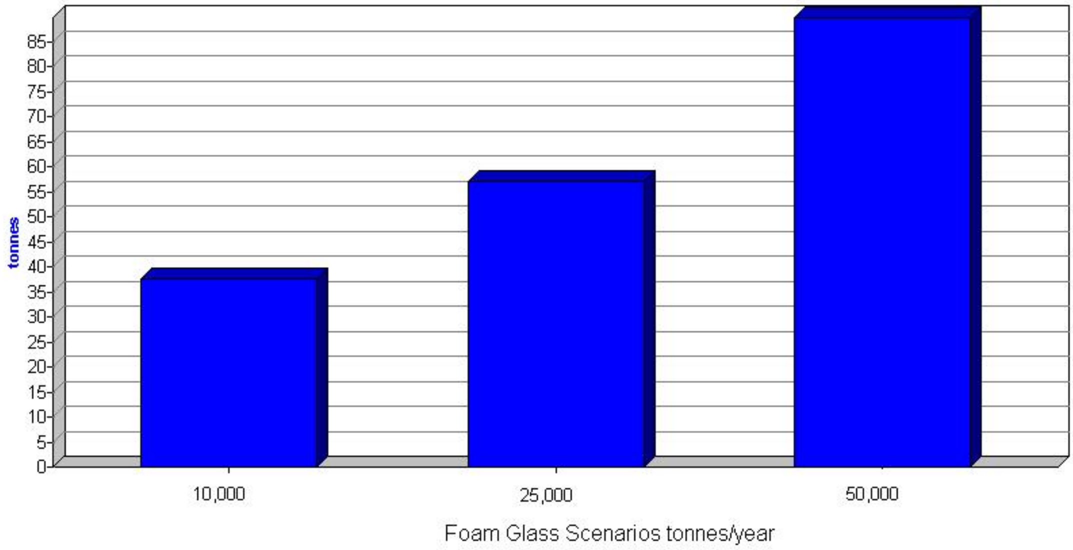


Figure 39 Tonnes of NOx produced for foam glass scenarios

BPEO scoring

Appendix 18 compares the BPEO Assessment for each of the scenarios. This data has been converted using a scoring system for each scenario based on the social, legislative, technical, economic and environmental criteria, giving an overall score, the 'environmental currency', the lower the score, the higher the value of that option (Table 32). The scoring systems ranges from 1 to 5 for each category, 1 having a low impact and 5 having a high impact. The BPEO assessment shows that Scenarios 3 and 1, using waste glass in aggregates and the recycling of waste glass back into containers scores the lowest, this is due to the fact that they are both an established system, technically proven and the most environmentally beneficial with regards to the savings made from emissions by recycling for container glass manufacture. Scenario 3 has a low environmental impact due to the lack of reprocessing required. As expected, Scenario 4, landfilling of the glass waste, scores the highest mainly due to environmental and social criteria. The foam glass scenario has a high impact in the technical criteria, as it is currently not undertaken in the UK, however it scores nearly the same for economic and environmental criteria as Scenario 1 and 3, meaning that is a high-value alternative to container glass recycling with similar environmental benefits. With the introduction of proven technology into UK, we can expect the foam glass scenario to score similar to that of recycling container glass when using the BPEO Assessment.

Criteria	Scenario 1: Containers	Scenario 2: Foam glass	Scenario 3: Aggregates	Scenario 4: Landfill
Legislative	1	2	1	3
Economic	2	2	1	1
Environmental	3	2	1	4
Social	1	2	2	4
Technical	2	3	2	1
TOTAL	**9**	**11**	**7**	**13**

Table 32: BPEO assessment scoring for the 4 glass waste management scenarios

When comparing the scenarios for foam glass at various tonnage levels, the largest tonnage level at 50,000 tonnes/annum has the lowest and therefore best BPEO score (Table 33). This is largely due to the environmental benefits of recycling 50,000 tonnes/annum of glass waste which displaces the environmental impact of collecting and transporting the cullet. The scenarios score the same for legislative and technical as the amount of tonnage does not impact on these criteria. With regard to the social criteria, this scores lower for 50,000 tonnes/annum, largely due to the extra number of jobs created. However, there is a social impact of the transportation of a larger tonnage of glass waste. The economic criteria scores low for Scenario 3, as the greater the tonnage the more economically viable the processing becomes.

To summarise, the BPEO model has compared the use of waste glass in a foam glass production process to other reprocessing methods in the scoping exercise and the option compares favourably. To enable enough tonnage of waste glass to be collected in low quality, flat glass is the most appropriate waste stream, if efficient collection systems can be set up within a defined region. The BPEO assessment predicts that the 50,000 tonnes/annum plant will have the least environmental impact.

Criteria	Scenario 1: 10,000 tonnes/annum	Scenario 2: 25,000: tonnes/annum	Scenario 3: 50,000 tonnes/annum
Legislative	2	2	2
Economic	3	2	1
Environmental	2	2	1
Social	2	1	1
Technical	3	3	3
TOTAL	**12**	**10**	**8**

Table 33: BPEO assessment scoring for the foam glass scenarios

Environmental Assessment of Foam Glass Products

Overview

This chapter presents the findings of an environmental assessment of foam glass products in terms of embodied CO_2 and the BRE Ecopoints. The results are presented as global warming potentials and environmental impact assessments for glass foaming agents, concrete mix alternatives, blockwork alternatives and insulation alternatives.

Methodology

The assessment was completed using the BRE Environmental Profiles methodology. The methodology was prepared as part of a Government project with input from 24 Trade Associations. It uses a level playing field approach to assess environmental impacts over the whole life cycle. The assessments therefore take into account any environmental impacts associated with transport, manufacturing and processing, maintenance and replacement, and disposal at the end of life. These are based on typical UK scenarios. For recycled and reclaimed items, environmental impacts are measured from the point at which the item becomes available for processing into its second function. Burdens from its previous manufacture are carried forward to its next use according to the relative value of the waste stream and primary product. If a recycled material has no value at any point in the process, e.g. during demolition, then no burdens are carried forward. The assessment uses BRE's Ecopoints single scoring system for environmental impact, also provided is the overall embodied CO_2. Ecopoints ascribe a value using an environmental assessment methodology to enable processes and products to be compared and ranked.

Ecopoints

A single score rating taking into account total contribution to, and relative importance of, a range of 12 environmental impacts. The total contribution is measured by BRE's approach to Life Cycle Assessment (LCA), and the Environmental Profiles Methodology for construction materials and components. The relative importance has been assessed by undertaking a consultation with stakeholders in the construction industry. BRE's Ecopoints are a single score which measure environmental impact. The average UK citizen would have an impact equivalent to 100 Ecopoints, and the lower the Ecopoints score, the lower the environmental impact. Further information on Ecopoints is provided in Appendix 19.

Embodied CO_2

Embodied CO_2 is important because it is associated with global warming. It is important to measure CO_2 separately from embodied energy because some construction products contain CO_2 that is not associated with the energy used. In addition, not all forms of energy have the same CO_2 emissions and therefore distinguishing embodied CO_2 allows the products which benefit from low-CO_2 forms of energy to be identified. Embodied CO_2 is actually a measure of "Embodied CO_2

equivalent" which means it does not measure simply CO_2 but all other gases responsible for global warming. See Appendix 20 for further details.

An environmental study of foam glass and components using foam glass has been completed. This study includes four separate investigations:

1. The foam glass manufacture process and alternative foaming agents
2. A foam glass concrete compared to a traditional concrete
3. Foam glass for application in structural blockwork
4. Foam glass insulation materials.

In each assessment, the global warming potential in kgCO_2 equivalent $^{(100\ years)}$ has been evaluated. Additionally, Ecopoints are used to assess the environmental burden in identified impact categories. The studies are based on information provided by the Swiss foam glass manufacture Misapor. In compiling each assessment, a number of assumptions and decisions have been made (Appendix 17). These have been based on the information provided from the above source. Study details are discussed separately below within each study summary. The examination of the environmental impact of a glass foam product compared to alternative market options is undertaken. These comparative assessments are based on environmental information on other materials already held within the BRE Environmental Profiles database.

Alternative foaming agents for foam glass production

In this assessment the production process for glass foam manufacture was investigated. This included the comparison of four separate foaming agents each of which can be used in the production process. The alternative foaming agents include:

- $CaCO_3$ – Calcium Carbonate (limestone)
- $CaSO_4$ – Calcium Sulphate (gypsum)
- Fly ash
- SiC – Silicon Carbide

During the manufacture of foam glass the foaming agent decomposes to form a gas. This gas forms bubbles within the melted and viscous liquid glass. In a carefully controlled system, the liquid glass is kept to a required viscosity and this prevents the gases from escaping when creating the foam glass product. However, ultimately some gases do escape. Such emissions have been included within assessments. For the manufacturing processes that use $CaCO_3$ or SiC, the emissions are CO_2. For processes that use $CaSO_4$ or fly ash, the emissions are SO_2. The quantity of foaming agent and the mass of CO_2 and SO_2 gas emission for all identified processes is based on the data provided by Misapor for the use of $CaCO_3$ as a foaming agent and has not been varied for the other foaming agents due to the absence of specific information.

Material inputs to the process consist of the waste glass cullet, water, and the foaming agent. Additionally, an electrical energy demand has also been included. Information provided by Misapor indicates that a foam glass product with lower thermal conductivity is achieved if the manufacturing process replaces the air in the furnace at the foaming zone with either SO_2 or CO_2. These additional material inputs have also been included within assessments. Finally, a generic transport distance of 25 miles for carriage of cullet to the manufacturing facility has also been included. Findings are shown in Figures 40-41.

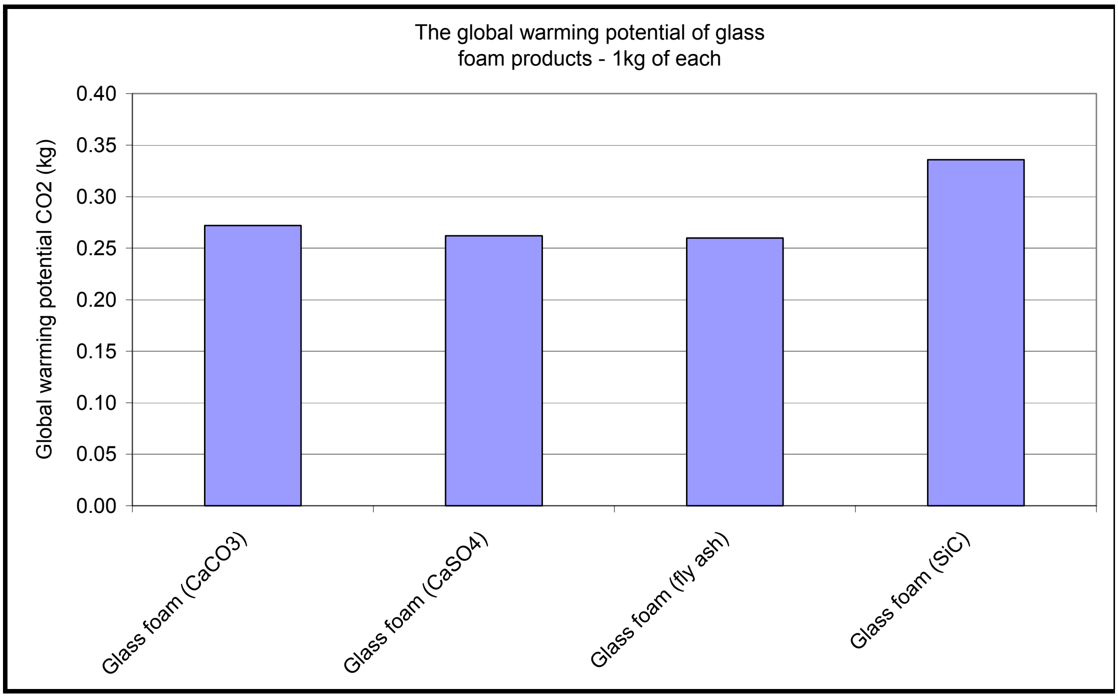


Figure 40 - Global warming potential of glass foaming agents

Figure 40 (above) shows that the global warming potential is evaluated in terms of CO_2 equivalent emissions over 100 years. The environmental impact of foam glass products manufactured using $CaCO_3$ and SiC foaming agents result in a higher environmental burden (in this impact category). This is because these foaming agents release higher quantities of CO_2, a major global warming gas, during manufacture. Manufacturing processes that use fly ash or $CaSO_4$ foam agents release SO_4 which has no significant impact as a global warming gas.

Figure 41 (below) presents findings in Ecopoints across a range of environmental impact categories. Collectively across all categories, glass foam made using $CaCO_3$ has the lowest environmental impact. This is followed by SiC and then products made using fly ash or $CaSO_4$. The reason that the latter two foaming agents cause a higher impact per quantity of material produced can be attributed to the SO_2 emissions that occur with the use of each. These result in higher burdens in air toxicity and acidification impact categories. The negative burden created by each product is a result of the avoided waste burden from the glass cullet used by the manufacture process. This is shown as a negative burden because it is representative of material that would otherwise be disposed of in landfill. The BRE Environmental Profiles Methodology does not apply the concept of “avoided burdens” to LCA studies made for comparative purposes between different products. However, the avoided burden for foam glass has been included here for this particular study due to the focus on use of a waste material. These figures should not be used outside of this study because the approach has not been expanded to all products. To make the results comparative, only the positive impacts should be compared.

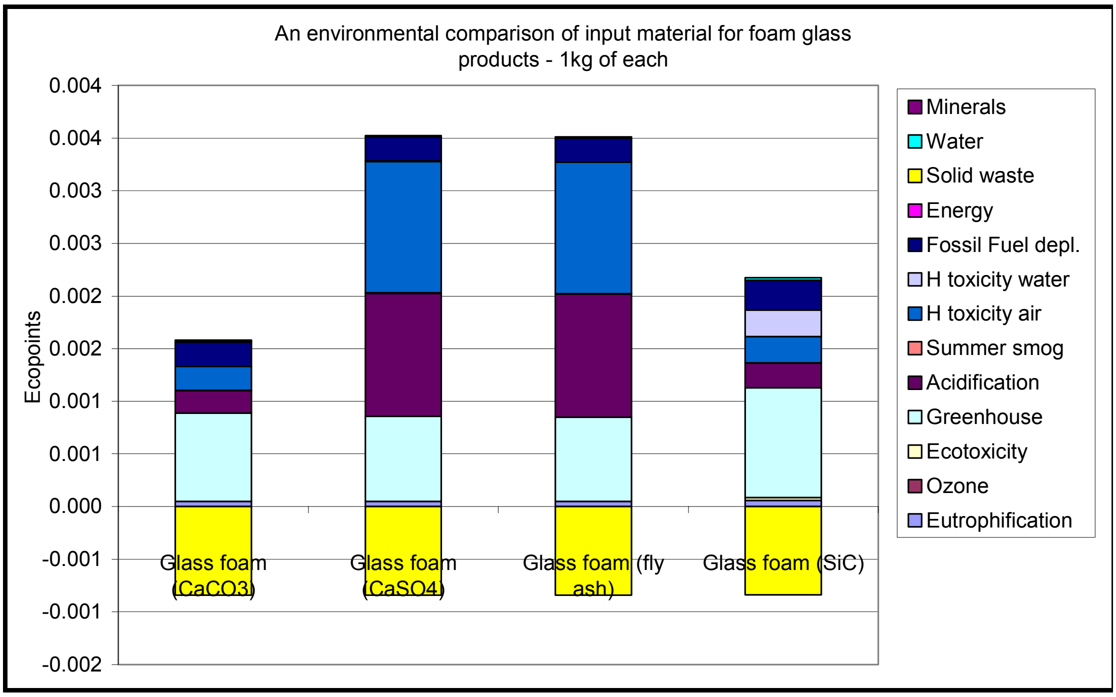


Figure 41 - An environmental comparison of glass foam products

Foam glass in concrete application

Foam glass has potential for use in both ready mix and pre-cast concrete. In these applications it has a number of inherent advantages. The objective of this assessment was to compare a standard virgin aggregate ready mix C40 concrete with a 28 day compressive strength of 30 N/mm^2 to a structurally equivalent concrete, but one which incorporated foam glass aggregates. Based on information provided by Misapor, the lightweight glass foam concrete was considered to have a density of 1300 kg/m^3 and consist only of water, foam glass and Portland cement components. An energy demand to represent aggregate crushing has also been included in the assessment. Findings of the environmental assessment are shown in Figures 42-43.

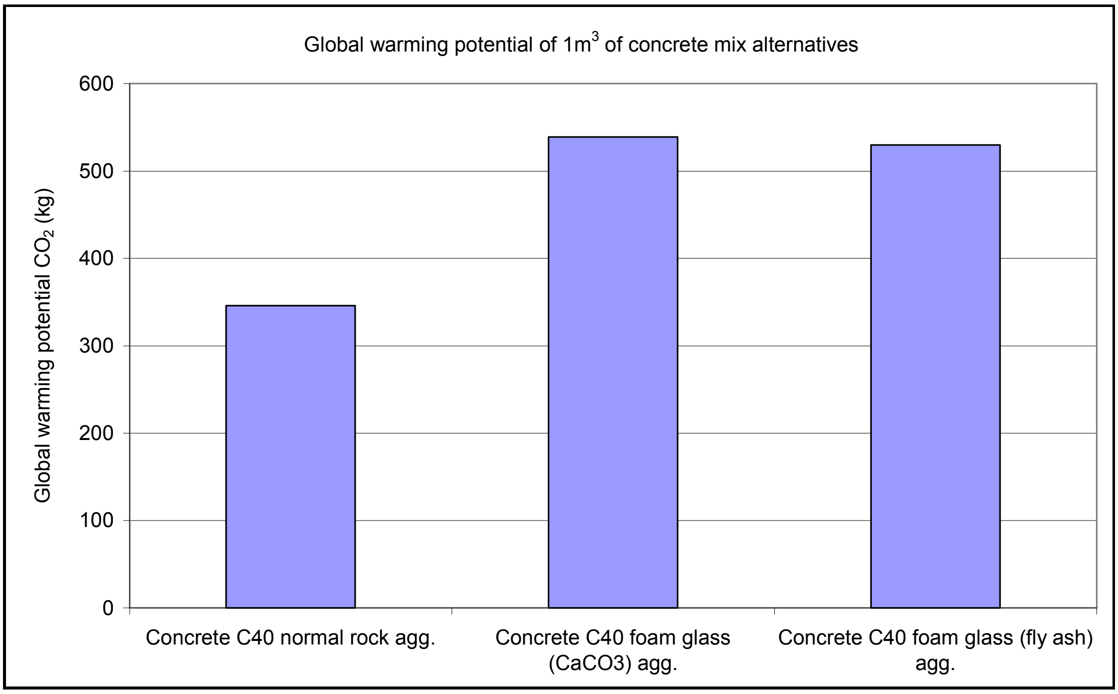


Figure 42 - Global warming potential of concrete mix alternatives

Figure 42 (above) illustrates that the concretes incorporating foam glass aggregate result in a higher global warming potential than a standard concrete using mineral aggregate. These higher impacts can be linked to the potential CO_2 and SO_2 emissions during the foam glass manufacture process. Figure 43 (below) shows that when findings are reviewed across all impact categories, the relative environmental burden of alternative concrete mix designs varies between alternatives. The environmental impact of concrete which uses virgin aggregate is higher than that of concrete using foam glass aggregate (produced using the $CaCO_3$ foaming agent) but similar to that using fly ash; this is reinforced by the negative burden from using waste cullet. Ultimately, the same conclusion can be also be made for concrete using foam glass which uses fly ash as the foaming agent, although the differences in net impact are marginal. The concrete made from virgin aggregate has significantly higher environmental burden due to the contribution from the minerals impact category.

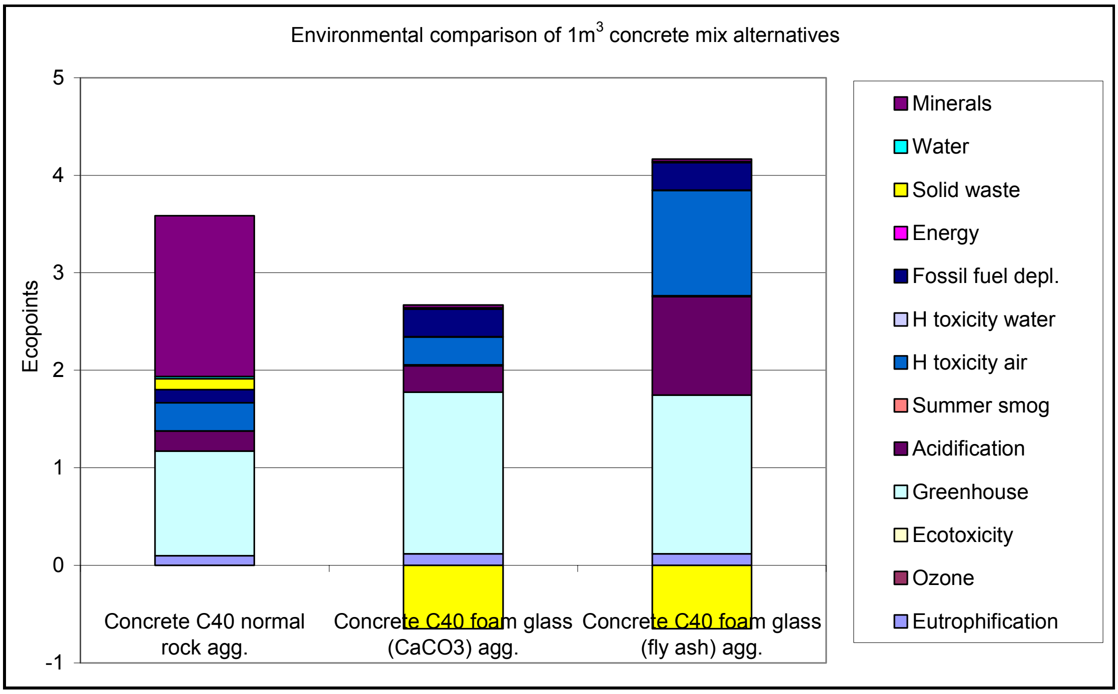


Figure 43 - Environmental comparison of concrete mix alternatives

Foam glass for application in structural blockwork

Foam glass has potential for application as a blockwork component. This assessment reviewed the environmental impact of six separate blockwork alternatives - four incorporated foam glass materials. The six alternatives included:

1. Aerated blockwork
2. Dense blockwork
3. Foam glass blockwork (foaming agent – $CaCO_3$)
4. Foam glass blockwork (foaming agent – fly ash)
5. Foam glass concrete blockwork (foaming agent – $CaCO_3$)
6. Foam glass concrete blockwork (foaming agent – fly ash)

The foam glass blockwork is blockwork made entirely of foam glass , whereas foam glass concrete blockwork is foam glass mixed with a cement. Assessments were conducted on the basis that each product had a surface area of $1m^2$ and a thickness of 0.1m. Findings are shown in Figures 44-45.

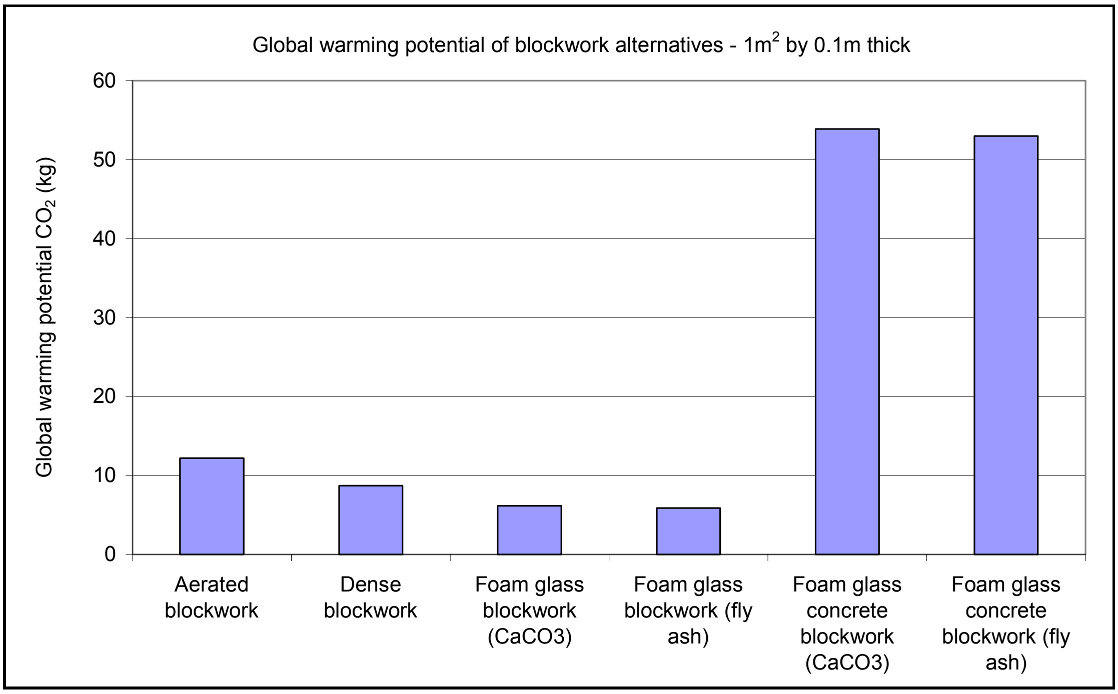


Figure 44 - Global warming potential of blockwork alternatives

Figure 44 (above) illustrates that solid foam glass blockwork has the smallest global warming potential when compared to aerated and dense blockwork alternatives. This is for blockwork components made entirely of glass foam material. However, for blocks made of foam glass concrete the impacts are noticeably higher.

Figure 45 (below) shows a number of interesting observations including the blockwork made of solid foam glass have the lowest environmental burden when combining impacts across all categories. This burden is further reduced when the negative impact associated with landfill avoidance is also taken into account. In comparing foam glass blockwork to blockwork made of foam glass concrete, it is clear that the latter creates higher environmental burden. This can be attributed to cement demand, but also to the higher quantities of foam glass material in the concrete blockwork. The foam glass concrete blockwork has a density of 1300 kg/m^3. Over 700 kg of this mass is foam glass aggregate. Therefore, these blockwork alternatives contain a greater mass of glass aggregate per unit volume than standard foam glass blockwork (that has a density of 225 kg/m^3). It follows that the environmental impact associated with the manufacture of this greater material demand is higher. Likewise, the foam glass concrete blockwork accounts for the higher negative burden - when compared to the standard foam glass blockwork. It should be noted that both aerated and dense blockwork can incorporate waste material components. Findings in this graph does not include the potential avoided waste burdens associated with the use of these materials.

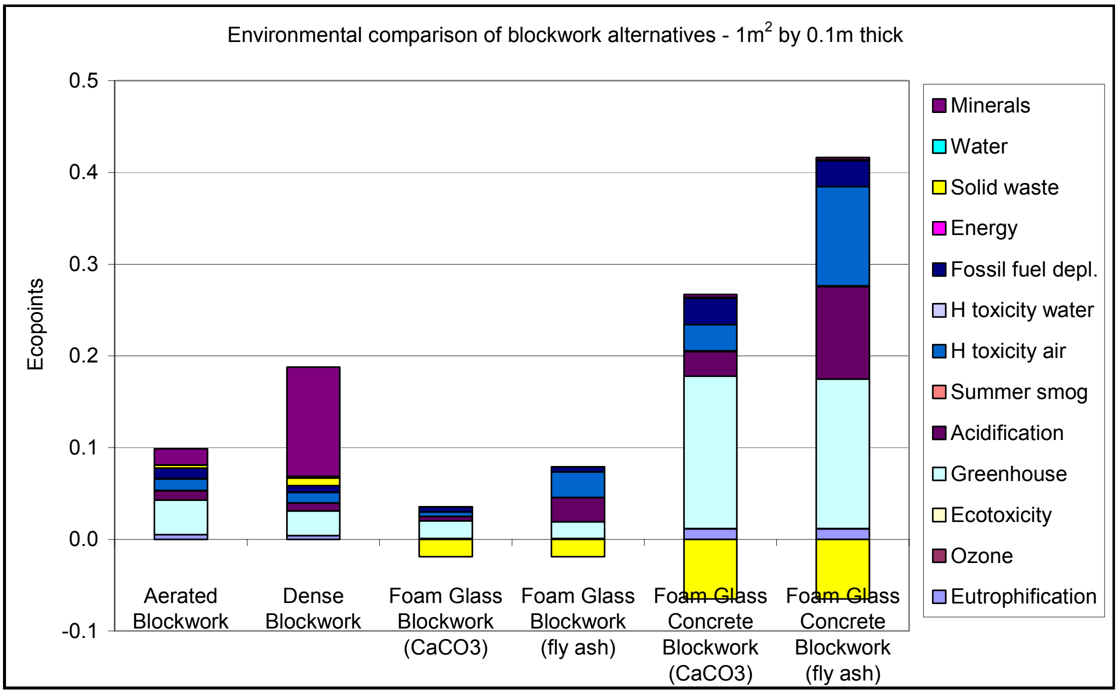


Figure 45 - Environmental comparison of blockwork alternatives

Foam glass as an insulation material

Foam glass has a number of inherent properties of which thermal insulation potential is particularly advantageous. There are many different insulation products on the market. This assessment reviews the environmental impact of five alternatives including:

1. Aerated block insulation
2. Foam glass insulation (foaming agent – $CaCO_3$)
3. Glass wool insulation – two alternative densities considered
4. Polyurethane (PU) – pentane blown insulation
5. Rock wool insulation – three alternative densities considered

In total, eight separate products have been considered by the study. Consistent for all is the thermal resistance of the alternatives. This is set at 1.45 W/m^{2}K for 1m^2 of surface area. Findings are shown in Figures 46-47.

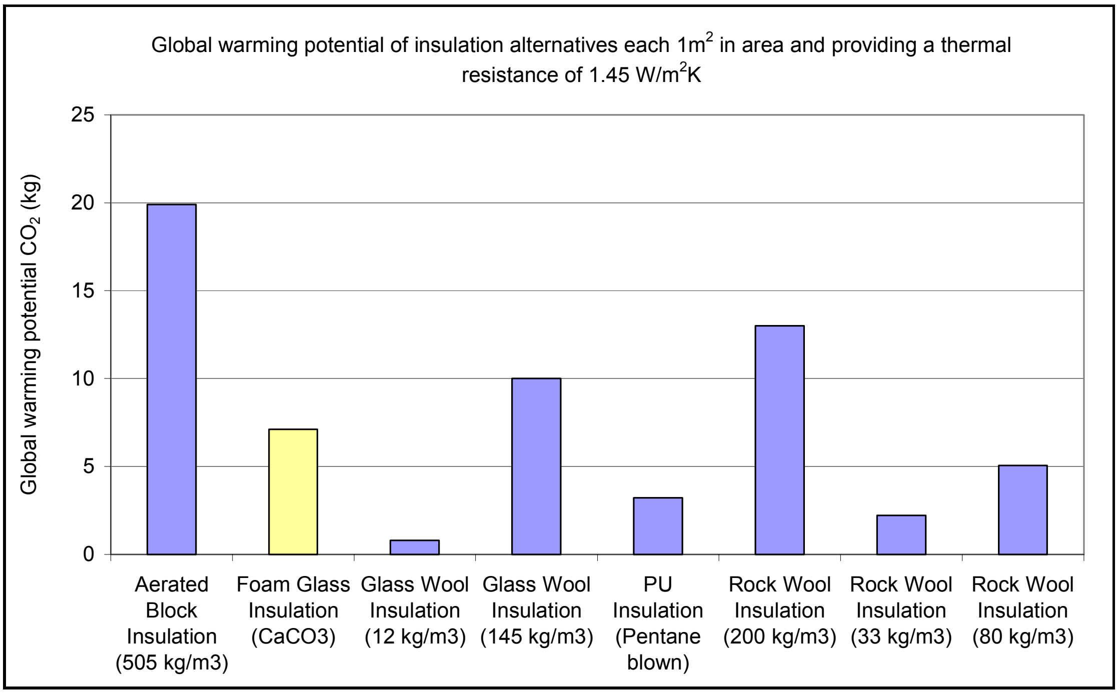


Figure 46 - Global warming potential of insulation alternatives

Figure 46 (above) illustrates that foam glass insulation has lower global warming potential than aerated block and in some circumstance, glass wool and rock wool products; although this is dependant of material density. In particular, glass wool and rock wool products that have low material densities appear to provide a lower global warming potential than the foam glass product.

Figure 47 (below) shows that when findings are reviewed across all impact categories the environmental benefits of lower density glass wool and rock wool products are diminished – when compared against the foam glass. This change in perspective is attributed to a number of variables, of which the negative burden from waste cullet use is a key contributor. Ultimately, findings concluded that only glass wool at 12kg/m^3 and rock wool at 33kg/m^3 have lower environmental impact across all categories than the glass foam. Aerated block, glass wool and rock wool can each be made using waste material components. Findings in this Figure do not include the potential avoided waste burdens associated with the use of these materials.

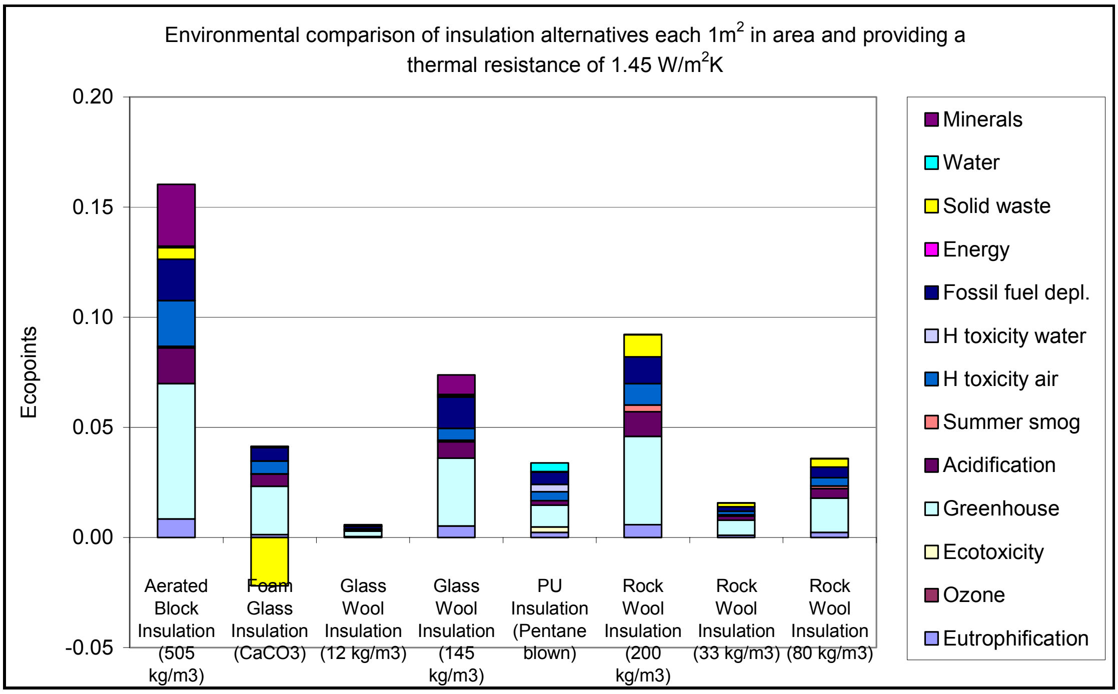


Figure 47 - Environmental Comparison of Insulation Alternatives

New Energy Saving Technologies

Overview

This chapter looks at two potential technologies for the introduction of heat into the body of the foam glass feedstock, these being microwave radiation and exothermic reaction heating.

Energy technologies

As a final part of this study, it is necessary to review the energy required to heat the feedstock to form the foam glass. From the operating information provided by a foam glass manufacturer, it is estimated that 70 KWh/m^3 of energy is required for the continuous foaming furnace and 25 KWh/m^3 for the glass preparation (delivery and grinding). Based on the Base Case model (45,000m^3/yr) in a previous chapter of this report, if the continuous foaming furnace energy was reduced by 50% this would save £80,000 (based on £0.05 KWh) on energy per annum. With the result of reducing the net manufacturing cost from £51 to £49m^3, 4% net cost reduction. Looking at economy of scale, a 50% energy saving for the following production capacity would have a greater affect as shown

- 135,000 m^3/yr - 5.9%
- 225,000 m^3/yr - 6.8%

However, the above is based on the assumption that the energy saving is achievable in the order of 50% for the foaming furnace. In reality this is probably not achievable by the alternative heating methods available. The process developed by Misapor requires approximately 100 KWh/m^3 (this equates to approximately £5/m^3 energy cost) for finish foam glass. Therefore, the reduction of energy consumption will not greatly move the economics of the process. A large percentage of the operating cost is attributed to the capital investment of the equipment and buildings. Therefore, reduction in these costs would have more impact on the economics.

Microwave Heating

Microwave heating technology has been developed for industrial processing such as drying and sintering of ceramics. The heat generation is a function of dielectric relaxations that occurs within the materials when subject to microwaves. This allows direct rapid heating with lower levels of energy to achieve temperature when compared to conventional heating. This may offer an economic advantage if the cost of the capital equipment was in the same order of magnitude as conventional heating equipment[68].

The limitation with glass is that commercial glass compositions are virtually transparent to microwave radiation at ambient temperature. However, at higher

[68] M. Knox & G. Copley, Use of microwave radiation for the processing of glass, Glass Technology, Vol 38, No3, pp91-96, 1996.

temperatures, in excess of 500°C, the glass structure relaxes and absorption of microwave radiation increases rapidly with consequent of rapid heating of the glass.

Microwave radiation heating has been investigated by numerous institutions for the heating and sintering of various ceramics from nuclear precursor materials to ceramics for whiteware[69,70]. But it is generally reported that microwave heating is not suitable for large production volumes but more for specialist applications. Bearing this in mind, it should be possible to heat the foam glass feedstock from 500°C by microwave radiation. This would require a furnace that was dual heated, this being a preheated zone by conventional heating to take the feedstock up to 500°C then the microwave radiation energy would increase heating to the required foaming temperature of around 800-900°C.

Another limitation is that most of the industrial microwave heating systems developed work on a static furnace. Foam glass production will require large production volumes to make it economically viable; a static microwave furnace would not be viable. Another limitation is that microwave radiation needs to be guided and focused using wave-guides and as a consequent can be very focused. Therefore, to heat a large volume a number of microwave sources and wave-guides would be required to heat a relatively large volume. Some conceptual work has been documented[71] whereby a continuous furnace similar to that shown in Figure 3 has a number of microwave radiation sources part way along the furnace as shown in Figure 49 below.

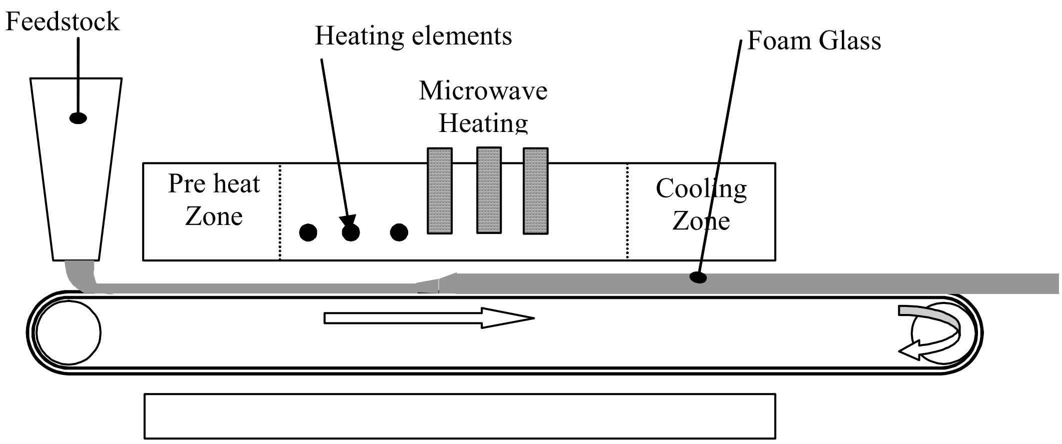


Figure 49 - Continuous furnace for production of foam glass using dual heating, conventional electric and microwave radiation.

Figure 49 shows the concept of dual heating with electric element heating to increase the feedstock to approximately 500°C and then microwave radiation heating to take up to the foaming temperature based on a documented concept. It is envisaged that the processing time would be shorter, due to the rapid heating.

The problem with microwave radiation heating of glass is that it is prone to thermal runaway. This is where the glass couples with the microwave radiation so well at the

[69] J. Binner, Microwave sintering, Ceramic Technology International, pp 183-186, 1992.
[70] K. Lee & G. Love, Commercial microwave sintering of ceramics, Proceeding of Innovative Processing: Ceramics, Glasses & Composites III, pp 71-80, 2000.
[71] G. Tayler, M. Anderson & M. Hamlyn, The use of microwave energy for the firing of heavy clay products, International Microwave Power Institute Proceedings, 36th Annual Microwave Heating Symposium, pp 27-32, Apr 2001.

elevated temperature, that very rapid heating occurs. With foam glass the foam will start to collapse after about 900°C and produce an inferior product. Therefore, the foam glass temperature needs to be controlled; pulsing the microwave radiation could do this. Dr Anderson at Stafford University who has been investigating microwave heating for a number of ceramic and glass applications and has decided to pursue conventional fast roller-hearth kiln technology for ceramic applications rather than pursuing microwave radiation heating. This is a similar heating technology as currently used by foam glass manufacturers.

Exothermic Reaction

An exothermic reaction is the release of heat from a reaction known as the 'heat of reaction'. In the special metal industry, exothermic reactions are used to produce special metal or alloys that are not practical by conventional methods. For example the production of chromium is as follows:

$$Cr_2O_3 + 2Al \Rightarrow 2Cr + Al_2O_3$$

The heat of reaction produces temperatures is in excess of 3000°C and the reaction is simply started by igniting a fuse. Obviously this reaction is very hazardous and generates so much heat that it would not be suitable for foam glass production. However, there are reactions that require heat to trigger the reaction and it might be possible to form a gas for the foaming reaction such as:

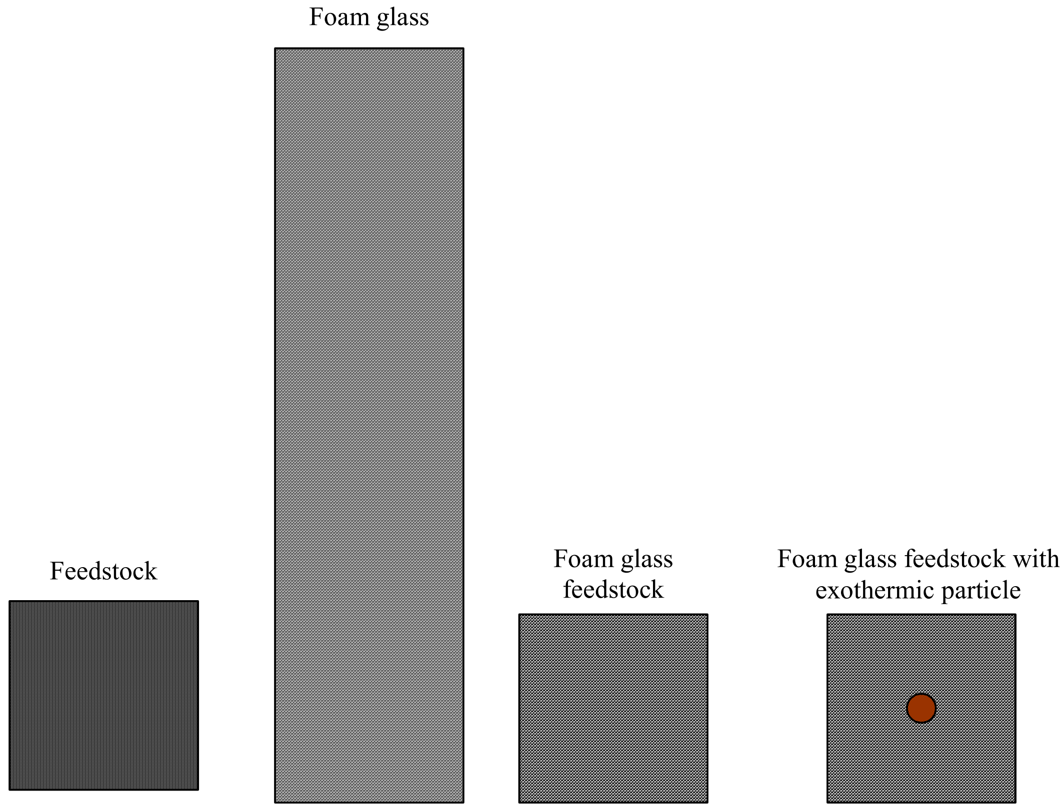
$$3CaSO_4 + 2Al \Rightarrow Al_2O_3 + 3CaO + 3SO_2$$

It is reported by Dr Kennedy of Nottingham University who works in the field of exothermic reaction research for the special metals industry, that this reaction will not occur until approximately 800°C, at which point it would release energy and SO_2. The concern with such a reaction is the controllability. This reaction would occur over a very short period, less than 1 second, resulting in a relatively high release of energy. This would most likely lead to a thermal runway where the foam glass is overheated and would collapse under its own weight. If this technique is deemed of interest then more detailed research needs to be undertaken.

Due to the nature of the reaction it is necessary to have very finely ground precursor materials for the exothermic reactions. The processing and storage of finely ground materials can be hazardous, for example, finely ground metallic aluminium is very volatile as it has an affinity to oxygen to form aluminium oxide. Therefore, any process that includes an exothermic reaction will require very strict health and safety controls. To try and understand the effect of introducing an internal heat source this condition was modelled using Computational Fluid Dynamics.

Computational Fluid Dynamics Modelling

As part of this study to understand the effect of introducing an internal heating effect into the body of foam glass, GTS commissioned Fluent Europe Ltd to undertake a Computational Fluid Dynamics (CFD) model of foam glass formation.



Figures 50-51 - The first CFD for the electric element top heating case (left) assumed an expansion in one direction with an expansion of four times the feedstock height. The second CFD for the exothermic case (right) assumes 2% volume addition of an exothermic compound, which equates to 99, 100 microns diameter particles of glass to a 125 microns diameter particle of exothermic compound.

The first scenario was based on electric element top heating in a continuous furnace as described earlier. GTS calculated the thermal characteristics of the feedstock and foam glass for the CFD model. It was assumed that the feedstock would expand by four times (Figure 50) to achieve the full foam glass body. It is known that foam glass takes approximately 20 to 30 minutes to reach its full expansion in a typical commercial process, the CFD model indicated a time of only 3 minutes. This discrepancy is probably due to the assumptions made, such as ignoring edge effects and heat transfer between the conveyor belt and the foam glass. Also, the thermal characteristic data is purely calculated, as there appears to be no information in the public domain on thermal properties of foam glass as it forms. However, this first model was a good benchmark for comparison against the second scenario, which was the use of exothermic compound distributed evenly throughout the feedstock.

The second scenario assumed a 2% volume addition (Figure 51) of an exothermic compound that releases heat at 800°C and SO_2 to create foam glass. This indicated that the foaming process time was reduced by 7% from 150 seconds down to 140 seconds. This would result in a possible energy saving 7 KWh/m^3 and based on £0.05/KWh this would reduce the cost of foam glass production by £0.35/m^3.

Summary

It would appear that the introduction of an internal heat source into the foam glass body has the potential to reduce heat energy by 7 KWh/m^3. However, when this is balanced against the potential capital and operational control cost of a continuous dual heated furnace using microwave radiation, it does not appear attractive. At present there appears to be no commercial supplier of a continuous furnace incorporating microwave radiation heating. However, if this situation changes in the future it may become viable and this should be revisited.

With regard to exothermic reaction heating, there needs to be further work to investigate suitable reactants that are both commercially viable and safe to use in a continuous production facility.

It is recommended that the use of traditional continuous rapid heating furnaces be adopted for foam glass manufacture.

Conclusion

Traditional construction products

The UK construction industry has witnessed a 54% growth in the last decade, was valued at £72 billion in 2001, consumes more than 290 million tonnes of construction products per year and is a significant market place for foam glass products – namely bricks, blocks, panels and pre-fabricated elements. This growth is predicted to rise by 66% by 2010 which will be matched by a growing demand for construction products.

This survey has identified 236 million tonnes of traditional construction products that could be manufactured using the foam glass process, but a more realistic figure would be between 2.3 million and 11.8 million tonnes at a 1% and 5% penetration of these traditional markets. The value of these products vary depending on their size, density and quality and commonly have a low and high value. These can be as low as £3.67 or high as £1,077 per m^2 but are commonly between £11 and £60 per m^2.

Foam glass products

Current foam glass products are manufactured as slabs, blocks or loose aggregate using a continuous process requiring energy for the drying, heating and firing of the foam glass product. This survey has identified 45 patents and 18 foam glass products currently being manufactured in Europe and USA. These range from underground pipe insulation to precast concrete panels. Typical process costs are from £30/m^3 to £200/m^3 for low and high value products.

Foam glass products commonly have properties that are good insulation, high strength, non-water absorbent, rodent resistant, effective sound absorption, non-toxic and chemically stable. Similarly, the lightweight nature of foam glass products has the advantage of design flexibility, construction productivity, lower construction costs, reduced manual handling, lower transport costs, and lower foundation costs. However, for foam glass production to be economically viable there needs to be a readily available supply of waste glass at a low cost. Foam glass can tolerate very poor quality waste glass, which is not suitable or required by other users.

Investment Appraisal for UK Foam Glass

The Investment Appraisal for foam glass assumed a Base Case scenario for the processing of 45,000 m^3 of foam glass product using 10,000 tonnes of waste glass per annum. The expected revenue assumed the price of foam glass would range from £30/m^3 to £200 m^3 and the most likely value of £60/m^3. The Base Case scenario, with an expected benefit of £60/m^3 concludes that the net present value (NPV) over the 25 year study would be £5.6 million. If the price was £30/m^3 the investment would fail to be financially viable. If £200/m^3 was earned the NPV would be nearly £80 million. This suggests that the expected revenue of the foam glass is a very significant parameter assumption.

An investment appraisal for two larger plants at 112,000 m^3 and 225,000/m^3 were chosen to compare economies of scale. The results show that these would require additional capital investment and higher operating costs but economies of scale would lead to cost savings with a savings to investment ratio (SIR) for both scenarios of 4:1. Hence, the ideal size of a processing plant will produce 225,000/m^3 of product (50,000 tonnes of waste glass) with an additional investment of £22.7 million providing an additional benefit of £98 million With this size of plant, the cost of foam glass products can be as low as £30/m^3 and still provide a discounted payback period of about 4 years with an internal rate of return (IRR) of 30%. Foam glass products generally range from £30/m^3 to £65/m^3 for loose foam glass aggregate and up to £200/m^3 for pre-shaped bricks, blocks, panels and insulation.

The size of the production plant will affect the internal rate of return (IRR). Whereas a plant capacity of 45,000 m^3 of output at £30 m^3 would never repay the initial investment, a plant capacity of 225,000 m^3 could provide a discounted payback period in just 4 years with and an IRR of 30%. Naturally, the greater the production rate the more economically viable the process becomes.

Best practicable environmental option for foam glass production

This study analysed the best practicable environmental option (BPEO) for foam glass production by comparing the process to other waste management routes (container recycling, bottle banks, landfill) and assessing the environmental impact of the foam glass products. The source and type of waste glass which could be used for the foam glass production was analysed with the recommendation that a mixture of packaging cullet, flat glass, end of life vehicles glass and cathode ray tubes is to be used. A scoping matrix identified the potential markets for waste glass and ranked the foam glass process as having a high impact as a waste management option in terms of waste quality, processing, value of product, technical issues, market size and environmental impact of process. It is scored equally with use of glass as a constituent in concrete, in glasphalt and as a decorative product.

The BPEO assessment revealed the global warming potential of several scenarios. The foam glass plant at 225,000 m^3 production and 50,000 tonnes of waste glass per annum has the least potential and is the most favoured of the three plant capacities tested. The key environmental considerations from the foam glass process is the actual collection and transportation of the glass cullet. Therefore, a plant should be situated near to the source of waste glass (preferably a mixture of types) and glass crushing should occur either on-site or at an intermediate facility which could also be used for stockpiling. The BPEO assessment scores the 225,000 m^3 facility the highest, in terms of environmental, legislative, technical, economic and social criteria. This is largely due to the cost savings in using a high amount of relatively unprocessed glass waste. The environmental benefit of using this amount is that the lower global warming potential offsets the increase in emissions from the transportation of the cullet.

Environmental assessment of foam glass products

The environmental assessment analysed the impacts of foam glass products in terms of the type of foaming agent used, and the most beneficial is either calcium carbonate ($CaCO_3$) or silicon carbide (SIC). An assessment of comparative products and foam glass was made for concrete mixes, blockwork and insulation products. Foam glass in concrete using $CaCO_{3,}$ has a lower environmental impact than traditional concrete, as does foam glass blockwork using $CaCO_3$ or fly ash. With regard to insulation products, foam insulation has a smaller environmental impact when compared to five other products.

This study has identified the BPEO for glass waste and the environmental assessment of foam glass products. A scoping matrix identified the markets for waste glass and ranks the foam glass production technique as having a high impact and as such is a better waste management option than some others. Foam glass is a high value product which can utilise a considerable amount of waste glass with low environmental impacts. In general, most of the emissions occur during the collection, transportation and sorting of the glass. Emissions from recycling will be greater in rural areas than urban areas due to the lower tonnage collected in sparsely populated areas. The key requirements from an environmental perspective for a foam glass production plant are that:

- the 50,000 tonnes per year plant would seem most beneficial in terms of air emissions, energy consumption and the BPEO Assessment.
- the foam glass production plant needs to be located close to the source of the waste as possible and sorting kept to the minimum.
- the amount of Nitrous oxides (NOx) produced increases with the amount of waste glass used in the process, as more cullet has to be transported. Emissions will reduce with the introduction of cleaner vehicles and fuels.
- collectively across all categories, glass foam made using $CaCO_3$ has the lowest environmental impact, closely followed by Silicon Carbide, fly ash and $CaSO_4$.
- the environmental impact of concrete which uses virgin aggregate is higher than that of concrete using foam glass aggregate (produced using the $CaCO_3$ foaming agent) but similar to that using fly ash.
- solid foam glass blockwork has the smallest global warming potential and lowest environmental burden when compared to aerated and dense blockwork alternatives.
- Foam glass insulation has lower global warming potential than aerated block and in some circumstance, glass wool and rock wool products.

Alternative energy sources

Prior to this study it was believed that foam glass production would require excessive quantities of energy. This study however, indicated that the energy consumption was not a major operating cost as the technology to minimise energy was well developed. It was the payback of capital and plant labour costs that contributed to the largest portion of the costs. It is believed that continuous microwave radiation heating is not currently employed by similar high volume manufacturing processes such as ceramic and brick manufacturing, for the reason of capital cost and inability to control microwave radiation heating. The use of exothermic reactions for heating is fraught with problems such as excessive heat, control and health & safety issues. Therefore, both these heating methods are probably not viable for foam glass production.

An alternative route to information is via modelling. Examining the computational fluid dynamics (CFD) modelling data in some detail suggests that the time required for foaming would be between 20% to 40% longer for a 200 mm thick block compared with the 100 mm cross section already modelled. There is, however, a distinct possibility that at this rate the top surface of the foam would start to collapse and therefore a slower heating rate may be required. In order to maintain the integrity of the block slower heating would be required. Based on this the energy consumption of blocks could be envisaged to be up to 50% higher per cubic metre compared to aggregate production. The capital and operating costs for block production will also be higher due to the requirement for moulds and machining equipment.

In light of this discussion it is clear that while the economics of foam glass production may be changed by an alternative heating method it is unlikely that this change will be significant. Further research into heating methods is therefore not to be recommended. Transfer and optimisation of existing technology is likely to be a much more viable route.

Recommendations for Future Work

- Geofil, Delamar, Misapor & Millcell have approached BRE and GTS and would each like the opportunity to develop a business plan for a foam glass manufacturing facility in the UK with prospective partners. BRE and GTS would welcome the opportunity to develop this partnership.
- Develop, test and certify a range of products and applications using foam glass. Products that have the least environmental impact compared to other comparable products are foam glass insulation, foam glass blockwork and foam glass concrete. These should be given priority over concrete foam glass and foam glass concrete blockwork.
- The original proposal submitted by BRE to WRAP to develop a process protocol for foam glass, should only be considered after it has been amended in light of this report. There is now, a greater need to develop products and get them to market rather than replicate lab- and pilot-scale trials. BRE would welcome the opportunity to amend the original proposal.
- Develop a system for the effective collection of contaminated glass for use in the foam glass process to include glass from end of life vehicles, cathode ray tubes and flat glass from the replacement window and demolition sectors. This should take into account transportation as it is a key issue in terms of emissions.

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Appendices

Appendix 1 – Imports and exports of UK construction products

Table 7: Imports and Exports of Aggregates 1992-2001 (DTI)

AGGREGATES	Imports of Aggregates	Exports of Aggregates	Balance of Aggregates
	£000s	£000s	£000s
1992	12,040	28,346	16,306
1993	10,735	27,344	16,609
1994	18,361	35,147	16,786
1995	18,221	43,283	25,062
1996	12,495	46,953	34,458
1997	12,260	44,648	32,388
1998	13,326	40,932	27,606
1999	12,687	44,254	31,567
2000	14,649	42,770	28,121
2001	16,009	52,123	36,114

Aggregates: Table 7 shows Imports have grown (33%) from approximately £12.04 million to £16.01 million and Exports have grown (84%) from £28.35 million to £52.12 million whilst the net balance of trade has been positive (121%) from £16.31 million to £36.11 million.

Table 8: Imports and Exports of Clay Bricks 1992-2001 (DTI)

CLAY BRICKS	Imports of Clay Bricks	Exports of Clay Bricks	Balance of Clay Bricks
	£000s	£000s	£000s
1992	5,503	4,558	-945
1993	5,108	4,138	-970
1994	9,948	8,398	-1,550
1995	8,891	11,213	2,322
1996	6,756	25,925	19,169
1997	7,600	7,099	-501
1998	6,444	7,005	561
1999	9,306	7,470	-1,836
2000	13,310	5,756	-7,554
2001	13,757	5,525	-8,232

Clay Bricks: Table 8 shows Imports have grown (150%) from approximately £5.5 million to £13.76 million and Exports have grown (21%) from £4.56 million to £5.53 million whilst the net balance of trade has been variable but positive (771%) from £-0.95 million to £-8.23 million.

Table 9: Imports and Exports of Clay Roof Tiles 1992-2001 (DTI)

CLAY ROOF TILES	Imports of Clay Roofing Tiles	Exports of Clay Roofing Tiles	Balance of Clay Roofing Tiles
	£000s	£000s	£000s
1992	5,047	1,513	-3,534
1993	898	1,577	679
1994	1,037	1,400	363
1995	3,418	1,442	-1,976
1996	4,967	3,756	-1,211
1997	4,262	2,962	-1,300
1998	7,857	3,630	-4,227
1999	6,001	3,490	-2,511
2000	5,636	5,017	-619
2001	4,339	2,611	-1,728

Clay Roof Tiles: Table 9 shows Imports have reduced (-14%) from approximately £5.05 million to £4.34 million and Exports have grown (73%) from £1.51 million to £2.61 million whilst the net balance of trade has been negative (-51%) from £-3.53 million to £-1.73 million.

Table 10: Imports and Exports of Concrete Blocks & Bricks 1992-2001 (DTI)

CONCRETE BLOCKS & BRICKS	Imports of Concrete Blocks & Bricks	Exports of Concrete Blocks & Bricks	Balance of Concrete Blocks & Bricks
	£000s	£000s	£000s
1992	2,519	4,826	2,307
1993	1,281	5,251	3,970
1994	2,324	7,034	4,710
1995	2,302	8,780	6,478
1996	2,259	13,308	11,049
1997	3,976	13,416	9,440
1998	5,173	12,633	7,460
1999	4,372	12,067	7,695
2000	3,930	11,697	7,767
2001	2,725	13,863	11,138

Concrete Blocks & Bricks: Table 10 shows Imports have grown (8%) from approximately £2.52 million to £2.73 million and Exports have grown (187%) from £4.83 million to £13.86 million whilst the net balance of trade has been positive (383%) from £2.31 million to £11.14 million.

Table 11: Imports and Exports of Concrete Roof Tiles 1992-2001 (DTI)

CONCRETE ROOF TILES	Imports of Concrete Roofing Tiles	Exports of Concrete Roofing Tiles	Balance of Concrete Roofing Tiles
	£000s	£000s	£000s
1992	645	1,324	679
1993	1,161	1,002	-159
1994	1,498	3,365	1,867
1995	1,753	2,192	439
1996	719	2,548	1,829
1997	415	3,031	2,616
1998	711	2,887	2,176
1999	1,393	4,445	3,052
2000	1,868	6,778	4,910
2001	2,796	7,643	4,847

Concrete Roof Tiles: Table 11 shows Imports have grown (334%) from approximately £0.65 million to £2.8 million and Exports have grown (477%) from £1.32 million to £7.64 million whilst the net balance of trade has been positive (614%) from £0.68 million to £4.85 million.

Table 12: Imports and Exports of Concrete Paving 1992-2001 (DTI)

CONCRETE PAVING	Imports of Concrete Paving	Exports of Concrete Paving	Balance of Concrete Paving
	£000s	£000s	£000s
1992	5,070	3,619	-1,451
1993	7,396	5,806	-1,590
1994	4,587	12,066	7,479
1995	3,143	16,638	13,495
1996	4,219	19,511	15,292
1997	3,703	19,217	15,514
1998	6,298	29,563	23,265
1999	7,690	26,861	19,171
2000	7,845	25,823	17,978
2001	6,642	28,188	21,546

Concrete Paving: Table 12 shows Imports have grown (31%) from approximately £5.07 million to £6.64 million and Exports have grown (679%) from £3.62 million to £28.19 million whilst the net balance has been positive (1,485%) from £-1.45 million to £21.55 million.

Table 13: Imports and Exports of Fibre Cement Products 1992-2001 (DTI)

FIBRE CEMENT PRODUCTS	Imports of Fibre Cement Products	Exports of Fibre Cement Products	Balance of Fibre Cement Products
	£000s	£000s	£000s
1992	21,090	6,482	-14,608
1993	17,588	3,110	-14,478
1994	21,497	5,140	-16,357
1995	18,473	5,543	-12,930
1996	14,696	8,556	-6,140
1997	14,572	15,810	1,238
1998	11,655	12,908	1,253
1999	12,162	14,456	2,294
2000	11,910	12,557	647
2001	13,588	10,886	-2,702

Fibre Cement Products: Table 13 shows that Imports have reduced (-36%) from approximately £21.09 million to £13.59 million and Exports have grown (68%) from £6.48 million to £10.89 million whilst the net balance of trade has been variable but negative (-81%) from £-14.61 million to £-2.7 million.

Table 14: Imports and Exports of Unglazed Ceramic Tiles 1992-2001 (DTI)

UNGLAZED CERAMIC TILES	Imports of Unglazed Ceramic Tiles	Exports of Unglazed Ceramic Tiles	Balance of Unglazed Ceramic Tiles
	£000s	£000s	£000s
1992	7,775	5,859	-1,916
1993	7,895	4,183	-3,712
1994	10,021	5,308	-4,713
1995	10,626	5,617	-5,009
1996	12,643	5,464	-7,179
1997	15,235	5,175	-10,060
1998	18,790	5,636	-13,154
1999	19,229	4,631	-14,598
2000	22,330	4,027	-18,303
2001	22,303	3,220	-19,083

Unglazed Ceramic Tiles: Table 14 shows that Imports have grown (187%) from approximately £7.78 million to £22.30 million and Exports have reduced (-45%) from £5.86 million to £3.22 million whilst the net balance of trade has been negative (-896%) from £-1.92 million to £-19.08 million.

Table 15: Imports and Exports of Glazed Ceramic Tiles 1992-2001 (DTI)

GLAZED CERAMIC TILES	Imports of Glazed Ceramic Tiles	Exports of Glazed Ceramic Tiles	Balance of Glazed Ceramic Tiles
	£000s	£000s	£000s
1992	115,544	13,048	-102,496
1993	97,502	17,902	-79,600
1994	120,973	16,491	-104,482
1995	130,441	16,662	-113,779
1996	177,871	18,288	-159,583
1997	205,218	19,548	-185,670
1998	231,477	15,770	-215,707
1999	204,059	13,999	-190,060
2000	227,862	12,518	-215,344
2001	211,977	12,835	-199,142

Glazed Ceramic Tiles: Table 15 shows that Imports have grown (84%) from approximately £115.54 million to £211.98 million and Exports have reduced (2%) from £13.05 million to £12.84 million whilst the net balance of trade has been variable but mostly negative (-94%) from £102.50 million to £199.14 million.

Table 16: Imports and Exports of Ceramic Sanitary Ware 1992-2001 (DTI)

CERAMIC SANITARY WARE	Imports of Ceramic Sanitary Ware	Exports of Ceramic Sanitary Ware	Balance of Ceramic Sanitary Ware
	£000s	£000s	£000s
1992	16,250	30,982	14,732
1993	14,101	27,961	13,860
1994	20,646	34,011	13,365
1995	22,957	35,772	12,815
1996	25,492	38,806	13,314
1997	32,545	39,639	7,094
1998	33,911	40,325	6,414
1999	41,277	41,936	659
2000	59,719	41,168	-18,551
2001	67,533	26,752	-40,781

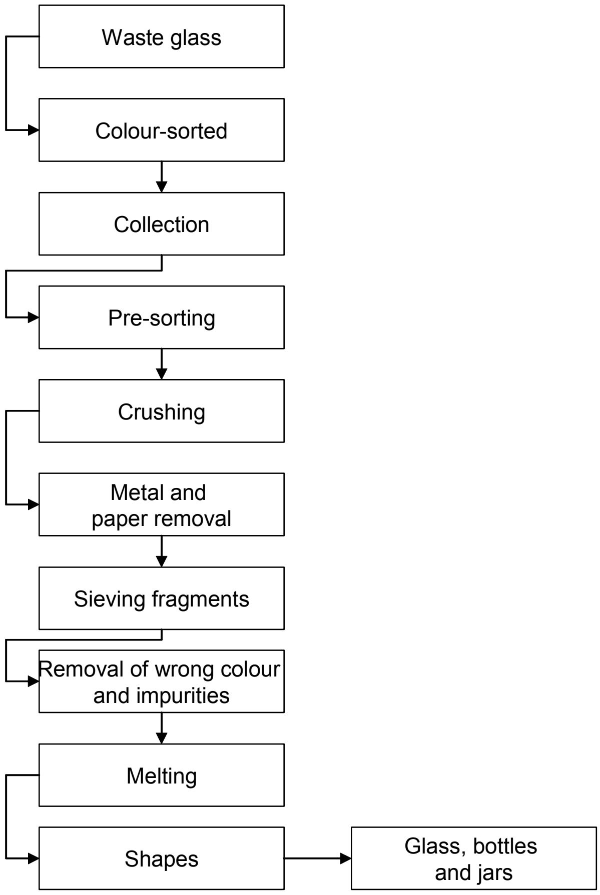
Ceramic Sanitary Ware: Table 16 shows that Imports have grown (316%) from approximately £16.25 million to £67.53 million and Exports have reduced (-14%) from £30.98 million to £26.75 million whilst the net balance of trade has been mostly positive but overall negative (-277%) from £14.73 million to £-40.78 million.

Appendix 2 – Table 17, Import and Export Matrix for select UK construction products

	Aggregates	Clay Bricks	Clay Roof Tiles	Concrete Blocks & Bricks	Concrete Roof Tiles	Concrete Paving	Fibre Cement Products	Unglazed Ceramic Tiles	Glazed Ceramic Tiles	Ceramic Sanitary Ware
Is the product net imported?	×	✓	✓	×	×	×	✓	✓	✓	✓
Is the product net exported?	✓	×	×	✓	✓	✓	×	×	×	×
Is the market expanding for exports?	✓	✓	✓	✓	✓	✓	✓	×	×	×
Is the market expanding for imports?	✓	✓	×	✓	✓	✓	×	✓	✓	✓
Market Value for 2001 (£000's)	68,123	19,282	6,950	16,588	10,439	34,830	24,447	25,523	224,812	94,285
% Growth of market (negative values = losses to UK economy)	121	-771	-51	383	614	1485	-81	-896	-94	-277

Appendix 16 – Container Glass Recycling

The figure below shows one example of the current process for container glass recycling. Cullet is fed into a reception hopper linked to a variable speed conveyor belt, the rate at which this moves controls the whole process i.e. the heavier the contamination level the slower the processing rate to maximise the efficiency of contaminant removal. Overband magnets remove any ferrous metal items and the conveyor belts passes onto a crusher, usually via manual picking stations to remove other large contaminants. After crushing, the cullet is fractioned dependant upon the fragment sizes using a vibrating two-deck system. Vacuum hoods remove light materials and the fines pass through a micro-processor which analyses the material via laser of infrared. Non transparent opaque materials such as ceramics are rejected using a high pressure air jet. There have been significant problems with cullet collections over the last few years due mainly to wide fluctuations in the market prices, reflecting price reductions for raw materials. Also, the increasing proportion of cullet used in the manufacturing process has led to a demand of much higher quality standards, and more sophisticated technologies for processing containers.



Container bottle recycling process

Although the glass container industry is striving to increase the amount of recycled glass it uses, the industry currently has the capacity to use only about a third of the total glass in the waste stream. With PRN revenue making recycled glass economically attractive and the industry being influenced by the Climate Change Levy, where the use of cullet reduces the energy consumption considerably, there has been a significant drive to use recycled glass in place of virgin raw materials. The amount of glass recycled for packaging increased to 35% in 2001. The table below indicates the amount of glass that has been recycled back into container manufacture in the UK.

	Thousand tonnes			
	Clear	**Green**	**Brown**	**Mixed**
2002	196.4	242.5	55.4	Unknown
2001	197.1	270.6	65.1	4.8
2000	217.8	279.5	65.4	3.9
1999	171.7	262.8	61.6	2.5
1998	148.7	267.5	60.1	1.4
1997	147.1	219.6	65.5	Unknown

Tonnage of glass recycled back into container manufacture in the UK[72]

Environmental benefits can be generated by using recycled glass cullet instead of raw materials in the manufacturing of glass, with reductions in energy, quarrying and emissions to be gained. The majority of the glass manufacturing plants for the recycling of glass cullet are located in the North of England. Therefore transportation and collection costs and the environmental impact of recycling glass back into containers can impact on the viability of any glass recycling system, if located long distances away. The main barrier to recycling glass back into containers is the shortage of clear cullet collected in the UK as the UK produces and exports a lot of clear glass. The UK imports twice as much green glass as is manufactured, mainly in the form of wine bottles. In the past this has led to a surplus of green cullet. Recently new markets for green glass such as glasphalt have increased demand so much that there is now a shortage of green cullet. An increase in demand for cullet from glassmakers and the aggregates industry has raised the market for used glass containers and there is growing competition for the glass packaging waste. This is being matched by investment in new plants and sorting equipment.

[72] Edwards, D.W. and Schelling J. Municipal waste life cycle assessment. Part 2: Transport analysis and glass study, Transactions of the Institute of Chemical Engineers, Vol.77, Part B, 2000

Appendix 17 – Assumptions for the BPEO Assessment and Ecoprofiling

Generic scenario data

Population	100,000
Average people per household	2.0
No of households	50,000
Distribution of petrol vehicles	90%
Distribution of diesel vehicles	10%
Distance from MRF	6km
Distance from sorting facility/bank to reprocessing plant/factory	100km
Diesel Truck - collection	20 tonnes
Diesel Truck – fuel usage	0.326 litres/km
Special trips to bottle banks per household per year	40
Average car journey to bottle bank	3km

Generic foam glass data (FROM MISAPOR)

Density of foam glass:	225 kg/m^3 (density for crushed foam glass used in concrete may be higher)
Transportation distance of waste glass cullet	25 miles
Energy demand at manufacture	100 KWh/ m^3
Cullet usage	22 kg/m^3
Foam agent	2.24 kg/m^3
Additional CO_2 or SO_2 demand	1.484 kg/m^3
Water demand	200 kg/m^3

Glass foam concrete data

Density of foam glass concrete	1300 kg/m^3
Cement content	350 kg/m^3
Aggregate content	774 kg/m^3
Water content	176 kg/m^3
Energy requirement for aggregate crushing	3.36 KWh per m^3 of glass foam aggregate

Glass foam structural block data

Density of foam glass structural blockwork	225 kg/m^3

Density of foam glass concrete structural blockwork	1300 kg/m^3
Unit surface area	1m^2
Unit thickness	0.1m

Glass foam insulation

Density of foam glass insulation	225 kg/m^3
Conductivity of foam glass	0.08 W/m^2K
Thermal resistance of all insulation	1.45 W/m^2K
Unit surface area	1m^2
Unit thickness	0.116m

Appendix 18 (a) BPEO Assessment for the Scenarios

	Specification Details	Name	Scenario 1: Bring Bottle	Scenario 2: Foam Glass
Description		Product Description	Container Glass	Container Glass
	Production Process	Process	Bring bottle, Stockpiled, Reprocessor	Bring Bottle, Stockpile, Foam Glass Factory
		Location	North England	North England
Baseline Assessment	Type of glass waste		Bring bottle	Bring bottle
	Quantity of glass waste		10,000 tonnes/annum, 25,000 tonnes/annum, 50,000 tonnes/annum	10,000 tonnes/annum, 25,000 tonnes/annum, 50,000 tonnes/annum
	Quality of glass waste		Heavily Contaminated	Moderately Contaminated
	Source of glass waste	Geographical source	Bring bottle sites within a defined region: population of 100,000	Bring bottle within 100,000 population region
		Transportation impacts	Diesel Truck: 20 tonnes	Diesel Truck: 20 tonnes
Scoping Exercise	Current technology for glass waste management	Type of technology	Container Recycling	Foam Glass
		Feasibility		
		Location		

Appendix 18 (b) BPEO Assessment for the Scenarios

	Specification Details	Name	Scenario 1: Bring Bottle	Scenario 2: Foam Glass
Social	Employment		2	10
	Skills base		Low	Meidum
	Transportation	Mode - road, rail & water	Road	Road
		Vehicle size and type	Diesel Truck: 20 tonnes	Diesel Truck: 20 tonnes
		Distance travelled	4km to Bring bottle site - 40/year/houshold. 100km to reprocessing plant	4km to Bring bottle site - 40/year/houshold. 100km to foam glass plant
		Route	A Roads & Motorway	A Roads & Motorway
		Fuel Efficency	0.328 (litres/km)	0.328 (litres/km)
	Community		Low	Low
	Accidental risks		Low	Low
	Public acceptability		High	Medium
	Health		Low	Low

Appendix 18 (c) BPEO Assessment for the Scenarios

	Specification Details	Name	Scenario 1: Bring Bottle	Scenario 2: Foam Glass
Legislative	Environmental legisation		Packaging Regulations	Packaging Regulations
	Proximity Principle		Reprocessor - 100km	Foam glass plant - 100 km
	Waste Hierachy		Recycling	Recycling - requiring MRF for kerbside glass
Technical	Practical deliverability		High	Medium
	Technical Feasibility		High	Medium
	Flexibility		Medium	Low
	Innovation		Medium	High
	Specifications and Standards		Standards for cullet processors	None required
Economic	PRN Value		£10.25 per tonne	£10.25 per tonne
	Operational costs		£2 per tonne crushing	£2 per tonne crushing
	Transport cost		£100 per tonne	£90 per tonne
	Stockpiling		£9 per tonne	£9 per tonne
	MRF Costs		n/a	£50 per tonne
	Markets		High value	High value

Appendix 19 – Environmental Issues and Ecopoints

Environmental Issues

Climate change

"Global warming" is associated with problems of increased desertification, rising sea levels, climatic disturbance and spread in disease. It has been the subject of major international activity, and methods for measuring it have been presented by the Intergovernmental Panel on Climate Change (IPCC).

Gases recognised as having a "greenhouse" or global warming effect include CFCs, HCFCs, HFCs, methane and carbon dioxide. Their relative global warming potential (GWP) is calculated by comparing their global warming effect after 100 years to the simultaneous emission of the same mass of carbon dioxide.

Fossil fuel depletion

This issue reflects the depletion of the limited resource that fossil fuels represent. It is measured in terms of the primary fossil fuel energy needed for each fuel.

Ozone depletion

Ozone depleting gases cause damage to stratospheric ozone or the "ozone layer". There is great uncertainty about the combined effects of different gases in the stratosphere and all chlorinated and brominated compounds that are stable enough to reach the stratosphere can have an effect. CFCs, Halons and HCFCs are the major causes of ozone depletion. Damage to the ozone layer reduces its ability to prevent ultraviolet (UV) light entering the earth’s atmosphere, increasing the amount of harmful UVB light hitting the earth’s surface.

Human toxicity to air and water

The emission of some substances such as heavy metals can have impacts on human health. Assessment of toxicity has been based on tolerable concentrations in air, air quality guidelines, tolerable daily intake and acceptable daily intake for human toxicity.

Waste disposal

This issue reflects the depletion of landfill capacity, the noise, dust and odour from landfill (and other disposal) sites, the gaseous emissions and leachate pollution from incineration and landfill, the loss of resources from economic use and risk of underground fires etc.

Water extraction

This issue reflects the depletion, disruption or pollution of aquifers or disruption or pollution of rivers and their ecosystems due to over abstraction.

Acid deposition

Acidic gases such as sulphur dioxide (SO2) react with water in the atmosphere to form “acid rain”, a process known as acid deposition. When this rain falls, often a considerable distance from the original source of the gas, it causes ecosystem impairment of varying degree, depending upon the nature of the landscape ecosystems. Gases that cause acid deposition include Ammonia, Hydrochloric acid, Hydrogen Fluoride, Nitrous Oxides and Sulphur Oxides.

Eutrophication (or " over-enrichment of water courses")

Nitrates and phosphates are essential for life, but in increased concentrations in water, they over-encourage the growth of algae, reducing the oxygen within the water leading to increasing mortality of aquatic fauna and flora and to loss of species dependent on low-nutrient environments. Emissions of ammonia, nitrates, nitrous oxides and phosphorous to air or water all have an impact on eutrophication.

Ecotoxicity

The emission of some substances such as heavy metals can have impacts on the ecosystem. Assessment of toxicity has been based on maximum tolerable concentrations in water for ecotoxicity.

“Low level ozone creation” (or Summer Smog)

In atmospheres containing nitrogen oxides (a common pollutant) and volatile organic compounds (VOCs), ozone creation occurs under the influence of radiation from the sun. Different VOCs, such as solvents, methane or petrol, react to form ozone at different rates. Although ozone in the upper part of the atmosphere is essential to prevent ultraviolet light entering the atmosphere, increased ozone in the lower part of the atmosphere is implicated in impacts as diverse as crop damage and increased incidence of asthma and other respiratory complaints.

Minerals extraction

This issue reflects the total quantity of mineral resource extracted. This applies to all minerals, including metal ore, and applies to both UK and overseas extraction. The extraction of minerals for building in the UK is a high profile environmental topic but the minerals themselves are not considered to be scarce. Instead, this issue is a proxy for levels of local environmental impact from mineral extraction such as dust and noise. It assumes that all mineral extractions are equally disruptive of the local environment.

Ecopoints

BRE’s Ecopoints are a single score which measure environmental impact. The average UK citizen would have an impact equivalent to 100 ecopoints, and the lower the ecopoints score, the lower the environmental impact.

Ecopoints are calculated in the following manner.

First, the impact for each issue must be measured in an appropriate unit. For example, for fossil fuel depletion, the impact is measured in tonnes of oil equivalent (toe). This is known as a characterised impact.

Next, the characterised impacts are compared to the characterised impacts of a typical UK Citizen. These have been calculated by dividing the impacts of the UK by its population. This process is produces normalised impacts.

Lastly, the normalised impacts are weighted. Weighting factors for each environmental issue have been determined by BRE from an extensive research exercise that included consultation with more than seven different interest groups including environmental campaigners, local and national government and manufacturers.

The weighted normalised impacts are called Ecopoints, and they can be added to provide a total Ecopoint score for the system under examination.

The weightings and characterised impacts associated with a typical UK Citizen are provided in the table below.

Issue	% weighting	Characterised Impact associated with a typical UK Citizen
Climate Change	37.8	12300 kg CO_2 eq. (100yr)
Fossil Fuel Depletion	12.0	4.09 tonnes oil eq.
Ozone Depletion	8.2	0.286 kg CFC11 eq.
Human Toxicity to Air	7.0	90.7 kg toxicity
Waste Disposal	6.1	7.19 tonnes
Water Extraction	5.4	418000 litres
Acid Deposition	5.1	58.9 kg SO_2 eq.
Ecotoxicity	4.3	178000 m^3 toxicity
Eutrophication	4.3	8.01 kg PO_4 eq
Photochemical Ozone Creation	3.8	32.2 kg ethene eq.
Minerals Extraction	3.5	5.04 tonnes
Human Toxicity to Water	2.6	0.0275 kg toxicity

% may not add up to 100% due to rounding

Examples

To calculate the Ecopoints for 1 tonne of mineral extraction

Characterised impact = 1 tonne mineral extraction

Characterised impact for 1 typical UK citizen = 5.04 tonnes mineral extraction

Normalised impact = 1/5.04 = 0.198

Weighting = 3.5%

Ecopoints = 0.198 * 3.5 = 0.693 Ecopoints.

To calculate the Ecopoints for 1000 kg of CO_2 emission.

Characterised impact = 1000 kg CO_2 eq

Characterised impact for 1 typical UK citizen = 12300 kg CO_2 eq

Normalised impact = 1000/12300 = 0.0813

Weighting = 37.8%

Ecopoints = 0.0813 * 37.8 = 3.07 Ecopoints

Appendix 20 - Embodied CO_2

"Global warming" is associated with problems of increased desertification, rising sea levels, climatic disturbance and spread in disease. It has been the subject of major international activity, and methods for measuring it have been presented by the Intergovernmental Panel on Climate Change (IPCC).

Gases recognised as having a "greenhouse" or radiative forcing effect include CFCs, HFCs, N_2O and methane. Their relative global warming potential (GWP) has been calculated by comparing their direct and indirect radiative forcing to the emission of the same mass of CO_2 after 100 years. E.g. CFC-11 is 3400 times more powerful as a greenhouse gas than CO_2 and therefore one tonne of CFC-11 is equivalent to 3400 tonnes CO_2. Global warming potential is measured in CO_2 equivalents for each emission, which can be added and entered into the Profile under "Climate change" as CO_2 equivalents (100yrs).

A timescale is applied to the GWP figure because the GWP of different gases is related to the amount of time they will spend in the atmosphere and the amount of radiative forcing they will induce over that period. It is important to recognise how long the gases will last in the atmosphere. For example, both carbon dioxide and CFC-11 are greenhouse gases but they have different half lives in the atmosphere and they will thus have a different relative effect over different timescales. Three different scenarios are available for GWP: 20 years, 100 years and 500 years. The 100 year scenario is most commonly used and has been applied here.

Further details of the calculation of embodied energy and embodied CO_2 are provided in the BRE Environmental Profiles Methodology. (Howard, Edwards and Anderson, BRE 1999)