THE NATIONAL CENTRE FOR BUSINESS & SUSTAINABILITY

SUSTAINABLE MARKETS FOR WASTE GLASS FROM FLUORESCENT TUBES AND LAMPS

Final Report
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This project is supported by Biffaward

Biffaward investing in the environment

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PREPARED BY: Mary Parkinson & Clair Visco
APPROVED:

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1 Summary

The overall aim of this project has been to look at alternative and more sustainable markets for waste glass from fluorescent tube recycling. Biffaward (see Annex A) and Mercury Recycling Ltd have funded the project through the Landfill Tax Credit Scheme.

It has been estimated that 100 million fluorescent tubes (FTs) and highway lamps are used annually in the UK. Much of this ends up in landfill. These products have the potential to cause serious environmental harm due to the mercury (and other components) they contain. The potential exists for mercury to escape from poorly engineered landfill sites into groundwater supplies. The mercury from just one FT is enough to pollute 30,000 litres of water so that the water is no longer safe to drink.

The UK needs to establish technologies and markets for recycling FTs because:

- The WEEE[1] Directive will set targets for recycling of these materials
- Landfill space is limited
- There are risks from mercury contamination from waste FTs in improperly contained landfill sites
- There are environmental impacts and increasing costs associated with the use of virgin resources
- Recycling creates jobs.

All of this points to the requirement for effective FT recycling technologies and markets for recycled materials. These issues are the focus for this project.

Mercury Recycling Ltd (MRL), based in Trafford Park, Manchester, is the UK's first recycler of FTs. It recycles FTs, sodium lamps and other products that contain mercury on behalf of a number of customers. MRL uses a well-established mercury recycling technology, which separates the tube into its component parts of mercury metals, ceramics, plastics and glass for re-use.

The NCBS project has focused on seeking markets for the waste glass from FT recycling by MRL. Some of the benefits of recycling in general have been stated above, however there is an additional benefit to recycling glass. Glass production is a major contributor to climate change (through greenhouse gas emissions) in both energy used and in raw materials consumed. Recycling glass from FTs will therefore contribute to reducing the UK greenhouse gas emissions.

A comprehensive list of potential applications for glass from FTs was drawn up. Many of these already use waste packaging glass collected in 'bottle banks' and waste glass from FT recycling has to compete in these already overcrowded markets.

[1] Waste Electrical and Electronic Equipment

Many potential users of the waste glass expressed concerns about the mercury contamination. Analysis undertaken during this project has shown that levels of mercury on the glass vary between batches from 1 – 9 mg/kg. Potential users of the material had concerns over whether this contamination may give rise to health risks (for handlers of the waste glass) and potential releases of mercury to the environment. The risks involved would vary between applications and need to be assessed against the risks that already exist from the disposal of this material in landfill sites. This may need input from regulators in defining, for example, the "best practicable environmental option". The levels of mercury that would be discharged to the environment as a result of using FT glass is minimal compared to other environmental releases of mercury in the UK.

The project focused on applications where contamination would not be so significant an issue and, for example, where the glass would be "encapsulated".

It was found that it is not possible at present to recycle waste glass back into glass products (including FTs), although technological advances may make this a viable option in the future. Most of the applications explored within this project are best described as "downcycling"[2] alternatives. The most promising applications appear to be as a replacement for aggregates in construction, for example, in roads.

The NCBS project has looked also at potential technologies for improving the recovery of mercury from the waste glass, to provide a less contaminated material for recycling. MRL continues to seek ways to improve the existing recovery process. This project has looked at potential additional technologies that could be used to remove mercury from the glass. Two alternative methods were tested:

1. abrasion, i.e. knocking the mercury off the glass, and
2. heat recovery.

Abrasion was very effective in removing mercury. The project was unable to determine conclusively at what temperature mercury could be removed from the glass.

If implemented, however, these processes would add to the overall costs of the process and could make FT recycling cost prohibitive. Using additional processing would only be viable if the glass could be subsequently put to higher value applications.

1.1 Structure of the report

The remainder of the report discusses the background to the project and the findings. It is structured as follows:

Section2 – describes the rationale and background to the project and the current status of glass recycling in the UK.

[2] True recycling would involve recycling the waste glass back into FTs and other glass products. "Downcycling" involves using the waste glass as an alternative to other materials with similar properties, for example sand, in lower grade applications.

Section 3 - describes the process used to assess the various options for recycling glass from FTs
Section 4 – provides some context for the mercury contamination to assist potential users in assessing the potential risks
Section 5 - contains the general conclusions that can be drawn from the project and provides a number of recommendations for the future.

Supporting information is provided in a series of Annexes at the end of the report.

2 Introduction

2.1 About this project

This project has been funded through the Landfill Tax Credit Scheme by Biffaward. Mercury Recycling Ltd provided the additional third party funding.

The project falls under the Biffaward programme on sustainable resource use (see Annex A), which aims to provide accessible, well-researched information about the flows of different resources through the UK economy based either singly, or on a combination of regions, material streams or industry sectors.

2.2 Background to the project

The UK needs to establish technologies and markets for recycling FTs because:

- The WEEE Directive (see section 2.3.3) will set targets for recycling of these materials
- Landfill space is limited
- There are risks from mercury contamination from waste FTs in improperly contained landfill sites
- There are environmental impacts and increasing costs associated with the use of virgin resources
- Recycling creates jobs.

The UK Waste Strategy sets out a number of targets for the reduction, re-use and recycling of waste. In order to achieve those targets, the UK Government will have to create conditions that will enable the shift from landfill to alternative ways of managing waste. This will necessitate the establishment of recycling technologies and markets for recycled components. The UK is already falling behind the rest of Europe in recycling and may need to export waste to the continent for recycling unless UK-based markets can be established soon.

This project has looked at the issues around recycling glass from FTs. Many of these issues (for example, the need for waste processing technologies to achieve uncontaminated materials and the need to understand the physical and chemical properties of the materials) will be common to other waste streams.

2.3 The legislative and policy context for this project

This project addresses a specific issue of finding alternatives for recycling of glass from FTs. However, it also highlights the difficulties faced in recycling generally. The EU is committed to switching the way we use resources to enable us to become more resource efficient[3]. This will involve developing

[3] ENDS Report – Issue 317, June 2001 ("Wallström hints at producer responsibility shift to materials" and "Ministers lay down guidelines for integrated product policy")

strategies for recovery, separation and recycling of end of life products, which is the focus of producer responsibility regulations, for example, for packaging and WEEE[4].

This section discusses the regulatory and policy framework on recycling and resource efficiency directly applicable to FT recycling.

2.3.1 Waste Resources Action Programme

The Government's Waste Resources Action Programme, WRAP[5], was set up in 2000. Its mission is to promote sustainable waste management by working to create stable and efficient markets for recycled materials and products and by removing barriers to waste minimisation, re-use and recycling. WRAP aims to create a strong demand for recycled materials and products, in conjunction with helping the waste and recycling industries to respond to that demand for recycled materials and products.

The first stage of WRAP's 'Strategy to Action' is to concentrate on achieving a significant increase in recycling. The plan to achieve its strategy is to undertake seven programmes of work which will:

- Create market confidence
- Create a critical mass of demand
- Improve the economics of recycling
- Deliver sufficient high quality feedstock to the recyclers

Four of the seven programmes are focused on specific material streams – paper, glass, plastics and wood. Glass has been selected as a priority because (together with paper) it offers the best potential for tonnage gains.

The targets for glass for 2003/2004 are:

- Recycle 35% (770,000 tonnes) of municipal waste glass a year
- Secure an extra 350,000 tonnes of glass a year from all sources for recycling, including 100,000 tonnes from commercial sources
- Absorb 100,000 more tonnes of glass a year through new uses including shot basting, aquaculture and glass fibre insulation
- Divert at least 200,000 tonnes of green and possibly mixed-colour glass into the construction industry for use as an aggregate
- An increase of 20% (20,000 tonnes) in flat glass collection for recycling

This will be achieved through the following actions:

- A review of key standards, specifications and testing procedures in the most promising areas for using recycled glass
- Help divert higher volumes of glass from municipal and commercial waste streams

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4 Waste Electrical and Electronic Equipment
5 www.wrap.org.uk

- Conduct a research and business support programme to identify and bring to market a high volume of high value recycled glass products
- Encourage more awareness of recycled glass products

Much of this is focused towards packaging glass. However, FT glass recycling could contribute significantly to the overall recycling targets. Currently, Mercury Recycling Ltd recovers approximately 1,500 tonnes of glass per annum. This is set to increase as the WEEE Directive comes into force and other FT processors enter the market. In the UK, it has been estimated that 20,000 tonnes of waste glass from fluorescent tubes is generated each year. Recycling of the glass from these components will contribute to the achievement of WRAP's targets.

2.3.2 The European dimension

In June 2001, the EU adopted a sustainable development strategy[6]. Key strands of the strategy include the development of a chemicals policy to protect public health and the protection of natural resources through greater resource productivity[7].

These themes are also contained within the sixth Environmental Action Programme (EAP), which contains commitments to reducing the impacts of hazardous chemicals on health and to de-coupling economic growth from resource use[8].

Achieving these policy commitments will require a shift from waste disposal to recycling/recovery and greater controls on hazardous chemicals (for example, as seen in the forthcoming WEEE Directive – see section 2.3.3).

2.3.3 Waste Electrical and Electronic Equipment (WEEE) Directive

A proposal was adopted on 13 June 2000 for an EU Directive on the priority waste stream of waste electrical and electronic equipment, WEEE.

The objectives of the WEEE Directive are:

- The prevention of WEEE
- To increase re-use, recycling and other forms of recovery thereby contributing to a higher level of environmental protection and encouraging resource efficiency
- To improve the environmental performance of all operators involved in the life cycle of electrical and electronic equipment, particularly those involved in the treatment of WEEE

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[6] ENDS Daily (18/06/01) *EU sustainable development strategy adopted*
[7] ENDS Report MAY 2001, Issue No. 316
[8] ENDS Daily (08/06/01) *Governments backtrack over EU action plan,* ENDS Daily (25/06/01) *Wallström sets out EU waste policy vision,* ENDS Report FEBRUARY 2001, Issue No. 313 *"Decoupling" ambition for EC's sixth environment programme*

The UK, in line with the rest of the EU, will need to increase the rate of recycling for WEEE. For many waste streams this will necessitate the identification and establishment of infrastructure, technologies and routes for recycling as well as outlets for recycled materials. This report focuses on a particular waste stream, the glass from FTs, but could provide a model for other WEEE waste streams.

An additional directive (Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment Directive) will require the substitution of a number of substances, including mercury, in electrical and electronic equipment.

2.4 Glass recycling in the UK and Europe

Approximately 27% of UK-produced glass is made from recycled glass (Clarke, 1999), of which 22% of the total is obtained from returned packaging deposited in public bottle banks. The remainder is from in-house scrap, broken flat glass and commercial sources. The UK falls well behind EU partners in recycling rates (in 1999 only Greece and Turkey had lower recycling rates than the UK), mainly due to the relative cheapness and availability of landfill capacity. This needs to change as the UK makes good commitments made at the EU level. UK Government is introducing both taxation and producer responsibility measures to encourage reuse and recycling over landfilling of waste. Annex B discusses the glass recycling in more depth.

There is already a struggle to find recycling outlets for glass collected through bottle banks, particularly for green glass. In 1997, the glass industry recycled 425,000 tonnes of glass, of which 206,000 tonnes was green glass. There are large and growing stockpiles of green glass in the UK, France and northern Europe. It is likely that glass from FTs will compete in markets already overcrowded with glass packaging waste.

Waste glass from tubes may have an advantage in costs over packaging glass. In 1997, it cost £30/tonne to transfer material from bottle banks to cullet manufacturers and a further £10/tonne to produce cullet suitable for fresh glass production (Coventry *et al*, 1999) or £15/tonne to produce cullet suitable for use as a construction material (glasscrete). These processing and transport costs for waste packaging glass require recovery of costs from recyclers. Glass container manufacturers pay approximately £40/tonne for cullet. Waste glass from tubes and lamps could significantly undercut the costs for recovery of packaging glass, although transportation costs would need to be taken into account.

2.5 Glass And Fluorescent Tube Manufacture

2.5.1 Fluorescent Tube Components

Fluorescent lighting occurs when an electrical discharge results in UV (Ultra-Violet) light that causes fluorescent powder to emit visible light. FTs are highly efficient and have a long life (3,000 - 5,000 hours, i.e. about one year of continuous use).

The components of a typical FT include:

- Glass tube, including several different glass compositions
- Mercury as a liquid or with iron as a solid
- Ceramic, metal and plastic ends of ballast
- Phosphate/phosphor coatings

2.5.2 Glass Manufacture

Glass is made by fusing silica with an alkali. The basic ingredients are SiO_2 (silica sand) and Na_2O_3 (soda ash) or, more rarely, K_2O (potash). Lime ($CaCO_3$) is essential for reducing melting temperatures to those that can be achieved with existing technology. Lime also increases stability and magnesium, which is also added, improves the clarity of the finished product. The ingredients are dry mixed and fused together in a furnace under intense heat. Cullet (waste glass) of the same composition may be added to facilitate fusion. The use to which the molten glass is put to and the quality of the product is subject to a number of variables, including the correct mix of ingredients, how they are melted and fused and the levels of impurities.

The cost of raw materials is comparatively low, with energy accounting for up to 20% or more of the total cost of production (Clarke, 1999). Heat loss is a significant contributor to this and high energy costs have lead the industry to implement optimisation procedures (Schaeffer, 1999).

Table 2.1 shows that 1,206kg of raw materials are required to produce 1,000 kg (1 tonne) of flat glass. The extra 206kg of raw material equates to the amount of CO_2 produced to make one tonne of glass, which, added to the CO_2 from the energy used, indicates a major contribution to greenhouse gas emissions. This is therefore a major incentive to recycle.

Table 2.1. Typical materials for the production of one tonne of glass

Material	Kg/t of glass	Typical Source
Silica sand	750	Cheshire
Sodium carbonate	215	Cheshire & USA
Dolomite	180	Yorkshire & Spain
Limestone	52	Derbyshire
Sodium sulphate	9	Various
Total	1206	-

Source: Coventry *et al* (1999)

The typical formula of a soda lime silica glass is set out in Table 2.2 below.

Table 2.2. Typical chemical composition of glass

Chemical Constituent	%
SiO_2	72.5
Al_2O_3	2.6
CaO	5.7
MgO	2.9
Na_2O	14.6
K_2O	1.2
B_2O_3	0.3

Source: www.britglass.co.uk

2.5.3 *Fluorescent Tube Manufacture*

The method of manufacture for FTs is 'automatic drawing'. The glass tubes are drawn from the furnace. Phosphor coating, mercury (which is needed to increase lighting efficiency) and ballast are added to the tube.

2.6 The Process of Fluorescent Tube Recycling

The process operated by MRL (Mercury Recycling Ltd) involves crushing the tubes and splitting them into component parts allowing the mercury and other components to be recovered. During this process, the glass from the tubes is crushed to approximately 1cm fragments. Contamination (with pieces of metal and ceramics from the light fittings) occurs due to the difficulties in achieving perfect separation. Around 30 tonnes of waste glass are produced per week (Lebor, *pers. comm.)* from MRl's process although this continues to rise. It has been estimated that around 20,000 tonnes of glass from FTs is disposed of each year.

3 Assessment of Potential Applications for Glass from Fluorescent Tubes

A variety of alternative uses of glass cullet have been identified during this project. Annex C provides a description of these alternatives, which are summarised in Table 3.1. Many already use packaging glass and other recycled materials. This section discusses the issues involved in using glass from FTs in these applications.

In addition, the project looked at the potential to recycle the glass back into FTs. Although this is not possible at present, technological advances may lead to this as an option for the future.

3.1 Initial screening of potential applications

The project looked at the potential for using glass from FTs in the applications listed in Table 3.1 by assessment against a number of criteria:

- Ease of implementation, i.e. is the application already using waste glass
- Timescale for implementation - short, medium or longer term. It will be necessary to identify an application that can take the glass in the short to medium term.
- Limitations of application, for example, specified chemical and physical properties that are required.

This assessment is summarised in Table 3.2.

From this assessment, the NCBS developed an initial shortlist of uses that are already in use or could be developed in the short to medium term. The most promising alternative uses identified during the project were:

- Aggregate in concrete
- Aggregate in cement
- Aggregate in glasphalt
- Cleaning and surface preparation
- Drainage aggregate
- Foam blocks
- Foamglass
- Glass-mica composites
- Traction sands
- Utility line backfill
- Lubricant in oil wells

The waste glass is already used in breeze block manufacture (after use as a flux in hazardous waste incineration) and as an abrasive in surface preparation.

This shortlist of applications was assessed further by looking at the physical and chemical properties of the glass and through contact with potential users.

Table 3.1. The potential alternative uses of glass	
❖ **CONSTRUCTION USES:**	
• Aggregate in concrete and cement;	• Fill;
• Utility line backfill;	• Backfill, e.g. in mines;
• Aggregate, e.g. glassphalt.	
❖ **CONSTRUCTION PRODUCTS:**	
• Bricks;	• Tiles;
• 'Glastic' bricks for decorative effects, e.g. pavers without adhesives;	• Inert filler or flux in conventional bricks;
• Wall and floor tiles;	• Reinforced glass;
• Clay pipes;	• Composite materials;
• Glass-polymer pipes;	• Filler or binder in plastics;
• Filler in paints and rubber.	
❖ **INSULATION:**	
• Foam blocks;	• Foamglass;
• Glass fibres;	• E.g. strengthening of cement, gypsum or resin products and household glass items;
• Fibre glass insulation products;	• Glass-mica composite;
• Glass matrix composites with metallic fibre mats;	• Aggregate in epoxy applications.
❖ **CLEAN-UP AND FILTRATION APPLICATIONS:**	
• Alkaline absorbents;	• In flue-gas cleaning applications;
• Oil spill clean-up material;	• Filtration media;
• Drainage aggregate;	• Sand replacement in septic treatment plants;
• Sand replacement in municipal and hazardous wastewater treatment plants.	
❖ **ABRASIVES:**	
• Non-skid surfaces;	• An aid in the fast-firing of ceramic shapes, tiles and stoneware;
• A lubricant to reduce sticking in drilling oil wells;	• Traction sands;
• Cleaning and surface preparation.	
❖ **WASTE MANAGEMENT:**	
• Landfill applications;	• Landfill cover;
• Components of landfill liner systems;	• Aggregate in leachate collection system;
• Aggregate in gas venting system;	• Waste encapsulation.
❖ **LANDSCAPE AND PLANT MANAGEMENT:**	
• Hydroponics growing medium;	• Landscaping;
• Golf sand traps;	• Decorative soil cover;
• Controlled release fertilisers.	
❖ **DECORATIVE EFFECTS:**	
• Trivets;	• Trinket boxes;
• Picnic benches;	• Tiles;
• Bricks;	• Jewellery;
• Bird houses;	• Home planters;
• Candle holders;	• Coffee tables;
• Paperweights;	• Imitation marble;
• Coasters.	

Table 3.2. Assessment of potential applications for waste glass from fluorescent tubes

Potential use	Timescale[9]	Limitations [10]	Current materials[11]
❖ **CONSTRUCTION USES**			
Utility line backfill	Short	• Possible heavy metal/mercury contamination and leaching potential • Handling difficulties – sharps • Compressibility strength • Particle size	Earth removed for access, Virgin aggregate, Packaging glass
Aggregate in concrete, cement and glassphalt	Short-medium	• Alkali-silica reactions associated with glass • Cost of processed glass vs. virgin aggregates • Speed limitations to 40 mph • Materials specifications do not promote recycling • Reduction in shear strength (particle size dependent) • Reduction in bonding between aggregate and cement paste (particle size dependent) • Potential handling difficulties • Potential heavy metal/mercury contamination	Virgin aggregate, Packaging glass
Backfill, e.g. in mines	Medium-long	• Chemical reactions that may affect stability or leach into ground water • Crushing requirement for a surface area off $300m^2/kg$ and associated cost • Possible sulphate content affecting strength properties • Economics against other alternatives	Waste tailings reinforced with Portland cement
❖ **CONSTRUCTION PRODUCTS**			
Bricks	Short-medium	• Crushing requirements to increase reactivity and associated cost • Economics against other alternatives	Fluoride-containing base clay, Soda (Na_2O), Lime (CaO)
Wall and floor tiles	Short-medium	• Suitability to applications – different tiles require specific characteristics	Flux
Clay pipes	Short-medium	• Crushing requirements to increase reactivity and associated cost • Economics against other alternatives	Flux

[9] Short – process already in place, Medium – process near to commercial use, Long – still at the research/testing stage

[10] Any limitations to use of fluorescent tube waste glass in this application – e.g. geographical location, contaminants, variability, etc. or none known

[11] In applications currently in place, what are the materials currently used

Table 3.2. Assessment of potential applications for waste glass from fluorescent tubes

Potential use	***Timescale***[9]	***Limitations*** [10]	***Current materials***[11]
Glass-polymer pipes	Short-medium	• Potential for heavy metal/mercury to leach from glass	Strengthening agents
Glastic bricks	Medium-long	• Potential heavy metal/mercury content • Suitability to applications – decorative not structural	Waste plastic, Packaging glass
Filler/binder in plastics	Medium-long	• Purity • Particle size	Silicates, Silica
Filler in paints and rubber	Medium-long	• Purity affecting properties, e.g. colour • Particle size	Silicon dioxide, Titanium dioxide and others
Reinforced glass	Long-never	• Contamination affecting strength and colour • Potential for damage to furnace	'clean' waste glass from processing
❖ **INSULATION**			
Foam blocks	Short	• Potential for metal leaching	Cement, Aggregate Note: Current use with Cleanaway
Foamglass	Short	• Potential for metal leaching	Cement, Cullet
Glass-mica composites	Short	• Potential for metal leaching	Cement, Cullet
Glass matrix composites with metallic fibre mats	Short-medium	• Potential for metal leaching	Glass, Recycled glass, Speciality glass
Aggregate in epoxy applications	Short-medium	• Reactions with contaminants	Virgin aggregate, Packaging glass
Glass fibres	Long-never	• Chemical composition • Metal contamination • Colour	Recycled glass
❖ **CLEAN –UP AND FILTRATION APPLICATIONS**			
Drainage aggregate	Short	• Heavy metal/mercury leachability	Virgin aggregate
Alkaline absorbents	Short-medium	• Crushing requirements to increase reactivity and associated cost • Chemical composition	Packaging glass, Lime
Sand replacement in septic treatment plants	Short-medium	• Heavy metal/mercury leachability	Sand
Sand replacement in municipal and hazardous wastewater treatment plants	Short-medium	• Heavy metal/mercury leachability	Sand
Oil spill clean-up materials	Medium-long	• Chemical composition • Metal contamination	Detergents, Burning agents, Glass nodules
❖ **ABRASIVES**			
Traction sands	Short	• Particle size • Contaminants	Coarse sand/grit, Packaging glass
Cleaning and surface preparation	Short	• Particle size • Contaminants	Silica sand (less now because of potential for silicosis), Plastic balls, Packaging glass
Non-skid surfaces	Short-medium	• Particle size • Contaminants	High value aggregates, Packaging glass
Lubricant to reduce sticking in drilling oil wells	Short-medium	• Particle size • Contaminants	Barite – a high density naturally occurring industrial mineral, Packaging glass

Table 3.2. Assessment of potential applications for waste glass from fluorescent tubes			
Potential use	***Timescale*[9]**	***Limitations* [10]**	***Current materials*[11]**
❖ **WASTE MANAGEMENT**			
Landfill cover	Short-medium	• Heavy metal/mercury contamination • Specifications given in regulations	Aggregate, soil
Component of landfill liner system	Medium-long	• Alkali-silica reactions • Contaminants • Specifications given in regulations	HDPE (high density polyethylene), bentonite clays, coarse aggregate
Aggregate in leachate collection system	Medium-long	• Alkali-silica reactions • Contaminants • Specifications given in regulations • Particle size and permeability	Coarse aggregate (not $CaCO_3$-rich)
Aggregate in gas venting system	Medium-long	• Specifications given in regulations • Potential damage to geotextile	Virgin aggregate
Waste encapsulation	Medium-long	• Heavy metal/mercury contamination and reaction with waste	Glass
❖ **LANDSCAPE AND PLANT MANAGEMENT**			
Hydroponics growing medium	Medium-long	• Heavy metal/mercury contamination	Sand, gravel, nutrient-rich liquids
Landscaping	Medium-long	• Visible contamination • Heavy metal/mercury leaching	Sand
Golf sand traps	Medium-long	• Visible contamination • Heavy metal/mercury leaching	Sand
Decorative soil cover	Medium-long	• Visible contamination • Heavy metal/mercury leaching	Limestone chippings, gravel
Controlled release fertilisers	Medium-long	• Heavy metal/mercury leaching	Cullet, Basalt rocks, Synthetic fertilisers
❖ **DECORATIVE EFFECTS**			
Trivets	Short-medium	• Aesthetics – Contamination from metal and ceramics	Metal, Ceramic, Textile
Trinket boxes	Short-medium	• Aesthetics – Contamination from metal and ceramics	Tiles, Wood, Metal
Picnic benches	Short-medium	• Alkali-silica reactions • Shear strength	Concrete , Wood
Tiles	Short-medium	• Aesthetics – Contamination from metal and ceramics	Clay, Packaging glass
Jewellery	Short-medium	• Potential mercury content. • Aesthetics - Contamination from metal and ceramics	Metals, Plastic, Wood
Bird houses	Short-medium	• Aesthetics – contamination from metal and ceramics	Wood, Concrete
Home planters/plant pots	Short-medium	• Aesthetics – contamination from metal and ceramics • Metal contamination and leachability	Ceramics
Candle holders	Short-medium	• Aesthetics – Contamination from metal and ceramics	Metal, Ceramics
Coffee tables	Short-medium	• Aesthetics – contamination from metal and ceramics	Wood, Metal

Table 3.2. Assessment of potential applications for waste glass from fluorescent tubes			
Potential use	***Timescale***[9]	***Limitations*** [10]	***Current materials***[11]
Paperweights	Short-medium	• Aesthetics – Contamination from metal and ceramics	Glass, Wood, Plastic
Imitation marble	Short-medium	• Aesthetics – Contamination from metal and ceramics	Marble
Coasters	Short-medium	• Aesthetics – Contamination from metal and ceramics	Cork , Wood, Metal, Ceramic

3.2 Assessment of the physical and chemical properties of the glass and implications for use

It was necessary to undertake an analysis of the physical and chemical properties of the glass in order to assess its suitability in the various applications. This information was also of use in contact with potential users of the glass. This analysis is described in Annex D and is summarised in Figure 3.3.

The analyses have shown that, although mercury is recovered from the glass through MRL's recycling process (and it has been estimated that MRL's process removes over 90% of the mercury from the tube), a residual amount (typically less than 10 mg/kg) remains on the inner surface of the glass tube.

Potential users have expressed concerns over the possibility of handling problems arising from health and safety considerations, and the risk to the environment. It is likely that risks will be greatest in applications where physical abrasion of the glass would take place or in situations where the glass may come into contact with an aqueous environment. Analysis has shown that abrasion can be used to remove mercury from the glass as a powder and that mercury can be easily removed by leaching with water. However, scale of the potential risk is difficult to assess and there is no applicable legislation of guidance on this issue. Section 4 discusses these issue more fully.

Because of concerns expressed by users, and in the absence of guidance, it was felt appropriate for this project to focus on applications where the risks from mercury contamination would be lower. This means that an application in which the glass would be 'bound' in some way and, therefore, unavailable to contact with water or for physical abrasion would be preferable. In addition, as the risk of mercury releases to the environment will increase in processes that require heat (as mercury is volatile at relatively low temperatures), 'cold' processes would be preferable to 'hot' processes to reduce risks of mercury release, unless the process already has abatement equipment in place to recover mercury[12]. Table 3.4 assesses the short list of applications according to these criteria as an indication of their potential for releasing mercury to the environment.

[12] For example, the glass has been used as a flux in a hazardous waste incinerator that has abatement equipment installed

Figure 3.3 Summary of findings from analysis of glass from MRL's recovery process

- The mercury recovery process does not remove all of the mercury from the glass. Typical residual concentrations are 1 – 9 mg/kg.
- The powdered coating from within the tube can contain fluorapatite, a calcium phosphate mineral
- The main chemical composition of the glass is typical of a soda-lime-silica glass
- Mercury or a mercury-bearing compound is unevenly spread on the inner surface of the tubes
- Analytical Transmission Electron Microscopy indicates that mercury is present as accumulates of crystalline particles of around 30nm in size and appear roughly pyramidal or octahedral in shape.
- No mercury has diffused into the glass substrate
- At ambient temperatures and under vacuum conditions only 0.52 μg of mercury per kg of glass can be recovered.
- Under elevated temperatures, 77.04 μg of mercury per kg of glass was removed. With an airflow of 40 ml/min, this equates to 10.7 μg of mercury per litre of air from 1kg of glass.
- Leaching experiments indicated that mercury is easily removed from the surface of the glass with deionised water and 0.01M sodium hydroxide solution
- Tumbling of the glass with an inert abrasive removes the mercury into the finer fraction after 48 hours, leaving the coarser fraction with mercury below detection levels
- Thermogravimetric analysis indicated the main weight loss to be in the region of 250 – 450 °C, although this may not be due to mercury recovery
- Simple compressive strength tests indicate that the glass may be used as a partial replacement for aggregate in concrete and backfill, where high compressive strength is not required

A further option is additional treatment to improve the quality of the glass before it is re-used elsewhere.

Table 3.4 Assessment of potential risks of environmental releases of mercury from shortlist of uses	
Potential Use	Process type and risk of mercury release
Aggregate in concrete	• 'Cold' process • Glass is bound
Aggregate in cement	• 'Cold' process • Glass is bound
Aggregate in glasphalt	• 'Cold' process • Glass is bound
Cleaning and surface preparation (shot-blasting)	• 'Cold' process • Glass is not bound • Mercury releases could occur due to abrasion
Drainage aggregate	• 'Cold' process • Glass is not bound • Mercury releases could occur due to contact with water
Foam blocks	• 'Hot' process – abatement would be required • Glass is bound
Foamglass	• 'Hot' process – abatement would be required • Glass is bound
Glass-mica composites	• 'Hot' process – abatement would be required • Glass is bound
Traction sands	• 'Cold' process • Glass is not bound • Mercury releases could occur
Utility line backfill	• 'Cold' process • Glass is not bound • Mercury releases could occur due to contact with water
Lubricant in oil wells	• 'Cold' process • Glass is not bound • Mercury releases could occur due to contact with water

3.3 Contact with potential users of the waste glass

From the above assessments, it was decided that attention should focus on the use of the glass as a replacement for aggregate in concrete, cement and asphalt (glasphalt) and as a lubricant in oil wells. Although the application of the glass as a lubricant may result in releases to the aqueous environment, it was thought that the releases may be insignificant as compared to the background levels of materials found in an oil well.

Potential users of the material were identified and contact was made. The aim was to identify interest in trialling the material and any concerns or issues. A list of contacts is given in Annex E. The findings from the contact are summarised in Table 3.5.

Table 3.5 Contact with potential users

Potential Use	Comments from users/expert views
Aggregate in concrete, cement and asphalt	• Glass may be too fine for some applications • Glass is only used when price is right
Lubricant in oil wells	• Mercury contamination may become significant factor in risk assessments that will become a requirement of the increasing regulatory controls on oilfield operations • new "high tech" approach to reservoir engineering (for example use of biotechnology) may be sensitive to mercury contamination • industry is typically rather conservative about new approaches and would be unlikely to take material unless the technical performance issues have been thoroughly researched (a significant programme of work)

Many of the users contacted had concerns about handling a material contaminated with mercury from a health and safety risk and environmental risk perspective, but also from the extra regulatory scrutiny that may be required. Section 4 provides a discussion on the significance of the levels of mercury found on the glass.

3.4 Potential for improvements in the mercury recovery process

MRL continues to seek ways to improve the process and the project looked at whether MRL's process improvements impacted on the levels of mercury on the glass. During the study, mercury levels on the glass have not been reduced.

In addition, the project laboratory tests were undertaken to assess whether additional processing technologies (heating and physical abrasion) could be used to remove the residual mercury from the glass. This would provide glass free from contamination and increase the number of potentially suitable applications.

The experiments to date have not been able to determine conclusively the temperature at which mercury would be removed from the glass. However, this option may be cost prohibitive due to energy required to heat the glass.

Tumbling the glass with an inert abrasive (sand) removed the mercury from the glass and resulted in three fractions:

- uncontaminated glass, which has the potential to be used in a wider range of applications
- an inert abrasive that could be re-used to recover more mercury
- mercury-contaminated fine glass and powder, which could be fed into the mercury distillation process operated by MRL

The experiment and results are discussed in more detail in Annex D.

Tumbling technology is available “off the shelf”. However, investment in the technology and the running costs are likely to add significantly to the overall costs for the mercury recovery process.

4 Mercury in context

A number of potential users of the glass contacted during the NCBS study have expressed concern over the potential risks to human health and to the environment from residual mercury on waste glass. It is difficult to quantify the risks that may be involved as they are likely to vary between potential applications. In addition, there are no specific guidelines or standards that can be referred to. However, the study has attempted to provide some context for the mercury contamination to assist potential users in assessing the significance. The following section discusses these issues and is split between:

- the environment
- human health

4.1 Mercury in the environment

In an ideal world, all releases of mercury should be avoided. However there are a number of releases of mercury each year:

- A total of 12 tonnes of mercury is released to the environment in the UK each year.
- Sewage effluent accounts for 6.5 tonnes of mercury discharged to UK waters every year and around 81% of this is believed to come from dental amalgam discharges[13].
- The chlor-alkali industry discharges an estimated 0.5 tonnes of mercury to the environment each year.
- In 1998 it was reported that crematoria emissions accounted for a total of 1.3 tonnes of mercury discharged to the environment, representing 11% of the total annual emissions of mercury.[14]
- In 1999, the Environment Agency reported 1.6 tonnes of mercury was released to the environment from ICI Runcorn's plant.[15]
- The total mercury from fluorescent tubes put into landfill each year is around 3 tonnes[16].
- In 1999 a single industrial plant (Britannia Zinc) discharged 1.3 tonnes of mercury to the environment and is thought to contribute to increased levels of mercury found in fish products from Colwyn Bay and Lynmouth, Devon.[17]

MRL's process aims to recover and recycle the mercury from fluorescent tubes to reduce the potential for contamination[18]. Although MRL continues to seek

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[13] "DoE mercury report puts dentists in the hot seat", ENDS Report MAY 1996, Issue No. 256
[14] "Spotlight falls on mercury emissions from crematoria" ENDS Report, JANUARY 2001, Issue No. 312
[15] "IPPC guidance puts squeeze on chlor-alkali industry", ENDS Report, OCTOBER 2000, Issue No. 309
[16] Assuming a fluorescent tube contains 30mg mercury and 100 million tubes are disposed of each year.
[17] "Shellfish polluted with industrial metals, MAFF study finds", ENDS Report, OCTOBER 1999, Issue No. 297.
[18] It is estimated that the process reduces the mercury content of the glass by over 90% based on the assumption that a fluorescent tube contains approximately 30 mg mercury and weighs

ways to improve the efficiency of the recovery process, the average residual level of mercury found on the waste glass from MRL's process is currently 5 mg/kg and varies between 1-9 mg/kg.

This means that if a potential application utilised 40 tonnes per week (around 2,000 tonnes per year) of glass from MRL's process and if all the mercury from this were released to the environment it would represent an annual release of mercury of 10 kg (or 0.01 tonnes). This would represent only 0.08% of the total annual environmental emissions of mercury to the environment in the UK.

To provide some context for the levels of mercury found on the glass, the study used UK and Dutch Contaminated Land standards as guidance[19]:

> Guidelines issued by The Interdepartmental Committee for the Redevelopment of Contaminated Land (ICRCL) provide trigger concentrations for a limited range of inorganic and organic contaminants for planned uses of differing sensitivity. For mercury, ICRCL gives a threshold value for domestic gardens and allotments of 1 mg/kg and a threshold value for parks, playing fields and open spaces of 20 mg/kg. The residual mercury on MRL's treated glass falls between the two values.
>
> Dutch guidelines give a target ("background") value of 0.3 mg/kg and an intervention value (indicating a concentration level above which there is serious environmental pollution requiring clean up) of 10 mg/kg. The residual mercury on MRL's treated glass is above the target value but below the intervention value.
>
> It should also be noted that any potential use of the crushed glass would most likely be mixed with other glass sources or other materials, thus diluting the mercury levels, although this should not be considered as the best solution to the contamination problem.

4.2 Mercury and health

The routes for mercury exposure are inhalation, consumption and absorption through the skin. It is likely that the main risk of exposure from the waste glass would be through mercury containing dust inhalation. The only relevant guidelines are the Occupational Exposure standards issued by the Health and Safety Executive[20], which give a limit for mercury of 0.025 mg/m^3. The levels of mercury that may arise from use of the material will depend on how it is handled by users and how it is stored. Regular checks (through urine samples) of workers at MRL have not revealed evidence of mercury exposure to date[21].

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around 200g, the mercury content is therefore approximately 150 mg/kg (30/0.2). MRL's process reduces this to below 10 mg/kg, i.e. over 90% reduction in mercury.

[19] http://www.contaminatedland.co.uk/std-guid.htm

[20] Guidance Note EH 40/97 Occupational Exposure Limits 1997 (1997) HSE.

[21] Personal Communication with MRL.

5 The future

This project represents a "snapshot" of the status and issues with respect to recycling of glass from FTs. It has shown that there is potential for reuse of this material in a range of applications, but that there are a number of barriers that will need to be overcome before this will occur.

Many users had concerns over the potential risks they saw arising from use of a contaminated waste. In the future this may become less of an issue as producers are forced to reduce levels of mercury in FT products. In the short term, users will need to be assured about the environmental and health and safety risks that may be associated with using the material. These risks will vary from application to application and dependent upon the amounts of material applied. It should be considered that the risks associated with landfilling this material might be similar or greater and that the levels of mercury are insignificant when compared to the annual releases of mercury in the UK. These issues may need to be addressed by regulators in defining a "Best Practicable Environmental Option" for disposal/reuse of the material.

The best option for using the glass would probably be to encapsulate it, for example, in asphalt for roads, to prevent any releases to the environment from the mercury. Unfortunately there are no incentives at present for users to use recycled materials and they will only do so if the costs are attractive.

The project has shown that it would be possible to process the glass further to remove contaminants, however it may not be possible at present to recover the additional costs this would entail.

To summarise, there are a number of barriers that will need to be overcome before effective markets for recycling glass from FTs will occur. These include:

- General lack of interest in using recycled materials
- Apprehension regarding contamination issues
- Uncertainty about how the material will perform and an unwillingness to undertake trials
- The general lack of support and incentives for recycling in the UK leading to many materials being sent abroad for recycling

In order to overcome these barriers, we recommend a range of measures including:

- Awareness raising programmes to promote recycling (for example, through WRAP)
- Offering potential users reassurances regarding potential risks to health and safety that may arise through handling the material
- Advising users as to the regulations they may be required to fulfill (both in terms of health and safety and environmental protection)

- Establishing the "best practicable environmental option" for glass from fluorescent tubes
- Encouraging users to undertake trials with the material
- Provision of support funding for improvements to existing technologies and for development of additional technologies to facilitate materials separation and recycling.

As the forthcoming WEEE Directive is implemented, the issue of outlets for the glass from FTs will need to be addressed more urgently and it is likely that interest in recycling glass from FTs will increase. There is a pressing need to ensure that technologies and markets are in place in the UK to avoid the need to transport these materials abroad for processing.

Annex A - Biffaward Programme on Sustainable Resource Use

Introduction

This project has been funded through the Landfill Tax Credit Scheme by Biffaward. Mercury Recycling Ltd provided the additional third party funding.

The project falls under the Biffaward programme on sustainable resource use, which aims to provide accessible, well-researched information about the flows of different resources through the UK economy based either singly, or on a combination of regions, material streams or industry sectors.

Background

Information about material resource flows through the UK economy is of fundamental importance to the cost-effective management of the flows, especially at the stage when the resources become 'waste'. However, at present:

- Information is not adequate in terms of quality and quantity
- The UK Government is finding it very difficult to meet even relatively unchallenging targets of waste reduction and resource recycling
- Businesses are faced with increasing costs of waste disposal

In order to maximise the projects' full potential, data will be generated and classified in ways that are consistent with each other, and with the methodologies of other generators of resource flow/waste management data, e.g.:

- The Environment Agency
- The Department for Environment, Food and Rural Affairs
- The Office for National Statistics

This entails the careful co-ordination of the projects and information sharing and mutual awareness between the projects.

In addition to the projects having their own means of dissemination to their own constituencies, their data and information will be gathered together in a common format to facilitate policy making at corporate, regional and national levels.

Annex B - Glass Recycling

Glass Packaging

Perhaps the best-known source of recycled glass is through the bottle bank system and this is generally sourced from glass packaging. In 1999, some 476,000 tonnes, ~22%, of glass packaging was recycled of a national glass production of 1,830,000 tonnes. The bottle bank scheme was introduced in 1977. By the end of 1998 there were 22,821 bottle banks in the UK, even though Glaspak reported in June 1997 that they were aiming for having 40,000 collection sites within four years, i.e. June 2001 (Anon. 1997). The amount of glass recycled in the UK is still only half of the European processing average.

The UK market for glass packaging in 1998 was worth £640 million (Clarke, 1999). The sale of glass packaging from manufacturers is primarily to the manufacturers and packers of food & drink, perfumes, cosmetics, toiletries, pharmaceuticals, household care and some miscellaneous products. Food and drink makes up 78% of these sales (Clarke, 1999). Glass packaging, which tends to be used to give the image of a quality product, makes up 6.1% of the total estimated £11.4 billion UK packaging market.

The demand for glass packaging is growing in niche markets due to a number of factors, including:

- Lower prices;
- The image as a premium packaging medium;
- The enhanced appearance of the product due to the clarity of the glass;
- The hygienic properties;
- The shape versatility;
- The variety of colours possible; and
- The strength of the containers.

As well as the fact that the UK glass packaging market is at least stable, if not increasing, the manufacture and sale of single trip non-returnable glass containers dominates the UK market. This ensures a steady demand for replacements, whilst waste bottles are recycled or landfilled.

Neither retailers nor end users are obligated to recover used containers. As a result, there are no in-store facilities for making returns for re-use.

Recycled glass has a lower environmental burden than the virgin equivalent (ENDS Daily, 22/07/99). It has been concluded that the main reason why environmentally preferable recycled materials are underused is a failure to include environmental costs in the price paid by manufacturers and a poor public perception of the materials' performance (DETR, 1999).

European Recycling of Glass Cullet

The European Container Glass Federation (FEVE) reported that container glass recycling increased by 3% between 1995 and 1996 to 7.64m tonnes (ENDS Daily, 02/10/97). FEVE stated that the gradually slowing growth trend in glass recycling reflected the relative maturity of the industry. The figures below show that this is only partially true for many parts of Western Europe. The 1999 total volume of glass collected in the EU countries listed below, plus Norway, Switzerland and Turkey, was 8.4m tonnes, up by 4.6% on the 1998 figures. FEVE estimates that the average recycling rate is 55%.

Rates of glass recycling in European Countries

Country	*Tonnes glass recycled (1996)*	*% Recycling rate (1996)*	*Tonnes glass recycled (1999)*	*% Recycling rate (1999)*
Switzerland	250,000	89	283,000	93
Netherlands	380,000	81	397,000	86
Germany	2,839,000	79	2,845,000	81
Norway	40,000	75	39,000	83
Finland	120,000	72	41,000	78
Belgium	224,000	66	295,000	N/A.
Denmark	122,000	66	120,000	63
Sweden	33,000	63	147,000	84
Italy	894,000	53	930,000	41
France	1,400,000	50	1,750,000	55
Ireland	43,000	46	38,000	35
Portugal	120,000	42	132,000	42
Spain	456,000	35	575,000	40
Greece	39,000	29	40,000	25
UK	420,000	22	499,000	26
Turkey	44,000	13	95,000	25
Austria	206,000	N/A.	200,000	84
TOTAL	**7,630,000**	**-**	**8,426,000**	**-**

The Swiss environment ministry reports that 40% of urban waste is being recycled, including a recycling rate of 89% for glass. The high recycling rates for many materials has been attributed to a well-informed public and a good recycling infrastructure, especially the reduced contamination because of householder source separation. It is, however, accepted that the success of the recycling policies has led to problems, such as the falling prices for recycled materials due to increased supply (ENDS Daily, 15/07/97).

In August 1999, Denmark confirmed that it would defend in the European Court the controversial national ban on the sale of drinks in disposable metal cans (ENDS Daily, 23/08/99). The Danish Environment Minister argued that the country's unique co-operative system for re-using glass bottles, which the can ban aims to defend, prevents the creation of 400,000 tonnes of domestic waste per annum.

Reclamation of Flat Glass

Flat glass waste can be sourced from the demolition or refurbishment of buildings. This does however require additional resources of time and labour for the careful removal of the glass.

If care is taken during the demolition of buildings, glass window units can be reclaimed. The reclamation of window components is the most beneficial option to avoid the materials entering the waste stream, with associated savings to be made in terms of energy, environmental impact and cost (Coventry *et al.*, 1999). However, this must be weighed up against the additional contract times and labour costs required for demolition.

Guthrie *et al.* (1995) considered that glass from construction and demolition industries has a low potential for re-use, a high potential for recycling and an intermediate potential for waste minimisation.

Another source of glass for recycling is waste generated from the grinding and polishing of plate glass (called "burgy"). Approximately 1,000 tonnes per week are being produced. Extensive burgy banks have accumulated close to glass works at St. Helens and Doncaster, forming significant landscape features (Coventry *et al.*, 1999).

Reuse/recycling of packaging glass

Contamination of glass cullet with, for example, metals, plastics and paper, causes a technical barrier to recycling (Guthrie *et al.,* 1995). The high cost of cullet compared to raw materials represents an economic barrier. However, the energy saving associated with using cullet, rather than raw materials, encourages the use of the cullet.

Attempts are being made to increase recycling efforts and reduce quantities being landfilled in the UK through the introduction of schemes, such as that instigated by the brewing industry. A national collection scheme is being phased in to collect non-returnable bottle glass from pubs and restaurants. Eighteen months into the scheme, which operates in four main conurbations (London, Birmingham, Manchester and West Yorkshire), approximately 120 tonnes a week of glass was being collected (Jones, 1999 & Conran, *pers. comm.*). It was also anticipated that the extension of the collection infrastructure, to all parts of the UK, might make it more attractive to crush and granulate this material. It could then be used as an aggregate substitute in locations that are distant from the glass reprocessing centres in central Scotland, Yorkshire and Hertfordshire (Coventry *et al.*, 1999). To date, this anticipated expansion has not occurred.

Polley *et al.* (1998) reported that not all waste glass can be recycled into new glass (generally for container use) because of impurities, prohibitive transport costs or mixed colour waste streams that may be difficult to separate into useful raw glass stocks. Use of this waste glass in construction materials is an attractive option due to the volume of material involved, the capacity for bulk use of the material and the likely ability of construction applications to allow for minor variations in composition and form.

Use of Secondary materials in glass making

The net external benefits associated with using secondary materials rather than primary in glassmaking was reported to be £176.55 per tonne of finished product (DETR, 1999). This included factors such as:

- Resource use (aggregates);
- Greenhouse gases (carbon dioxide as carbon, methane, nitrous oxide as nitrogen);
- Particulates;
- Acid gases (sulphur dioxide and nitrogen oxides);
- Casualties;
- Road congestion; and
- Traffic noise.

The benefits are generally realised in the manufacturing stage but external costs arise from the collection and sorting of waste materials.

Annex C - Options for Recycling Glass

The following sections provide a description of the options for recycling glass and summarise some of the research that has been carried out to date. Particular emphasis has been placed upon physical and chemical properties that may impact on the suitability of the waste glass from FTs for these potential alternatives. Many of the potential applications currently use waste packaging glass. The potential application of waste glass from tubes will be dependent upon factors that include the sensitivity of the application to contaminants, the specification of glass required and the costs.

Recycling of waste glass into Fluorescent Tube Manufacture

Many consumers have the expectation that recycling ultimately means "closing the loop". In other words, using waste glass from FTs used to make more glass products or to make FTs. It has been reported that FTs are not appropriate for direct re-use in to glass production (Trusty *et al.*, 1998), due mainly to contamination and variations in composition of the glass. However, it may be possible to overcome these difficulties, through technological advances (British Glass, 2001), and this option for recycling of the glass should be considered for the future.

Incineration to produce Breeze Blocks

An option already used by MRL is to use the waste glass as a flux material in a hazardous waste incinerator. The glass is mixed with sand at approximately 50:50 ratio, although this can vary depending upon the properties of the materials that are being incinerated. The glass/sand flux mixture is put into a rotary kiln at 1200°C so that it becomes a molten slag. This aids the incineration process and certain elements of the waste are incorporated into the slag. All combustible elements are burnt off.

When the mixture cools down, the material is separated by grain size. Any material less than 10mm (generally 90%) is made into breezeblocks. The larger particles (approximately 10%) are not suitable for re-use into the blocks and are sent to landfill.

Unfortunately many clients of MRL have expressed concern over this particular outlet for the waste glass, due to the connection with hazardous waste incineration.

Recycling television glass from Cathode Ray Tubes

The project investigated disposal and recycling routes for glass from television glass from Cathode Ray Tubes (CRTs). The issues surrounding the reuse of television glass are likely to be similar to those for the glass from FTs. O'Neill (*pers. comm.*) indicated that the chemical composition of CRTs varies within the tube as is seen in FTs. This relates to the different purposes required of the tube such as light diffusion and expansion.

CRTs from televisions and computer monitors use leaded glass that requires specialist recycling, where available. The basic concept of CRT recycling relies on the separation of the different glass found in CRTs by chemistry and type. The CRT glass is then cleaned of all coatings and is returned to CRT glass manufacturers for re-use in the feedstock (Envirocycle, 1999).

Tietze (1995) reported that there are limitations to the recycling of television glass. He also stated that the many operations involved in dismantling electronic waste make it difficult to recycle and that it would be 'wrong to fuel expectations to the effect that glass manufacturers can simply put the glass back into the melt'. This would also be true for waste glass from FTs.

Other ideas for "downcycling" CRT waste glass into alternative materials have also been considered. Ideas ranged from ashtrays to sewer pipe linings to structural building components. It was noted that simple market principles have prevented many of these ideas from taking off.

Downcycling has also been considered in the container glass industry, where applications have included road construction, cement manufacture, clinker and brick applications and lead smelting. The use of television glass as a component of glazes in the ceramics industry has also been considered. Many of the elements used in soda-lime glass are the same as in ceramic glaze formulations, although in different proportions (Clean Washington Center, 1998).

Tietze states that television glass, and other special glass, could reasonably be used in vitrification processes to encapsulate hazardous waste and thus make it inert. The use of vitrification products as raw materials has not met with much acceptance. Vitrification products are suitable for packing mining operations, where they are used to stabilise the ground by filling mine cavities. This practice has been carried out in Germany but may not be globally applicable.

Construction Uses

Clean Washington Center (1996e) reported that recycled glass could not be collected, processed and delivered to a construction site and compete with the cost of an aggregate on an absolute basis. Economic incentives are required.

Typical geotechnical parameters have been identified by the Clean Washington Center (1996f) and include:

- 100% cullet should be used only in lightly loaded or non-loading applications and compacted to 90-95% of the maximum dry density.
- Unit weight increases with decreasing cullet size.
- Well-graded cullet has a higher unit weight than poorly graded cullet.
- The typical bearing capacity for small load areas (e.g. footings or piers) is 1,000-1,500 pounds per square foot.
- The typical bearing capacity for large load areas (e.g. mat or rigid pavement) is 100-200 pounds per cubic inch.
- Typical permeability values range from 0.05 to 0.25 cm s^{-1}.

Glassphalt – glass as an aggregate in road construction

Crushed glass used as aggregate in road construction or bituminous concrete pavements is popularly known as ‘glassphalt’. A number of field trials of glassphalt pavements have been carried out in the USA (Coventry *et al*., 1999).

The Clean Washington Centre has conducted laboratory tests on glass cullet (from packaging) for compaction, durability, gradation, permeability, shear strength, thermal conductivity and workability as a construction aggregate. It was observed that glassphalt holds heat longer than conventional asphalt. This may be advantageous when roadworks are carried out in cold weather or when long transport distances are required (Clean Washington Center, 1996g). The increased reflectivity of the road surface may improve night-time road visibility. Enhancement of night time visibility of road edges was also reported in Universal Glass Cullet (1999). Snow was also predicted to melt sooner on this type of road surface. Most glassphalt installations have been designed for use to a maximum 40 mph. Glassphalt can be used as a base layer in the road, but not as a surface layer as it does not provide enough skid resistance.

RMC Aggregates has developed a material from waste glass containers that can be used in the place of aggregate in roads (Anon, 21/07/00). Recycled glass is crushed to make a bitumen-coated end product suitable for use in road making. Local councils who currently undertake glass bottle recovery may soon be purchasing back this glass for use in road repairs and construction.

Glassphalt uses 25% of glass in the mixture and it is estimated that the process has a potential to use 1,000 tonnes of recyclable glass a month. RMC uses the same machinery at its plant to crush asphalt and so no additional plant equipment is required. RMC has plans to patent the product and so others will be allowed to make the material (ENDS Report, 2000b).

Many highway agencies in the USA have specified how much glass cullet can be used as a substitute for aggregate in asphaltic concrete pavements. Field trials indicate that pavements containing 10% glass perform as well as conventional pavements (Coventry *et al*., 1999). It was noted by McCoy *et al*. (1999) that specifications should include the words ‘shall use’, rather than ‘will be permitted’ in an attempt to promote recycling.

Glass cullet could improve the stability of an unbound (no asphalt) aggregate base mix (Universal Glass Cullet, 1999).

Glasscrete - Glass as a substitute for aggregate in Concrete

Research developments in Sweden have identified a novel fine aggregate consisting mainly of glass. The product, ‘microfiller’, is the result of a stepped industrial process for the purification of glass material by separation and washing. The product is added to the concrete batch in the mixing process and acts as a pozzolanic[22] material. The addition of this material improves the concrete properties in both fresh and hardened states.

[22] See glossary of terms

The main benefits were reported as:

- Improved workability
- Increased flowability
- Reduced need for superplasticisers and/or water reducing agents
- Potential to use lower grades of aggregate
- Improved frost resistance
- Improved long-term strength
- Suppressed harmful expansive aggregate reactions.

Figg (1981) reported that the reactivity of amorphous glass depends upon the reactivity of the silica structure and the surface characteristics of the particles, particularly the specific surface. Tang *et al*. (1987) added its silica content and chemical composition to Figg's initial findings.

When waste glass is used as an aggregate, obvious differences in the structure of the resulting concrete include reduced bond strength between aggregate and cement paste (Polley *et al*., 1998). The interlocking shear strength between the aggregate and cement is expected to be less with glass than with a natural aggregate. It is thought that the friability of coarse glass particles may weaken the concrete structure by failure of the aggregate particles.

It was determined that the use of finely crushed (<1.5mm) glass aggregate generally produces a highly unsatisfactory concrete, due to alkali-silica reactions and poor strength development (Polley *et al*., 1998). However, these problems may be mitigated by careful selection of glass sources, the proportions of materials used and by the use of low alkali cements (Clean Washington Center, 1996b). A study in New York (Anon, 1995) aimed to eliminate the alkali-silica reactions, which would have widespread implications, not just for the uptake of glass cullet in glasscrete, but also for general concrete technologies.

The experiments by Polley *et al*. (1998) used actual municipal waste glass streams, allowing problems with surface contamination, washing and crushing, together with the concerns of construction personnel, to be addressed. The results are:

- The use of larger particles resulted in more handling difficulties
- Finer particles resembled a sub-angular sand that was more easy to handle and presented no friability problems
- Cement paste was unable to coat all edges of larger particles, although this was significantly improved when using more finely crushed particles
- Field trials identified that although the mixes using finer particles alone were workable, additional water was required to produce additional paste during finishing
- Drier mixes were difficult to consolidate but it was concluded that vibration could improve this
- Coarse glass mixes gave low strength at all glass proportions, with an overall trend of decreasing strength with increasing glass content. This was due to poor shape, poor surface characteristics and high friability

- Fine glass mixes showed nearly constant normalised strength with increasing glass content
- The strength of the mix increased if the waste glass was washed. The cost of washing could equal or exceed the cost of the raw glass aggregate
- The freeze-thaw durability of waste glass mixes was generally promising and was confirmed by field trials.

Polley *et al*. (1998) concluded that glass aggregate is a satisfactory substitute for natural fine aggregate at replacement levels of up to 20% of the total aggregate and at a glass gradation between 75µm and ~1.5mm. The alkali-silica reactions in this study were mitigated by the addition of a suitable fly ash, although it was noted that the reaction might occur in the future.

This study indicated the need for further research into the following:

- A thorough characterisation of the waste glass/cement paste interface
- An investigation of the complex pozzolanic and other chemical reactions between fly ash, waste glass and cement paste, with particular emphasis on the <75µm waste glass
- An examination of production issues before extensive use of waste glass as aggregate can become practical.

Sherwood (1995) reported a number of different materials that may be suitable for use in concrete. These included colliery spoil, steel slag, construction and demolition waste and incinerated refuse. It was noted, with regard to incinerated refuse, that although some ashes may have gradings that make them potentially suitable as a selected granular fill or unbound sub-base material in a road, the main use is as bulk fill. Incinerated refuse can not be used as a cement-bound material because it may contain aluminium, heavy metals and glass. These 'contaminants' are capable of reacting adversely with cement.

Tang *et al*. (1987) noted that container glass is an amorphous or cryptocrystalline silica material that may interact with the hydration of cement paste and is certainly expected to take part in alkali-silica reactions.

Fill

Crushed cullet has been used as backfill around utility pipes and cables (Universal Ground Cullet, 1999). The cullet acts as an aggregate and as a warning marker, alerting construction diggers to the location of utility lines. It was also noted that cullet is easier to work with than sand when wet.

Archibald *et al*. (1995) reviewed factors that could influence the incorporation of waste glass as a partial replacement in cement. Sources of waste glass were considered (mainly from packaging), together with economics and the suitability of the chemical and physical properties of the replacement material.

The application of Portland cement-reinforced tailings as backfill agents is a common feature of underground support in Canadian mines. Over 39,000 tonnes of backfill is placed per day, annually consuming 5-6% of Canada's cement production. Research has been carried out in order to identify pozzolanic binder substitutes for Portland cement in backfill. Waste glass is not self-cementing and can therefore be considered to be pozzolanic. It was realised that the waste glass would require crushing to a particular grain size and it was estimated that costs would be in the region of C$1.18/tonne (~£0.55/tonne), excluding labour, operating costs and plant overhead charges. If a specific grinding facility was required, these costs could increase to C$15/tonne (~£6.75/tonne). Transportation costs must also be considered.

Equipment is available that can crush glass to non-sharp, sand-like aggregate of specified sizes at one pass through the machine. For example, GAME Inc. produce several machines that can process from 100 pounds per hour up to 20 tonnes or more an hour (GAME Inc., 1999).

The binder agents for backfill needs two essential properties:

- A low percentage ignition loss (<6%) to ensure product quality; and
- A specific surface area of 300 m^2/kg.

Several strength tests were carried out on samples with partial replacement by ground glass, including strain rate controlled unconfined failure, unconfined compressive strength, modulus of deformation and percentage axial strain to failure over several time periods. Finely ground waste glass material was found to enhance the pozzolanic reaction for all sample mixtures. The pozzolanic strength reactivity was found to vary in relation to differences in glass type, e.g. clear versus coloured. Materials which did not have a high sulphate content demonstrated very beneficial long-term strength development following the partial replacement of Portland cement with up to 35% ground waste glass. It was envisaged that the use of waste glass as a partial replacement would provide a cost-effective and physically effective binder alternative for the mining industry.

Following on from the research of Archibald *et al.* (1995), De Souza *et al*. (1997) reported on the use of ground waste glass as a partial replacement of Portland cement fractions in mine backfill in Canada. The authors were able to demonstrate that a significant, large and stable source of glass supply could be developed and be effectively recycled as backfill additives.

It was estimated that in Ontario alone, the mining industry annually spends C$64-75 million (~£29-34 million) on normal Portland cement for the consolidation of backfill in underground mining operations. Backfilling can account for up to 50% of the overall mine operating budget. The partial substitution of Portland cement with ground waste glass could provide maximum annual savings of up to C$305,000 (~£137,000). The estimated cost per tonne of the substitute material would be competitive against normal Portland cement and slags but not with fly ash.

Construction Products

Bricks

Ground glass cullet acts as inert filler in the unfired state. During firing, its fluxing properties from the soda lime content dominate. This results in increased vitrification with an accompanying increase in firing shrinkage, reduction in water absorption and improved strength (Coventry *et al*. 1999). As with other applications identified, the effectiveness of the glass cullet as a flux is greatly affected by its fineness. The consistent chemical composition of ground glass cullet is beneficial in brick making.

Initial tests indicated that the addition of powdered glass provided a comparable strength to conventional bricks but at lower firing temperatures and shorter firing times. There is therefore the potential for fuel savings and reduced acid gas emissions. Production capacity can increase by up to 20%. The addition of sand-sized glass as filler, rather than flux, reduces fluoride emissions. This is a direct result of requiring less fluoride-containing base clay.

Carvalho *et al*. (1998) developed a plastic and glass, 'glastic', waste composite prototype consisting of a mixture of eight polymeric powders and different weight proportions of coarse ground waste glass. The material was produced in a brick form. Potential applications considered include brick veneer for residential construction, curtain walls or patio and landscaping pavers. All of the prototype compositions outperformed conventional bricks in compression testing and failure performance.

It was considered that the prototype glastic bricks developed would not be suitable as alternatives for the structural applications of clay bricks. It was also felt that the use of unsorted plastic waste would preclude indoor uses. Simple outdoor applications involving walkways, patios etc., that have interlocking patterns and do not require adhesives would be suitable and could be considered as attractive features.

It was reported by Onishchuk *et al*. (1999) that in Russia and the former Soviet Union countries many factories transport high-quality clear cullet to brick and ceramic plants, rather than glass factories, at negligible prices.

Tiles

Tiles are made using similar methods to bricks. Different types of tiles require different characteristics. Coventry *et al*. (1999) reported the potential benefits of using glass in tile manufacture. Roof tiles must be of low porosity. The use of glass as a flux helps reduce porosity, thus producing a more resistant tile. Processed cullet can be added as a surface treatment for ceramic tiles and cuts costs by 20% (Universal Ground Cullet, 1999).

Sandhill Industries (2000) in the US produce a number of tile products made from recycled glass, including floor and wall tiles, coasters, trivets and trinket boxes.

Clay Pipes

Trials using finely ground glass in clay pipe manufacture found that a reduction in firing temperature was possible. This reduction was sufficient to increase throughput and provide a small energy saving (Coventry *et al*, 1999).

Composite Materials

Glass-polymer composite (GPC) can be cast into sewer pipes. The GPC pipe has two to four times the strength of concrete pipes and is highly resistant to the corrosion often found in sewers. It is not subject to abrupt failures, hydrostatic leakage or permeability problems associated with concrete. GPC pipe is easy to machine and easier to install than concrete pipes due to its lighter weight (Universal Ground Cullet, 1999).

Processed glass cullet has been used as a filler or binder in plastics, replacing the need for silica and/or silicates. This tends to be in rigid building products, rather than film packaging. Glass can also be used as a filler in paints and rubber (Min'ko *et al*., 1999).

Reinforced Glass

In research carried out by Polokhlivets *et al*. (1995), glass waste from the settling pits of glass furnaces was used to produce processed glass. It was concluded from experimental data that by maintaining a steady input of cullet and observing the optimum technological conditions, the system could operate successfully at elevated cullet contents. Strength characteristics were no worse than conventional reinforced glass. It is unlikely that this approach will be suitable for the waste FT glass, due to the potential for contamination in the furnace.

Insulation

Foam Blocks

The addition of waste glass to foaming agents and other materials has produced foam blocks that are similar to breeze and insulation blocks. Samples produced under controlled conditions have improved strength and heat transfer compared to conventional breezeblocks. The blocks with waste glass are easy to handle and can be cut accurately and easily using a hand saw (Coventry *et al*., 1999).

PhD research, currently being undertaken at the University of Sheffield, into the detoxification and re-use of contaminated fly ash from incinerators aims to convert the waste into a material that can be disposed of cheaply or used in the construction industry (University of Sheffield, 2000). The study approach is based upon the fact that the sintering or melting of the incinerator ash causes the destruction of its toxic organic components and fixes the heavy metal content to form an unleachable material which can be used in landfill or for building roads.

Foamglass

Foamglass is recycled glass in cellular form and used for its insulating and moisture resistance properties. The product is cost competitive and is less costly to produce than foamglass from virgin materials (Universal Ground Cullet, 1999).

Onishchuk *et al*. (1999) reported that the most promising area of application for glass cullet (both graded and mixed) is in the production of heat-insulating, soundproofing and decorative facing materials for construction.

Glass Fibres

Recycled glass is used in the manufacture of glass fibres that are used in thermal and acoustic insulation materials. To ensure production of consistent fibres, cullet must meet specifications for major and minor oxide chemical composition, colour consistency and contaminant levels (Clean Washington Center, 1996d). Glass fibres can also be used for strengthening cement, gypsum or resin products and household glass items (Coventry *et al*., 1999). The inclusion of up to 60% recycled glass into any of these uses does not impact on the standard or quality of the product (Universal Ground Cullet, 1999).

One US company, Johns Manville, uses a minimum of 20% cullet in its fibreglass insulation products. The company uses more than 100 million glass containers annually and estimates that a typical truckload of insulation contains 1.5 tonnes of recycled glass (Anon, 1998).

Glass Composites

Glass-mica composite material is suitable for rigid insulation applications. It has good thermal insulation values and high strength. It is a better insulator and has higher strength than foamglass.

Trusty *et al* (1998) investigated a potential use for recycled speciality glasses, specifically those containing hazardous elements. A processing route has been developed for the fabrication of metallic fibre mat reinforced glass matrix composites. The glass matrix used in the experiments was a borosilicate glass that had been used as fluorescent tubing in radiation experiments. The composite, made of fibre mats with the glass matrix between, was of sufficient integrity with regard to temperature capability, toughness and damage tolerance. It was noted that suitable uses include structural materials for low to moderate load bearing applications, with the proviso that the environment where they are used guarantees a low leachability of the contaminant elements they may contain.

The Clean Washington Center reported (1996c) that waste glass could be used as an aggregate in epoxy applications to achieve certain properties. The epoxy-glass mix can be used to make moulds, floors with abrasive/non-slip surfaces or countertops with a surface that is resistant to knife-cuts. The glass aggregate is often considered to have an aesthetic benefit over normal aggregate. The same author provides several examples of best practice in how to remove contaminants for ferrous and non-ferrous metals and ceramics (Clean Washington Center, 1996i, j & k).

Clean-up and Filtration Applications

Alkaline Absorbents

Research carried out by Arthur *et al*. (1998) indicates the potential for recycled glass to be used as an alkaline absorbent in environmental gas cleaning applications. Calcium silicate hydrates were prepared from hydrated lime and post-consumer recycled glass in an aqueous slurry. The large surface area of these solids is the property that makes them potentially suitable as absorbents. The rate of surface area formation was found to be directly proportional to the initial surface area of the glass. This means that the grinding of the glass has a direct impact on the length of the sorbent preparation reaction.

The calcium silicate hydrates are more reactive towards acid gases and were reported to achieve higher conversions than lime, the most common semi-dry absorbent. Potential acid gases for chemical absorption include SO_2, NO_2, HCl and HF.

The original research was based on fly ash as the source of the silicates, because the gas cleaning applications is generally related to power plant operations. Fly ash is therefore the most economical source. However, it was realised that at some locations, e.g. those with smaller boilers, other more cost-effective sources of silica exist, e.g. post-consumer glass.

Consumer glass has a greater concentration of silica, calcium and sodium than a typical fly ash. It was expected that the calcium and sodium would contribute to the total reactive alkalinity.

Oil Spill Clean-up

It has been reported that cellular glass nodules can be used to absorb oil for burning in oil spills (Universal Ground Cullet, 1999). The low density of foamglass nodules causes buoyancy, whilst the open cells soak up oil through capillary action. This application is found to be as efficient as other systems. It is cost competitive compared to detergents and less expensive than other burning agents.

Filtration Media

Cullet can be used as a drainage aggregate to drain moisture quickly from an area. The capability of cullet to remove solids and improve wastewater turbidity is reported to be equal to or better than natural aggregates due to the particle angularity (Universal Glass Cullet, 1999). It may also help in the oxygenation of water.

Cullet wrapped in a geotextile can be used as an underground water collection system. Flow rates are equivalent to those achieved by conventional perforated pipework. This type of underdrain is stronger than plastic pipes and is easier to install and remove (Universal Ground Cullet, 1999).

Cullet can be used as a substitute for sand in water filtration, in applications ranging from swimming pool filters to slow sand filtration in rural sanitary waste treatment (Universal Ground Cullet, 1999). It was noted that if correctly prepared, glass should be more inert and pure than sand.

The replacement of sand with crushed glass in in-situ residential septic treatment plants means that fines are removed more easily. This is beneficial as it prevents filter clogging, 'biomat' formation and thus system failure (Clean Washington Center, 1997). The increased filter permeability may allow greater hydraulic loading of the septic system, which means that the size and thus the installation costs of the filter may be reduced. When compared to standard sand (C-33), the crushed glass performed as well with regard to the following parameters:

- Five-day biochemical oxygen demand (BOD_5)
- Faecal coliform count
- Total suspended solids
- Oil and grease
- Nitrates

Crushed glass can be used in an electromagnetised bed to clean municipal and hazardous wastewater. The system filtration is efficient, high quality and very reliable when compared to other systems. Municipal wastewater can be treated to tertiary standards. The capacity of existing municipal systems can be increased by decreasing the pressure drop through the system. The system requires less space than a conventional system and gives higher backwash rates and shorter backwash cycles. Water and chemical costs can be reduced and, as a non-chemical treatment, environmental liabilities are reduced. Sludge waste can be reduced by 80%. The system lasts 10 times longer with glass than with sand. The installation costs are comparable to conventional systems and the operating costs are significantly lower (Universal Glass Cullet, 1999).

Abrasives

The largest glass abrasive manufacturer in the US lists several potential uses of crushed recycled glass, including:

- Cleaning
- Removal of surface deposits
- Surface preparation
- Transparent non-skid surfaces
- An aid in the fast-firing of ceramic shapes, tiles and stoneware
- A lubricant to reduce sticking in drilling oil wells

The recycled glass is reported to contain essentially no heavy metals. The glass abrasive contains no significant chlorides or other salts that may accelerate corrosion on clean surfaces. The abrasives also have low dust generation, which may result in less abrasive residues on cleaned surfaces thus reducing post blast clean-up costs (Universal Ground Cullet, 1999).

A health consideration associated with silica sand producing crystalline silica dust is silicosis. Tests have shown that recycled container glass contains less than 1% crystalline silica (Clean Washington Center, 1996h).

Crushed glass can be used as a substitute for silica sand to produce non-skid surfaces. Initial trials indicate that glass performs as well as or better than silica sand and provides good traction (Universal Ground Cullet, 1999).

Processed cullet has been used by railroads to provide traction under the wheels of trains. In typical applications with coarse sand, the sand breaks up any leaves that may fall on the line, as well as providing grip.

Waste Management

Landfill Applications

Soil is traditionally used to cover closed landfills. Crushed glass may be used as an alternative landfill cover, as it shows good compaction and has lower processing costs than most other aggregate applications. This is because of less stringent applications for gradation and contamination.

Replacement waste materials have been trialled for use in cementitious barriers for waste containment (Claisse *et al*., 1996). Cementitious materials in waste containment can act in two different, and possibly conflicting, ways. One is the physical containment of waste and the other is chemical containment. This works whereby water passing through the barrier is buffered to a high pH, thus reducing the solubility of many species and promoting sorption on to the cement matrix. This type of barrier has been extensively researched for radioactive waste containment. Its suitability for non-nuclear waste is being tested.

Loss of strength of the concrete may be caused by the reaction with sulphates. In non-nuclear applications, this could be prevented by the use of sulphate-resisting cement or blast furnace slag cement. It was noted that a single cementitious barrier would not satisfy current (1996) landfill regulations. A composite system of several layers would be required.

This research is now being continued in a UK Waste landfill tax funded project between the University of Coventry and Imperial College (Ganjian, *pers. comm.*). Several waste materials are being trialled to test suitability for use as a novel landfill liner, including a sample of the waste glass from FTs. Initial results were promising, with a compressive strength at 28 days of ~4.5 MPa. Further tests are to be carried out.

Schmucker *et al*. (1995) demonstrated the potential use of pulverised glass as a liner system protective cover layer and as a leachate collection system aggregate. Laboratory and field tests indicated that it may perform better than natural aggregates in the long term, as:

- The pulverised glass did not break down during placement
- The permeability is above regulatory requirements and similar to natural aggregates
- The glass is silica based and would be expected to last longer than aggregates with a carbonate content
- The use of pulverised glass did not cause any damage to the geotextiles

Swyka (1996) also reported the use of recycled glass as a component in the landfill leachate collection system. The aggregate used did not act as a filter against migrating particles from incinerator ash. Crushed recycled glass, at a low cost, proved to be a suitable filter between the two materials.

Swyka (1996) reported that waste glass has been used in the gas venting systems of several landfill sites in New York. The glass had to meet the following minimum requirements:

- A minimum permeability of 1×10^{-3} cm s^{-1}
- A maximum of 10% by weight passing through a No. 200 sieve

In the experiments carried out by Swyka, no special processing was required to meet these specifications. In order to prevent damage from the glass particles on the overlying flexible membrane liner, a heavy geotextile was employed.

Waste Encapsulation

Waste materials can be encapsulated by the vitrification of glass. This is frequently used in the long-term storage of radioactive wastes.

Landscape and Plant Management

Hydroponics

It has been reported (Universal Ground Cullet, 1999) that cullet can be used as a growing medium for soil-less gardening. The main properties that make this possible are that the cullet is free-flowing and can be easily sterilised compared to other materials. It has been noted that no statistical difference was observed between basil plants grown in glass and those grown in a conventional hydroponic medium (Clean Washington Center, 1996a).

Landscaping

Cullet has been used in golf course sand traps (Universal Ground Cullet, 1999). When using glass as a landscaping medium such as soil cover (e.g. like limestone chippings). The following issues were identified:

- The glass should not be recognisable as broken bottles etc.
- If crushed too fine, problems may result from airborne dust
- Fine glass will be less reflective and may not 'shimmer'
- Furnace-ready cullet looks 'dirty' because of residual moisture causing dust to adhere to the surface
- Contamination from labels, lids, etc.
- Colour considerations

Fertilisers

Research by Barba *et al*. (1998) concluded that a low-cost material, made from 40% glass cullet, 40% bones and 20% potassium carbonate (% by weight), could be powdered and used as a fertiliser. The material is able to release the nutrient elements at a slow rate as a 'controlled release fertiliser'. It was also noted that luminescence related to the Nd(III) (neodymium) and Mn(V) (manganese) ions was observed and that this could be of interest in the field of solid state lasers.

Szabò (1996) carried out similar work where another frit soil conditioner was produced using recycled cullet and naturally occurring basalts. The solubility is the most important factor for the slow release of essential microelements.

Decorative Effects

Decorative effects can be produced with glass on tiles and bricks, either as a surface finish or as a colour. Glass can also be combined into cement to produce decorative panels and artefacts, (Coventry *et al*., 1999 & Universal Ground Cullet, 1999). Jewellery is another favourite recycled product (Aiken, 1995). Glasscrete, a concrete with at least 65% recycled glass, has been used for a number of products including bird houses, landscaping bricks, paving squares, home planters, candle holders, coffee tables and paperweights (Harrington, 1998).

An imitation marble composite can be made from glass granules in a resin matrix. This is cheaper than natural marble and has better wear and weathering properties. Colour can be closely controlled and there is more control of end product consistency than with natural marble (Universal Ground Cullet, 1999).

As the result of a co-operative venture involving Shetland Islands Council, glass is turned into high grade silica sand and put into uses as diverse as breezeblocks, shot-blasting and picnic benches (Anon, 23/06/00).

Annex D - Analysis of Glass from Fluorescent Tubes

Introduction

The aim of the tests was:

- to improve understanding of the physical and chemical properties of the waste glass to enable potential users to assess how the glass might perform in different applications, and
- to aid Mercury Recycling Ltd in improving the mercury recovery process.

Many of the tests were undertaken in response to comments made by potential users who wished for more information on a range of issues, including:

- Quality issues and variability in product
- Contamination issues (for example, potential for damage to processing equipment)
- Health and Safety in handling
- Environmental implications

These issues vary between applications and there is no single answer that can be supplied to potential users. However the analysis provides an initial indication to users as to how the waste glass might perform in each application.

The study involved a range of analysis. The significance of the data gathered is discussed, but can only ultimately be determined with reference to how the glass is to be used.

Much of the analysis was undertaken on discreet samples of glass taken from the process at Mercury Recycling Ltd, which operates with a variable feedstock. It is not clear how this variability would affect the analytical results presented in this report.

To summarise, the laboratory analyses undertaken has shown that:

- The mercury recovery process does not remove all of the mercury from the glass.Typical residual concentrations are 1 – 9 mg/kg.

- The powdered coating from within the tube can contain fluorapatite, a calcium phosphate mineral.

- The main chemical composition of the glass is typical of a soda-lime-silica glass.

- Mercury or a mercury-bearing compound is unevenly spread on the inner surface of the tubes.

- Analytical Transmission Electron Microscopy indicates that mercury is present as accumulates of crystalline particles of around 30nm in size and appear roughly pyramidal or octahedral in shape.

- No mercury diffuses into the glass substrate.

- At ambient temperatures and under vacuum conditions only 0.52 μg of mercury per kg of glass can be recovered.

- Under elevated temperatures, 77.04 μg of mercury per kg of glass was removed. With an airflow of 40 ml/min, this equates to 10.7 μg of mercury per litre of air from 1kg of glass.

- Leaching experiments indicated that mercury is easily removed from the surface of the glass with deionised water and 0.01M sodium hydroxide solution.

- Tumbling of the glass with an inert abrasive removes the mercury into the finer fraction after 48 hours, leaving the coarser fraction with mercury below detection levels.

- Thermogravimetric analysis indicated the main weight loss to be in the region of 250 – 450 °C, although this may not be due to mercury recovery.

- Simple compressive strength tests indicate that the glass may be used as a partial replacement for aggregate in concrete and backfill, where high compressive strength is not required.

The following sections provide a more detailed discussion of the analysis undertaken, including:

- The rationale
- The method
- The results
- Conclusions

Residual mercury on the glass

Inductively Coupled Plasma Mass Spectrometry (ICP-MS) was used to determine the levels of residual mercury on the glass. It was also used to assess the changes resulting from MRL process improvements.

1 kg samples of crushed glass were sub-sampled and acid digested. The acid-digest liquid was put through the equipment, which determined the amount of mercury present in the sample.

Results

The initial analysis for mercury contamination used five samples in an attempt to determine process homogeneity over the period.

Sample ID	***Sample Date***	***Mercury mg/kg (ppm)***
1	16/10/00	1
2	17/10/00	6
3	18/10/00	5
4	19/10/00	4
5	20/10/00	6

These results showed that the mercury contamination was in the same order of magnitude in each sample.

Further analysis was undertaken after Mercury Recycling Ltd had carried out improvements to elements of the recycling process.

Sample ID	***Sample Date***	***Mercury mg/kg (ppm)***
1	23/01/01	8
2	24/01/01	4
3	25/01/01	3
4	26/01/01	4
5	29/01/01	9

Conclusions

The results show that mercury is present on the glass in the range 1-9 mg/kg. Process improvements made by MRL had no impact on the levels of mercury in the waste glass.

The significance of these results is dependent upon the use to which the glass is put. Further analysis (for example, leaching tests, heating, tumbling and vacuum removal tests) demonstrate how the mercury may behave under a range of conditions.

Of particular relevance to some applications (for example as an aggregate for backfill during pipe and cable laying) is the potential for contaminating land.

In an attempt to put the results into some context, two standards for assessing land contamination have been considered:

- ICRCL
- Dutch guidelines

The Interdepartmental Committee for the Redevelopment of Contaminated Land (ICRCL) values provides trigger concentrations for a limited range of inorganic and organic contaminants for planned uses of differing sensitivity. For mercury, the

ICRCL threshold for gardens is 1mg/kg and parks is 20 mg/kg. There is no ICRCL guidance relating to use in buildings, hard cover and landscaped areas.

The waste glass samples analysed are above the ICRCL threshold for domestic gardens and allotments. They are all below the threshold limit for parks, playing fields and open spaces.

The Dutch guidelines are more exacting. They give a Target Value of 0.3 mg/kg, which is the level of contamination that is naturally present (a background level) and an Intervention Value of 10 mg/kg which, if exceeded, indicates serious environmental pollution requiring clean up.

All MRL samples exceed the Target Value but fall below the Intervention Value.

However, this assumes that the material would be used undiluted, i.e. that it would not be mixed with other materials prior to application. It is likely that many applications would need the waste glass to be mixed with other materials prior to use.

The nature of the mercury on the waste glass

X-Ray Diffractometry (XRD) was used to identify the minerals that are present in the glass to assess the nature of the mercury contamination.

A sample of powdered coating was taken from a used FT prior to MRL's recovery process.

Results

The x-ray diffractogram for this sample displayed a good range of peaks, of which all the major ones are accounted for by fluorapatite with possibly some hydroxylapatite.

Conclusions

Apatite is a calcium phosphate mineral that may also contain fluoride, chloride, hydroxyl or carbonate, depending upon the variety. It is assumed that this mineral forms from the phosphor coating that is applied to the FT prior to use.

It has been suggested that as heavy metals, such as lead, can be substituted into the mineral structure of apatite, this may be where the mercury is located on the waste glass.

Chemical composition of the waste glass

X-Ray Fluorescence (XRF) was used to determine the chemical composition of the waste glass and the trace elements within the phosphor coating of the tube.

Results

Two discreet samples were analysed and the results are shown in the table below.

Compound	***Sample 1***[♣]	***Sample 2***[♦]	***Uncoated 'blank' tube***[♥]	***Recovered glass***[♠]	***Typical soda-lime-silica glass***[#]	***Typical uncoated glass tubes***[+]
	%	*%*	*%*	*%*	*%*	*%*
Silica (SiO_2)	70.75	71.22	71.68	71.67	72.5	71.74
Titania (TiO_2)	0.04	0.05	0.04	0.06		
Alumina (Al_2O_3)	2.04	2.08	1.72	2.11	2.6	1.77
Ferric oxide (Fe_2O_3)	0.12	0.12	0.15	0.14		0.12
Lime (CaO)	5.05	4.99	5.55	4.73	5.7	5.49
Magnesia (MgO)	3.12	3.11	3.46	2.82	2.9	3.70
Potash (K_2O)	0.91	0.91	0.93	1.52	1.2	0.90
Soda (Na_2O)	16.11	16.32	15.8	16.08	14.6	16.08
Phosphorus pentoxide (P_2O_5)	<0.02	<0.02	0.03	0.25		
Chromium sesquioxide (Cr_2O_3)	<0.01	<0.01				
Manganic oxide (Mn_3O_4)	0.01	0.01				
Zirconia (ZrO_2)	0.02	0.03				
Hafnia (HfO_2)	<0.01	<0.01				
Lead monoxide (PbO)	0.35	0.29				
Zinc oxide (ZnO)	<0.01	<0.01				
Barium oxide (BaO)	0.07	0.10				
Strontia (SrO)	0.02	0.02				
Stannic oxide (SnO_2)	<0.01	<0.01				
Cupric oxide (CuO)	<0.01	<0.01				
Boron (III) oxide (B_2O_3)					0.3	
Manganese (II) oxide (MnO)			0.02	0.02		
Sulphur trioxide (SO_3)			0.16	0.12		
Loss on ignition at 500ºC	0.81	0.56	[∝]	[∂]		
Total	99.42	99.81	99.54	99.52	99.8	99.80
Approximate sulphur trioxide after L.O.I. and fusion	0.19	0.19				

[♣] Recovered glass. Analysis undertaken by CERAM, November 2000
[♦] Recovered glass. Analysis undertaken by CERAM, November 2000
[♥] Uncoated glass. Analysis undertaken by Mineral Solutions Ltd, June 2001
[♠] Recovered glass. Analysis undertaken by Mineral Solutions Ltd, June 2001
[#] Typical formula given by www.britglass.co.uk
[+] The uncoated tubes are glass tubes that have not been processed with the phosphor coating necessary for use. These tubes and associated data sheet were provided by SLI Glass Ltd.
[∝] XRF major component oxide results recalculated to include LOI
[∂] XRF major component oxide results recalculated to include LOI

Additional XRF analyses were undertaken for selected trace elements, comparing an uncoated tube and the glass recovered through the recycling process. These results are shown in the table below.

Trace element	***Uncoated 'blank' tube mg/kg***	***Recovered glass mg/kg***
Barium (Ba)	369	8410
Cerium (Ce)	18	<2
Chlorine (Cl)	62	48
Fluorine (Fl)	191	666
Mercury (Hg)	<2	7
Lanthanum (La)	<2	2
Neodymium (Nd)	6	<2
Yttrium (Y)	6	49

Conclusions

XRF analyses showed that the major constituents of the four samples were silica, alumina and soda, as would be expected from the typical compositions quoted.

The trace element XRF analysis showed high levels of barium in the recovered glass, indicating that the glass tube was most likely an ultra-violet application.

Surface characteristics of the glass

Electron microprobe analysis was used to view the surface of the glass at high magnification and to map the position of the mercury on the glass. This would help to determine whether mercury is present on the inner surface, diffused into the glass, or in both locations. The analysis involves the sample being hit by an electron beam that excites the sample. The resulting energy signal indicates the intensity of the element. It is a semi-quantitative analysis.

The electron microprobe allowed the examination of the distribution of particulate or diffused mercury levels on the glass. The inner concave surfaces of broken FTs were examined, as this is where the phosphor coating with mercury had been in contact with the tube during use. An investigation through the glass was undertaken to determine if the mercury had diffused into the structure of the glass. The glass samples were mounted in resin blocks.

Results and Conclusions

The cross section through the glass found that there was no mercury diffusion into the glass substrate.

It appears that the mercury or a mercury-bearing compound is unevenly spread on the inner surface of the glass at levels approaching eight times the background detection levels and is not diffused into the glass structure. Detection limits are <1 mg/kg and so the mercury levels on the surface of the glass are of the order of 8 mg/kg. This confirms the results from other analytical techniques. Darker areas may be due to hollows or pitting in the glass surface where the mercury is either not present or is not accessible to the microprobe beam.

Removal of mercury from the glass under vacuum

Contact with potential users of the recovered glass indicated that there were concerns over handling issues and the potential of mercury to be removed as vapour upon storage.

To indicate the potential for mercury to be released into the air, the waste glass was subjected to vacuum and the amount of mercury released was estimated.

53.71 grams of glass were maintained under vacuum (5×10^{-3} Torr) at room temperature (27°C). Any vapour that was produced was collected in a liquid nitrogen cold trap. The experiment was carried out for three hours, after which the cold trap was sealed under vacuum and allowed to rise to room temperature. The trap was filled with dry nitrogen to obtain atmospheric pressure. Any condensate was then dissolved in 35% nitric acid, which was analysed for mercury using an atomic absorption spectrophotometer (AAS). A blank of nitric acid was used to subtract background mercury contamination.

Results

It was found that there was no measurable weight loss from the sample. AAS analysis determined that 0.02775 μg of mercury was collected in the nitric acid. Given that 53.71 grams of glass was used, this equates to mercury removal under vacuum conditions of 0.52 μg per kilogram of glass.

Conclusions

The level of mercury detected in the nitric acid is extremely low. Assuming that the expected mercury level would be in the range of 1 – 9 mg/kg of glass (as indicated by the ICP-MS analysis), less than 0.001% of the mercury content was removed from the glass under vacuum conditions.

Removal of mercury from the glass using heat

The aim of this experiment was to assess:

- the capabilities for recovery of residual mercury using heat
- the potential releases of mercury that may occur in applications that would heat the glass.

50.14 grams of glass were placed in a round-bottomed flask to provide maximum thermal contact between the vessel and the glass. This vessel was then placed in an oil bath that was maintained at 100°C. A flow of air (~40 ml/min) was passed over the heated glass, after which the air stream was bubbled through 35% nitric acid to dissolve any mercury vapour. The experiment was carried out over three hours, after which the nitric acid was analysed for mercury using an atomic absorption spectrophotometer (AAS).

Results

No measurable weight loss was observed from the glass. AAS showed that 3.852 μg of mercury was collected in the nitric acid. Given that 50.14 grams of glass was used, this equates to mercury removal under raised temperature conditions of 77.04 μg per kilogram of glass. With an airflow rate of 40 ml/min, this equates to 10.7 μg per litre of air.

Conclusions

The level of mercury detected in the nitric acid is extremely low. Assuming that the expected mercury level would be in the range of 1 – 9 mg/kg of glass (as indicated by the ICP-MS analysis), less than 0.1% of the mercury content was desorbed from the glass under elevated temperatures.

Although this level of desorption is still low, it is two orders of magnitude greater than desorption under vacuum conditions as would be expected due to the increased volatility of mercury at higher temperatures. The low level of desorption again implies that the mercury content is 'locked away' within the sample.

Leaching of mercury from the glass

Some applications under consideration would require the glass to have contact with water, for example, contact with groundwater when used as a utility backfill. In order to assess the removal of mercury from the glass under these conditions, a series of experiments were undertaken using a procedure adapted from the National Rivers Authority (now the Environment Agency) standard leach test for contaminated land.

The following solvents were used to extract the mercury from the recovered glass:

- Deionised water (DIW)
- Nitric acid (0.1 molar HNO_3), AnalaR grade
- Sodium hydroxide solution (0.01 molar NaOH) AnalaR grade

The methodology required one aliquot of ground glass to be placed in a conical flask with 50 ml of the appropriate solvent. Blanks were also run without the recovered glass in the flask. The flasks were placed on a stirrer and allowed to leach for 24 hours. After this time period had elapsed, the solutions were filtered. The sodium hydroxide extract was diluted by a factor of two. Each extract was then analysed for mercury by ICP-MS.

Results

The results have been corrected for dilution. The DIW and 0.01M NaOH both have a mercury content of 1.5 mg/kg of glass, compared to the 0.1M HNO_3 of 0.72 mg/kg. These results have a 25% error. The solution of NaOH became strongly coloured after reaction with the glass.

Conclusions

The results obtained for leaching with DIW and NaOH suggest that the mercury is easily leachable from the surface of the glass. The change in colour of the NaOH solution when applied to the glass strongly suggests that some reaction has taken place and that the glass has been etched.

The results also suggest that, within experimental error, there is little additional mercury diffused within the glass. This is confirmed by the electron microprobe analysis. The reasons for the nitric acid leaching approximately 50% of the amount of mercury compared to DIW and NaOH have not been established. It was, however, noted that these results were obtained from just one sample and were in essence a 'look-see' approach.

Tumbling to remove mercury

Investigations were undertaken to determine how easy it would be to remove the residual mercury, so as to provide MRL with a means to remove mercury from the glass to below detection levels and enable a greater range of applications to be considered for reuse of the glass. Heating the glass was one potential solution (see above). Physical abrasion to "knock off" the mercury containing powder was another possibility. The following describes benchscale experiments, in which the glass is tumbled with an abrasive (sand), to test the capabilities of abrasion for mercury removal.

50 gram samples of the glass were weighed and placed in rectangular plastic bottles with a known quantity (5 grams or 10% by weight) of an inert abrasive, in this case a high purity quartz sand, also known as silver sand. To determine the benefits of adding the silver sand, controls were also taken from samples of glass tumbled without the addition of silver sand.

The containers were continuously rotated on an end-over-end tumbling machine for known periods of time at a set speed of 15 rpm. The tumbling periods were set at 1 hour, 4 hours, 24 hours, 48 hours and 72 hours.

After the appropriate time had elapsed, the samples were leached with DIW for 15 minutes prior to filtering and analysis for mercury content by ICP-OES (ICP Optical Emission Spectroscopy – a variation on ICP-MS). The glass samples tumbled with silver sand were split into a coarse fraction (>250 μm) and fine fraction (<250 μm). The fine fraction consisted of all of the silver sand and any material that had been abraded from the surface of the glass.

Results

Following tumbling, the visual appearance of the glass had altered from transparent to a cloudy translucent appearance. Samples collected after one hour of tumbling showed a slightly abraded surface. Samples taken after 4, 24, 48 and 72 hours showed visually increased levels of abrasion, resulting in the glass surface becoming white and less transparent.

The full results of the interaction of the glass samples with DIW after the tumbling experiments are shown in Table 6.1 and Figures 6.2 and 6.3.

Analysis of the DIW after leaching indicated that the uncoated ‘blank’ samples had a mercury content averaging 1 mg/kg, compared to the recovered glass that averaged 2 mg/kg.

Analysis carried out after interaction with DIW on the coarse glass fraction showed that the mercury content decreased with tumbling time, whereas the mercury content in the fine fraction increased with tumbling time (Table 6.2). Glass tumbled without the addition of silver sand demonstrated that some mercury was removed purely by the action of tumbling glass shards together (Table 6.3).

Table 6.1 Interaction of the glass samples with DIW after tumbling				
Sample No.	***Sample Description***	***Tumbling Time***	***Fine/Coarse*** [*]	***Hg Content***
		hours		***ppm***
MS-1	Processed glass	0	N/A	2.40
MS-2	Processed glass	0	N/A	1.60
MS-3	Unused glass (blank)	0	N/A	1.30
MS-4	Unused glass (blank)	0	N/A	0.70
MS-5	Used 'coated' glass	0	N/A	1.25
MS-6	Silver sand (blank)	0	N/A	1.00
MS-7 A&B	Glass only	1	coarse & fines	1.70
MS-7B	Glass only	1	coarse	1.14
MS-8 A&B	Glass only	24	coarse & fines	1.60
MS-8B	Glass only	24	coarse	1.17
MS-9 A&B	Glass only	48	coarse & fines	2.60
MS-9B	Glass only	48	coarse	1.36
MS-10 A&B	Glass only	72	coarse & fines	3.70
MS-10B	Glass only	72	coarse	1.31
MS-11A	Sand + fines	1	fine	2.30
MS-11B	Glass only	1	coarse	1.60
MS-15A	Sand + fines	4	fine	3.30
MS-15B	Glass only	4	coarse	2.20
MS-12A	Sand + fines	24	fine	6.30
MS-12B	Glass only	24	coarse	1.40
MS-13A	Sand + fines	48	fine	4.40
MS-13B	Glass only	48	coarse	1.00
MS-14A	Sand + fines	72	fine	3.20
MS-14B	Glass only	72	coarse	1.00

[*] Fine – sample <250µm, including silver sand and material abraded from the surface of the glass during tumbling.
Coarse – sample >250µm, the glass sample remaining once the <250µm has been sieved off for analysis.

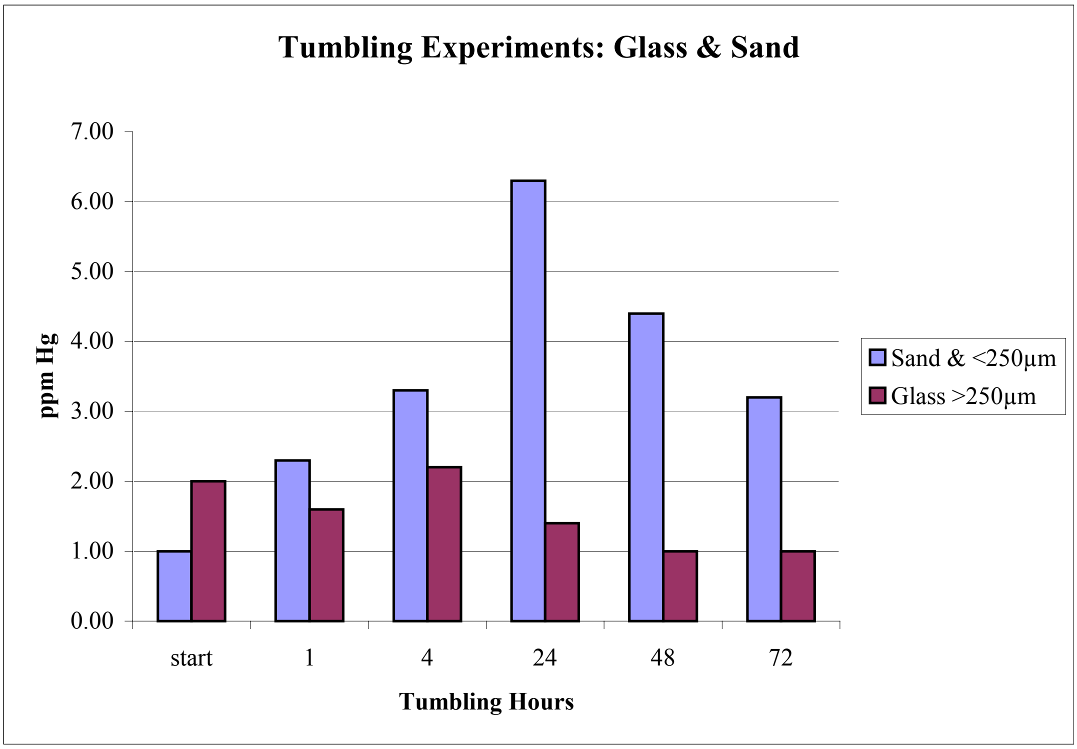

Figure 6.2: Tumbling experiments showing mercury removed from the glass into the fine fraction (<250µm). After 48 hours tumbling Hg levels within the glass (or coarse fraction) are at the same levels as the 'blank'.

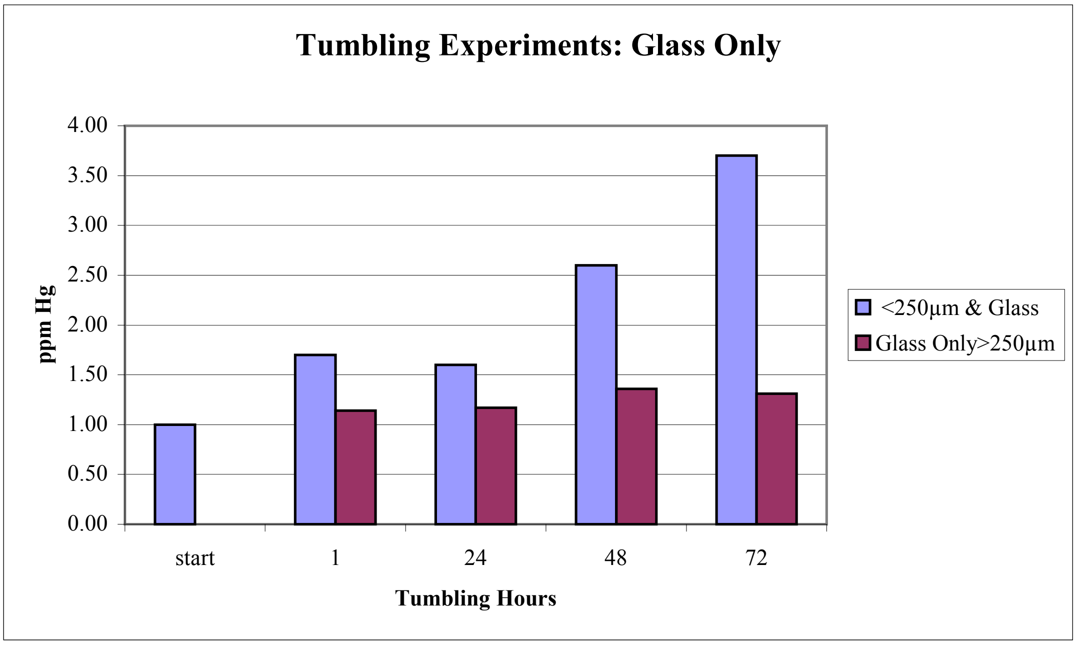

Figure 6.3: Glass tumbled without the addition of silver sand. Levels of Hg in the <250µm fraction increase with tumbling time.

Additional ICP-MS analyses were undertaken in combination with the tumbling experiments. Four samples were tested.

Sample ID.	***Sample Description***	***Mercury mg/kg (ppm)***
1	Glass before tumbling	5
2	Sand 'blank'	<1
3	Glass after 72 hours of tumbling	3
4	Glass and sand after 72 hours of tumbling	<1

Conclusions

These experiments indicated that mercury is still present on the surface of the recovered glass. The apparent increase in mercury content of glass tumbled without additives over 72 hours may be caused by the abrasion of fine particles. This would increase the surface area thus allowing more mercury to be leached from the surface by DIW.

In the samples with the inert abrasives, there is an increase of mercury in the fine fraction and a decrease in the coarse fraction with increasing tumbling time. This indicates that tumbling with the abrasive is effective in physically removing the mercury coating from the coarser glass pieces. After 48 hours, the glass samples show the same reading as the uncoated glass, indicating that the mercury present has been removed to below detectable limits.

The glass tumbled without the addition of inert abrasive also showed an increase of mercury in the fine fraction. This indicates that abrasion of the glass alone will further release mercury from the surface of the glass. This may present a problem of the recycled glass releasing more mercury through further handling and transporting.

The additional ICP-MS analysis undertaken showed a typical mercury content on the glass representative of all the previous analyses undertaken. The blank uncoated glass showed mercury levels below detection limits.

The results on the tumbled samples (Samples 3 and 4) were not as expected. The mercury content of the glass sample had decreased by approximately 50%. From the leaching experiments, it would have been expected that all of the mercury would have been removed from this coarse fraction into the fine fraction. Sample 4 indicated a mercury content below detection limits of 1 mg/kg.

Compressive strength tests

The literature review[23] undertaken as Task 1 of this project identified that ground glass could be substituted for aggregate in concrete. In experiments of binder agents for backfill, finely ground waste glass material was found to enhance the pozzolanic reaction of all sample mixtures. It was envisaged that the use of waste glass as a partial replacement for fillers would provide a cost effective and physically effective binder alternative for the mining industry.

A sample of 100 grams of recovered glass was finely ground and mixed with 25% by weight of lime. Water was added to make a slurry, which was then heated for five days at 70°C. After the sample had cured, it was tested for compressive strength at the University of Coventry.

Results

The sample hardened over the five days. The mix was found to be hydraulic. The equivalent cube compressive strength at 28 days was ~4.5 MPa.

Conclusions

This result is considered to be promising as it indicates that the glass might be suitable for many applications that do not require high compressive strength in the construction industries.

[23] The NCBS (November 2000) *Sustainable markets for waste glass from fluorescent tubes and lamps, Interim report* NCBS reference 2132

Annex E - Contacts

Baroid
Halliburton Energy Services, Don Facility, Howe Moss Cresent, Kirkdale Industrial Estate, Dyce, Aberdeen, AB21 0GN
Tel: 01224 79 5013
Contact:Sandie Maddox
E-mail: sandie.maddux@halliburton.com

T. Berryman & Sons Ltd
Lidgate Crescent, Langthwaite Grange Industrial Estate, South Kirby, South Yorkshire, WF9 3NR
Tel: 01977 608020
Contact: William Prescott
E-mail: wprescott@berryman-uk.co.uk

Chelwood Brick Ltd
Adswood Road, Cheadle Hulme, Cheadle, SK8 5QY
Tel: 0161 485 8211
Email: technical@chelwood.co.uk

DJ Ryan & Sons
Inglethwaite Road, Longbridge, Preston, PR3 2DA
Tel: 01772 783545
E-mail: djryan@djryan.co.uk

Highways Agency
Sunley Tower, Picadilly Plaza, Manchester, M1 4BE
Tel: 0207 921 4635
Contact: John Williams

North West Water Ltd (now United Utilities)
Davyhulme Sewage Treatment Works, Davyhulme, Manchester
Tel: 01925 463783
Contact: Clive Deadman

Pilkington Tiles
PO Box 4, Clifton Junction, Manchester, M27 8LP
Tel: 0161 727 1000

Richardson's
St Helens
Tel: 01744 454444
Contact: Lisa Fern

RMC Aggregates (UK) Ltd

RMC Aggregates (UK) Ltd, RMC House, Church Lane, Bromsgrove, Worcestershire, B61 8RA,
Tel: 01527 575 777
Contact: Gordon Lemon

Tarmac Quarry products
Dalton Quarry, Middleton Dale, Stoney Middleton, Hope Valley, S32 4TR
Tel: 01433 631227
Contact: Chris Worthy

Tarmac Recycling
Tarmac Recycling, Millfields Road, Ettingshall, Wolverhampton, WV4 6JP
Tel: 01902 382 332
Contact: Kate Fowler (Special Projects Manager)
E-mail: kate.fowler@tarmac.co.uk

Annex F - Glossary of terms

Aggregate	A mixture of sand and gravel or crushed rock used in concrete, mortar, plaster or any bulk fill used in construction
Alkali-silica reaction	Alkali-silica reaction causes the growth of calcium-silica gels in concrete, causing stresses, expansion and cracking This reaction in cements prevents the cement from hardening to full strength or causes strength to degrade after a short period of time. This is detrimental to the properties of the cement/concrete
Alkaline absorbent	An absorbent is a substance in to whose structure other substances are absorbed.
Amorphous	A material without an ordered structure of crystalline solids with a 'glassy' appearance.
Backwash (cycles and rates)	Backwash is the reversal in flow across a filtration process. It is used to prevent clogging of the filter. It aims to clear adhered materials from the filtration media to allow the filter to carry on operating.
Ballast	Supplies the fluorescent tube with the correct operating current at all times. As it limits the current, it protects the discharge lamp from burning out too soon. There are two types of ballast: a conventional control system and an electronic control system. Electronic control systems provide the greatest energy savings (Osram, 1999) .
Bearing capacity	The load per unit area that the ground can safely carry.
Biomat	In wastewater filtration systems, fine sand can flow through coarser sand to form low-permeability lenses. These lenses then reduce the rate of flow, thus encouraging the accumulation of biological material, 'biomats'. Biomats cause the filter to clog, resulting in system failures. A system failure means that the filter sand must be replaced.
Borosilicate glass	A type of glass, based on silica and boric oxide that has a higher resistance to thermal shock and is more chemically resistant that soda-lime-silica glass. It can be used for domestic ovenware, laboratory glassware and for glass-to-metal seals, e.g. at the ends of fluorescent tube.
Calcine	A process in which a metal is roasted in air to convert it to its oxide, e.g. calcium carbonate ($CaCO_3$) to calcium oxide (CaO).
Calcium silicate hydrates	A class of minerals including many cement paste minerals. Some can be used as alkaline absorbents.
Capillary action	The movement of water due to the effects of surface tension.
Contaminants	The contaminants, or undesirable elements, of the waste glass are other components of the fluorescent tube, such as metals (including mercury and end fittings), ceramics and plastics.
Cryptocrystalline	A material where the ordered crystalline structure is so fine-grained that it can not be seen even with a microscope. This gives the materials a 'glassy' appearance.
Cullet	Waste glass, generally from packaging. When added with other raw materials to the glass-making process, cullet aids melting and provides energy savings.
Downcycling	Recycling of materials to produce a product of less value and lower quality than the original material.
Faecal coliform count	An indicator of the possible presence of pathogenic organisms. The test quantifies faecal coliforms, e.g. *E. coli*.
BOD	BOD (Biochemical Oxygen Demand) is an indicator of organic contamination. The test measures how much oxygen is needed by micro-organisms during the biodegradation of an effluent sample.
Flux	Material added to a furnace that promotes melting at a lower temperature than would otherwise be required. In some materials, e.g. bricks, the glass acts as a flux, reducing firing temperatures and thus provides energy savings. The glass in its current use as flux in a hazardous waste

	incinerator combines with those constituents not wanted in the final product and forms as a separate slag. This is then made into breezeblocks.
Fly ash	A fine ash from the pulverised fuel burned in power stations, recovered from flue gas scrubbing. It can be used in brick-making and as a partial substitute for cement in concrete.
Friability	The ease with which a material can be easily fractured or crumbled.
Frit	A frit is a partially fused or calcined mixture, often of sand and fluxes as material for glass-making.
Gas cleaning applications	Gaseous emissions from any process, e.g. fuel combustion, are cleaned to remove environmentally harmful substances, e.g. sulphur dioxide.
Geotextile	A textile material used in civil engineering applications, to provide a permeable layer with high tensile strength in a weak soil and to prevent failure and/or deformation.
Glasscrete	A form of concrete where part of the aggregate content has been substituted with glass cullet.
Glassphalt	A form of asphalt where part of the aggregate content has been substituted with glass cullet.
Glastic	A composite from waste plastic and glass.
Ignition loss	The percentage weight loss of a material due to firing.
Leachate	The liquid that seeps through a landfill site, picking up the soluble components of the waste. This liquid can pollute local water supplies if not effectively contained.
Modulus of deformation	This is a test of the strength of the material.
Packaging glass	Glass containers and jars, generally associated with household goods such as food, drink, perfume, pharmaceuticals and household care.
Percentage axial strain to failure	This is a test of the strength of the material.
Permeability	The ability of a material to transmit fluids.
Pozzolanic	A pozzolan is a substance capable of reacting with other materials in the presence of water to form a hard material. MRL's waste glass is pozzolanic. Initial trials of this type of reaction have been carried out on the waste glass from fluorescent tubes.
Refractory	The material used to line furnaces. They must resist high temperatures, changes in temperatures, the action of molten metals, slags and hot gases carrying solid particles.
Self-cementing	A substance that hardens when mixed with water.
Shear strength	This is a test of the strength of the material.
Silicosis	Lung disease due to the inhalation of particles of silica.
Sorption	Includes absorption (the taking up of one substance into the structure of another) and adsorption (the taking up of one substance at the surface of another.
Strain rate controlled unconfined failure	This is a test of the strength of the material.
Sulphate content	Sulphates in cement mixes cause a reduction in long-term strength properties.
Surface area	A large surface area of a material increases the potential for reaction.
Thermal conductivity	A measure of the rate of flow of thermal energy through a material.
Total suspended solids	Quantity of solid material in a liquid (usually water). The test measures the amount of solid material that can be filtered from a liquid. This is an important test for effluent samples as suspended solids in a river can reduce light penetration.
Turbidity	This is an indication of the quantity of undissolved (suspended) matter in water. It is an important test for water and effluent samples – for the same reason stated above under "suspended solids". The test measures

	the reduction in light penetration as compared with a sample of clean water.
Unconfined compressive strength	This is the standard method for defining rock strength and is broadly related to porosity.
Vitrification	The incorporation of waste products, often radioactive, into glass.
Workability	The ease with which a material can be used, installed or emplaced.

Annex G - References

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