CREATING MARKETS FOR RECYCLED RESOURCES

Materials recovery from waste cathode ray tubes (CRTs)

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R&D Interim Report: Glass

Executive summary

Objectives

This is the second interim report of this project being carried out by ICER with support from Glass Technology Services. The project is examining potential markets for waste CRT glass. In this second stage five potential applications have been investigated, three for screen glass which does not contain lead and two for lead-containing funnel glass or mixed glass. The technology for separating the leaded funnel glass from the non-leaded screen glass has also been explored. This stage of the project also looked at current practice in collecting CRTs for recycling.

Use of CRT screen glass in bricks and tiles

Bricks and cladding tiles can be manufactured by pressing together glass particles and firing the resulting product to increase density and strength. The project analysed two products made with CRT glass. The first was a brick product developed by Staffordshire University. Tests showed that the physical properties of the product make it suitable for a range of non-engineering applications e.g. decorative bricks, cladding tiles. Chemical durability tests showed that likely levels of toxic leachates were below the levels set for drinking water. The manufacturing process has a reduced environmental impact in terms of CO_2 emissions compared to standard clay bricks and also compares well in terms of cost. This application has the potential to use significant quantities of the UK's waste CRT screen glass but considerable market research is needed to understand and develop a market for this niche product.

The second product was a cladding tile manufactured by Innolasi Oy. This was found to be expensive to produce compared to imported natural stone. It is therefore unlikely that there would be substantial demand for this product in the UK.

Use of CRT screen glass as flux in brick and ceramic manufacture

Research by CERAM into the use of container glass as flux in brick manufacture indicates that a 5% addition of glass could save between 3 and 5% of the energy used in the firing process. CERAM has undertaken further research which shows that additional energy savings could result from the use of CRT glass. It may also be a more effective fluxing agent than container glass because of its higher alkali content. This application has the potential to use a significant amount of the UK's waste CRT screen glass. If all UK brick manufacturers used 5% some 370,000 tonnes of CRT glass would be required, over 5 times the annual arisings of waste CRT screen glass in the UK. The use of glass as flux will, however, add some cost to brick manufacture because of the need to grind the glass very finely. Further work is needed to raise awareness among brick manufacturers of the potential for using CRT glass and to explore the collection and processing infrastructure needed to ensure consistent supply

There is a similar potential for using CRT glass as flux in the manufacture of ceramic-ware but further research is needed and demand has not been quantified.

Use of CRT screen glass in ceramic glaze

Because the metal oxide content of waste CRT screen glass varies from batch to batch it would be technically difficult to incorporate CRT glass in ceramic glazes and glass frits. Furthermore, these applications would use only a fractional amount of UK arisings of waste CRT glass.

Use of CRT Screen glass in foam glass

Foam glass is an insulating material which can be made from post-consumer waste glass. Experience in Norway indicates that it is technically feasible to incorporate at least 20% CRT screen glass. There are no known technical barriers to using CRT glass and no adverse environmental impacts compared to using other types of waste glass. Demand for foam glass in the UK, however, is limited and there is currently no production capability. Production facilities are being considered but the projected demand for CRT glass in this application is low starting at 3,000 tonnes per annum and rising to a maximum of 9,000 tonnes per annum.

Use of CRT glass (screen and funnel) in the manufacture of new CRTs

There is potential to use 10% of the UK's total annual arising of waste CRT glass (14% of screen glass arisings) in the manufacture of new screens in the UK. Demand for waste CRT glass – screen and funnel - across the 15 EU member states is currently between 8% and 10% of estimated arisings and could increase to as much as 20% if it proves technically and commercially feasible to use over 50% glass cullet in the manufacture of new funnel glass and 30% in screen glass. The glass must be separated, sorted and cleaned to meet glass manufacturers strict quality requirements Further work is needed to explore the technical limits on using post-consumer cullet and to raise awareness of the demand from glass manufacturers for waste CRT glass. Use of cullet in the manufacture of new CRT glass is an important application for waste CRT glass particularly for lead-containing funnel glass for which recycling options are limited.

Use of CRT glass (screen and funnel) in smelting operations

In some types of smelting operations, CRT glass (mixed or separated) can replace sand which is used as a flux. Copper smelters have the greatest potential to use CRT glass but lead smelters such as Imperial Smelting Furnaces (ISFs) used for primary lead and zinc may also have potential to use this material. In order to use CRT glass in smelting operations it is necessary to establish that the lead in the glass can be recovered and that the resulting slag is sufficiently non-toxic to be used in secondary applications such as road aggregate. Smelting is potentially an important application for lead-containing funnel glass for which other recycling options are limited.

Methods of separating CRT glass

There are two approaches to separating the screen glass from the lead-containing funnel glass. The first is to manually remove the CRT from its casing and split it. Established techniques in commercial operation include hot-wire, laser-cutting, diamond-sawing and thermal shock. The second approach is to shred whole TVs and monitors, recover the glass from the remaining material and separate it into different types. This approach is still under development in the UK.

Next steps

The next stage of the project will put together a business development plan to identify commercial operators and take forward the four applications which have been identified as having potential to use significant amounts of the UK's arisings of waste CRT glass i.e. to make bricks, to make new CRTs, as flux in brick and ceramics manufacture and as flux in smelting operations.

MATERIALS RECOVERY FROM WASTE CATHODE RAY TUBES

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1.Introduction

1.1 Purpose of this report

This is the second interim report for the project which ICER is carrying out with support from Glass Technology Services (GTS) to find new applications for waste glass from cathode ray tubes (CRTs). It fulfils Milestone H of the project and covers the methodology and findings of Milestones F and G. The deliverables of milestones F and G covered in this report are listed in 1.2 below. It also covers some of the findings of Milestone I i.e. the results of laboratory trials on brick products.

1.2 Summary of research objectives

This project is examining potential markets for waste CRT glass and the recycling potential of the plastic casings surrounding CRTs.
The deliverables of Milestones F and G are to:

- conduct a detailed study of five prioritised end-use applications for CRT glass, taking into account
  - technical barriers
  - production costs
  - potential demand for CRT glass
  - the environmental impact of using CRT glass
- identify current and emerging techniques for separating CRT screen glass from the lead glass fraction.

1.3 Scope and limitations

This second interim report does not cover composition and recyclability of the plastic casings surrounding CRTs. This work is under way and will be submitted as a separate document by the end of January. It also does not include best practice on collection. This element of milestone F will be covered in the final report.

1.4 Background to this stage of the project

One of the tasks of Milestone C was to identify possible applications for CRT glass cullet. GTS carried out a literature search and brainstorming session which identified some 35 possible applications. ICER also conducted a brainstorming session with producers and recyclers of CRTs. This produced one additional application, the use of CRT glass in metal smelting operations. The use of CRT glass in foam glass was also added later to the list by GTS.

These applications were evaluated in terms of:

- the quantity of CRT glass likely to be used
- the environmental implications of using mixed and/or separated glass in this way
- economic considerations

On the basis of these parameters, the following eight applications were selected for further investigation:

- glass tiles/bricks
- foam glass
- waste encapsulation (nuclear and/or hazardous waste)
- feedstock for new CRTs
- fluxing material in metal smelting
- radiation shielding clothing
- concrete
- tile and brick glaze.

These applications were examined in more detail and a summary of the findings was submitted to WRAP in June. Using the criteria listed above, five of these eight applications were prioritised for in-depth investigation. They were:

- bricks and tiles (for screen glass which is non-leaded)

- flux in brick and/or ceramics manufacture (for screen glass which is non-leaded)
- foam glass for insulation (for screen glass which is non-leaded)
- manufacture of new CRTs (for both funnel and screen glass, mixed and separated)
- flux smelting (for mixed glass and/or leaded funnel glass)fluxing material in metal smelting

2. Methodology and approach

2.1 Analysing end-use applications

The five prioritised end-use applications for CRT glass were analysed in terms of:

- technical barriers
- likely production cost
- potential market size
- quantity of CRT glass that could be consumed
- environmental impacts of the manufacturing process

2.1.1 Bricks and tiles (research by GTS)

Two manufacturing technologies for the production of bricks and tiles were investigated. In order to review the above issues brick samples were manufactured and existing information on available products was reviewed.

2.1.2 Flux in brick and/or ceramics manufacture (research by GTS)

The use of CRT screen glass as a flux in bricks and as a ceramic glaze was reviewed. CERAM has been commissioned to undertake further research as identified from previous studies.

2.1.3 Foam glass (research by GTS)

The manufacture of foam glass is well established in a number of European counties, predominantly using container glass. However, foam glass products have successfully been manufactured using CRT glass. Samples of foam glass incorporating foam glass were produced and tested for chemical durability.

2.1.4 Manufacture of new CRTs (research by ICER)

ICER identified manufacturers of CRT glass in Europe and explored the opportunities of and technical barriers to using recycled cullet in the manufacture of both funnel and screen glass. It looked at the capacity of individual manufacturers and estimated the potential in both the UK and the rest of Europe for incorporating waste glass now and over the next 10 years. It also assessed the economic and environmental benefits of using recycled cullet.

2.1.5 Flux in smelting (research by ICER)

To investigate the potential to use CRT glass in metal smelting a literature search was undertaken and discussions were held with the Lead Development Association, the International Zinc Association, the Non-Ferrous Association and the European Copper Institute. Smelting operations of different type were then visited to understand the opportunities and barriers to using CRT glass in specific operations. The environmental and economic implications of using CRT glass in smelting were explored along with potential capacity for using CRT glass across the EU.

2.2 Techniques for separating funnel and screen glass

A literature search was carried out to identify and evaluate different techniques. The survey of recyclers carried out for the first stage of this project identified several UK companies which either had either already developed techniques for separating and cleaning the glass or were researching and developing such techniques. These companies were visited to explore issues surrounding separation and cleaning in more detail. Discussions were also held with the glass manufacturers who buy the separated glass. Information was sought on the nature of the process, technical issues to be overcome, costs (capital and labour) and environmental impact in terms of energy use and waste emissions.

3. Use of CRT screen glass in bricks and tiles

3.1 Description of products

Bricks and cladding tiles can be manufactured from pressing together glass particles to produce a green body product that is then fired to increase density and strength. Two manufacturing techniques were reviewed and investigated, namely:

- Staffordshire University, UK
- Innolasi Oy, Finland

3.2 Staffordshire University, UK

Staffordshire University has developed and are in the process of patent protecting for a process that produces bricks and tiles from waste glass. Their process requires ground glass of a particle size between 0.5 & 1 mm, that is then pressed in a mould with a binder. The green product is then strong enough to be handled prior to firing, which sinters together the glass particles to form a dense strong product.
Their original work was based on the use of container glass. However, as part of this project Staffordshire University was commissioned to produce a number of products for further testing and evaluation using CRT panel glass. The technology will be marketed by Stoneglass Building Products Ltd a spin-out company of Staffordshire University.

Figure 1. Stafford University bricks

As part of this project Staffordshire University was commissioned to produce a number of products for further testing and evaluation. DBS, York, provided the panel glass and GTS provided the container glass for the production of test bricks at Staffordshire University, the composition of the waste glasses was as follows:

Oxide	Panel Glass Wt%	Container Cullet Wt%
SiO_2	54.15	71.71
SrO	12.91	

BaO	9.28	
K_2O	8.81	0.65
Na_2O	6.80	12.98
ZrO_2	3.08	
Al_2O_3	1.97	1.85
CaO	0.96	10.77
TiO_2	0.541	0.07
CeO_2	0.372	
ZnO	0.298	
Sb_2O_3	0.262	
MgO	0.152	1.36
Fe_2O_3	0.141	0.38
Cl	0.056	
Bi_2O_3	0.051	
SO_3	0.048	0.15
HfO_2	0.043	
PbO	0.040	
NiO	0.022	
CuO	0.014	
Cr_2O_3		0.08

Table 1. Chemical composition of panel and container glass used in the brick production trial.

Series Number	Panel wt%	Container glass wt%
B1	100	0
B2	66.7	33.3
B3	33.3	66.7
B4	0	100

Table 2. The composition of the series of bricks produced for chemical and mechanical testing.

Staffordshire University received the CRT panel glass as whole panels and the container glass as broken pieces with a particle size between 5 & 20 mm. The glass was processed by grinding down to an average particle size of 1mm. These were then mixed together as necessary to achieve the mixtures listed in Table 2. The mixtures were then pressed to form small bricks (briquettes), approximately 110 x 55 x 35mm and fired. Four bricks were produced for each series.

It was noted that all four series appeared to have similar forming characteristics and there appeared to be no production issues with any of the above series. The bricks were then tested for physical properties and chemical durability.

3.2.1 Physical Testing

Four tests were undertaken, namely, water absorption, compressive strength, rupture of modulus and frost resistance. Below is a brief description of the testing methodology.

3.2.1.1 Water absorption

The procedure was based on BS 3921 appendix E. However, there were not sufficient number of samples and they were not of a standard brick size (225 x 112 x 75 mm), as BS3921 specifies at least 10 bricks of the standard brick size. The methodology of BS 3921 was followed, thus:

- The mass (g) of each of the fired samples was measured and recorded;
- The samples were placed into cold water, which was then heated to boiling over a one hour period;
- The samples were boiled continuously for 5 hours;
- The samples were allowed to cool down (in the boiled water) over night;
- Each sample was removed from the water, surface water removed with a damp cloth and the mass (g) immediately measured (to an accuracy of within 1% of the sample mass) and recorded;
- The water absorption was then calculated.

3.2.1.2 Compressive strength

The procedure was based on BS 3921 appendix D. However, there were not sufficient number of samples and they were not of a standard brick size (225 x 112 x 75 mm), as BS3921 specifies at least 10 bricks of the standard brick size. The methodology of BS 3921 was followed, thus:
The length and breadth of the load face of each of the fired brick samples (ex water absorption test) were measured:

- Each brick sample was located within the compression test rig;
- The sample was loaded (N) slowly at a uniform rate until failure was indicated;
- The compressive strength was then calculated.

3.2.1.3 Modulus of rupture

Each fired sample (ex water absorption test) was located within the modulus of rupture machine.
The sample was loaded centrally at a slow uniform rate and loading was continued until failure occurred.
The width and depth of the tile sample were measured, in close vicinity of the point of failure and the modulus of rupture was then calculated.

3.2.1.4 Frost resistance:

The brick industry standard test procedure generally accepted is the panel freezing test devised by CERAM, in which a panel made from 30 bricks (225 x 112 x 75 mm) is exposed to a 100 freeze thaw cycles. Again, there were insufficient number of brick samples and they were not of a standard brick size. Therefore, Staffordshire University devised a freeze resistance test for replicating the standard test that gives an indication of the suitability of the sample brick under freeze thaw conditions. The procedure used was as follows:

- The brick samples were initially fully saturated with water by boiling and then cooling in water;
- The samples were placed semi-submerged in water in a retaining tray;
- The tray was placed in the freezer (~ minus 15ºC) and left overnight.
- The next day the tray was removed from the freezer and allowed to thaw.
- At midday, the samples were removed from the tray and placed in a bowl of water.
- The tray was examined for the presence of any material lost from the samples.
- Then the samples were replaced semi-submerged in water in the retaining tray and placed back into the freezer overnight;
- Steps 4 to 7 are repeated every 24 hours.

3.2.2 Results of Physical Testing

Property	Unit	Series Number			
		B1	B2	B3	B4
Water absorption (mean)	%	9.9	10.9	10.7	8.8
Modulus of rupture (mean)	MPa	9.5	8.7	10.0	14.2
Compressive strength (mean)	N/mm_2	42.4	38.5	51.4	65.4

Table 3. Physical property measurements for the series of brick samples.

The frost resistance test was conducted on brick sample B4 and has survived over 100 freeze/thaw cycles with no noticeable signs of failure.

It is likely that the properties of the bricks in this trial were not optimised and it is probable (based on previous development trends) that the products can be further densified, yielding products of lower absorption and greater strength. This could be achieved by manipulation of particle size distribution, forming pressure and firing schedule.

The following list of tables (Table 4 to Table 7) shows the relevant British Standards for comparable products.

Class	Compressive strength (N/mm^2)	Water absorption (% by mass)
Engineering A Engineering B	≥ 70 ≥ 50	≤ 4.5 ≤ 7.0
Damp-proof course 1 Damp-proof course 2	≥ 5 ≥ 5	≤ 4.5 ≤ 7.0
All others	≥ 5	No limits
NOTE 1 There is no direct relationship between compressive strength and water absorption, as given in this table, and durability. NOTE 2 Damp-proof course 1 bricks are recommended for use in buildings whilst damp-proof course 2 bricks are recommended for use in external works.		

Table 4. Abstract from BS3921:1985 Clay Bricks, Classification of bricks by compressive strength and water absorption.

Designation	Class	Compressive strength (N/mm^2)	Predicted lower limit of crushing strength not less than (N/mm^2)
Load bearing brick	7	48.5	40.5
Facing brick	6 5 4 3	41.5 34.5 27.5 20.5	34.5 28.0 21.5 15.5

Table 5. Abstract from BS 187:1978 Calcium silicate bricks, Compressive strength classes and requirements.

Type of paver	Minimum mean transverse breaking load (kN)	Minimum individual transverse breaking load (kN)
PA	3.0	2.0
PB	7.0	4.0

Table 6. Abstract of BS 6677-1:1986 Clay and Calcium silicate pavers, transverse breaking loads.

Paver dimensions(mm)		*Min. mean transverse MoR (MPa)*		*Min. individual transverse MoR (MPa)*	
width X	*thickness*	*Type PA*	*Type PB*	*Type PA*	*Type PB*
100	***50***	***3.2***	***7.4***	***2.1***	***4.2***
100	*65*	*1.9*	*4.4*	*1.2*	*2.5*
102.5	*50*	*3.1*	*7.2*	*2.1*	*4.1*
102.5	*65*	*1.8*	*4.3*	*1.2*	*2.4*
105	*50*	*3.0*	*7.0*	*2.0*	*4.0*
105	*65*	*1.8*	*4.2*	*1.2*	*2.4*

Table 7. Abstract of BS 6677-1:1986 Clay and Calcium silicate pavers, calculated equivalent transverse Modulus of Rupture; span = 175 mm.

Class	**Compressive strength (N/mm^2)**	**Water absorption (% by mass)**
Autumn leaf (pressed brick)	23 – 35	20 – 24
Cambridgeshire mixture (handmade brick)	12 - 18	29 – 32
Anfield red multi (extruded brick)	45 – 55	8 – 11

Table 8. Average properties of 'non-engineering' Hanson clay bricks.

With reference to physical properties in Table 3 and the British Standards in Table 4 to Table 7 the following conclusions can be drawn:

- None of the brick samples satisfied engineering brick requirement; BS3921 (Table 4);
- All the brick samples satisfied calcium silicate brick strength specification class 3 to 6 of BS 187 (Table 5) and B3 & B4 satisfied all classes. There was no water absorption requirement for this specification;
- All the brick samples satisfied the maximum PA & PB paver strength specification; BS6677 (Table 6 & Table 7). There was no water absorption requirement for this specification;
- All the brick samples satisfied the 'non-engineering' clay brick specification (Table 8) except for extruded class, of which only B3 & B4 satisfied the requirement. There was no water absorption requirement for this specification.

The freeze thaw test was undertaken on B4 and the sample survived over 100 cycles without any visible damage.

All of the physical tests were conducted on samples that were below the required brick size (225 x 112 x 75 mm) for the relevant British Standard. The results indicate that the samples tested were suitable for non engineering decorative applications such as cladding tiles, facia bricks, floor tiles etc.

3.2.3 Chemical Durability Testing

The chemical durability of the brick samples needed to be assessed both for in use application and end of life (landfill). The landfill scenario is considered the worst environment as this generally involves the involuntary breaking of the product into many smaller pieces, then being exposed to groundwater. Currently there are no British or European standards for testing of durability of waste in landfill conditions. There are numerous tests for food and drink containers that require the product to be very finely ground which is not a true representation of the actual end of life situation.

Initially, the leaching tests were going to be conducted on complete samples to test that the product was fit for purpose. However, after careful examination of the bulk composition of the bricks it was calculated that it was likely that the level of dissolution of potentially toxic compounds would be below the detection limit of the analytical equipment. Therefore, it was decided to follow a USA test method CONEG 3050b 'Acid Digestion of Sediments, Sludges and Soils', whereby, the samples were crushed and passed through a 2mm sieve to obtain the correct particle size. Approximately 1 gram of the sample was then accurately weighed to 4 decimal places into a conical flask. To this was added to 10ml of 1:1 Nitric acid, the solution was mixed and heated gently without boiling for 15 minutes. The sample was cooled and then 5ml of concentrated Nitric acid was added. The conical flask was returned to the hot plate and heated to approximately 95°C for 2 ½ hours. The solution was cooled and 2 ml of ultra pure deionised water and 3ml of 30% hydrogen peroxide were added. This solution was warmed until the effervescence had subsided. 30% hydrogen peroxide continued to be added in 1ml aliquots with warming until a total of 9ml had been added to the solution. The conical flask was returned to the hot plate and heated without boiling for 2 hours.

The conical flask was cooled and 10ml of concentrated hydrochloric acid was added. The solution was returned to the hot plate and heated without boiling for 15 minutes. The solution was cooled and filtered through a filter paper. The filtrate was collected in a 100ml volumetric flask and made up to volume with ultra pure deionised water. The solution was then analysed by Inductively Coupled Plasma (ICP).

Analyte	B1 (ppm)	B2 (ppm)	B3 (ppm)	B4 (ppm)	Blank (ppm)
Ti	<0.01	0.01	<0.01	<0.01	<0.01
Cr	<0.03	<0.03	<0.03	<0.03	<0.03
Fe	2.12	1.70	2.09	2.14	0.07
Ni	<0.02	<0.02	<0.02	<0.02	<0.02
Cu	<0.03	<0.03	<0.03	<0.03	<0.03
Zn	0.20	0.07	0.07	0.04	<0.03
Sr	3.41	1.63	0.39	0.14	<0.01
Zr	0.02	0.04	<0.01	<0.01	0.02
Cd	<0.01	<0.01	<0.01	<0.01	<0.01
Sb	<0.10	<0.10	<0.10	<0.10	<0.10
Ba	3.29	1.57	0.47	1.09	0.09
Hf	<0.10	<0.10	<0.10	<0.10	<0.10
Hg	<0.10	<0.10	<0.10	<0.10	<0.10
Pb	<0.10	<0.10	<0.10	<0.10	<0.10
Bi	<0.10	<0.10	<0.10	<0.10	<0.10
Ce	<0.10	<0.10	<0.10	<0.10	<0.10

Table 9. Analysis of the leachate from the brick testing, all results in ppm. Orange cells above the water drinking limit and blue cells not specified.

3.2.3.1 Summary of results

To put the results in Table 9 into context, the results have initially been compared to current UK limits for leaching from food contact glassware and drinking water as detailed in Table 10 & Table 11. Considering these limits as the extreme and therefore probably not suitable for the brick application; then referring to Table 9, only barium and iron were above the drinking water limit, 1 ppm barium and 0.2 ppm iron is permitted. Strontium is not specified in the drinking waste limits. Therefore, the only elements from a toxicity point of view that may warrant further investigation are strontium and barium. The analysis for heavy metals, lead and cadmium were below the levels set for food containers and lead cadmium, mercury and chromium were below the levels for drinking water.

	Cookware, Packaging and Storage Containers >3L	Hollow ware
Pb	1.5 ppm	4 ppm
Cd	0.1 ppm	0.3 ppm

Table 10. Current UK Limits for lead and cadmium leaching in tableware (BS 6748).

	ppm
Al	0.2
As	0.01
Br	1
Ba	1
Ca	250
Cd	0.005
Cr	0.05
Cu	2
Fe	0.2
Mg	0.05
Na	200
Ni	0.02
Pb	0.025
Sb	0.005
Se	0.01
Zn	5

Table 11. The current limits of elemental concentration in drinking water in the UK as ppm.

3.2.3 Conclusions

The physical properties testing of the brick samples indicated that the bricks will be suitable for most non-engineering applications such as decorative bricks, façade tiles etc.

The chemical durability testing indicated that the likely levels of toxic leachates from the brick under the experimental conditions were below the levels set for drinking water. Barium and strontium were at a level that was considered low enough to be of no concern whilst in service or at the end of life disposal of the bricks.

3.2.4 Technical barriers relating to manufacturing process

To date Staffordshire University has only undertaken laboratory scale production of the bricks and tiles. Therefore, any possible technical production barriers have not been realised. The next stage in the development of these products is an industrial production scale trail to manufacture bricks and tiles of a size appropriate for the application.

The short term technical barrier will be the acquisition of sufficient quantity and quality of CRT panel glass. It has been demonstrated that the CRT panel glass can be mixed with container glass to produce a satisfactory product. Therefore, this risk could be alleviated by the use of both container and CRT panel glass in the bricks.

3.2.5 Likely production cost

At this stage the technology developed by Staffordshire University has only been conducted on a laboratory scale. Staffordshire University has provided some costing information; however, they have not undertaken a rigorous costing exercise. At a later stage a complete business appraisal needs to be undertaken to ascertain the production cost and necessary investment to manufacture bricks and tiles in the UK.

3.2.6 Size and value of current and potential markets for these products in the UK

Currently the bricks are not commercially manufactured and therefore there is no proven developed market for the potential products. It is difficult to predict the potential size of the market for this product. Based on the above production cost model of 10 million units per annum, the annual usage of panel glass would be approximately 32,200 tonnes. To put this into context approximately 3 billion bricks are manufactured in the UK and thus a production of 10 million bricks using CRT panel glass would make up approximately 0.33% of current UK brick production.

3.2.7 Amount of CRT glass that could potentially be used in these products

At this stage it is difficult to estimate future demand for a product which has yet to be marketed. It is likely that this product will be initially accepted as an alternative green product for the public and private sectors that are developing a green procurement policy. It is envisaged based on other similar European manufactured products that the growth will be conservative and that for the exercise of predicting future markets it would be prudent to assume no more than 20% growth over the next 10 years.

3.2.8 Environmental impact of manufacturing process

The environmental impact of the Staffordshire University brick process was accessed against typical clay brick manufacture in terms of CO_2. The study undertaken was limited to the collection, processing and manufacture of bricks. It can be seen from the simplified example in Table 12 that the SU brick manufacturing process is most likely to have a reduced environmental impact over traditional brick manufacture. Putting this into context on the assumption that the process will manufacture 32,500 tonnes, there could be the potential reduction of 2200 tonnes of CO_2 per annum

Process	Brick kg CO_2/tonne	SU brick kg CO_2/tonne	Assumptions
Extraction of clay	2	0	
Transport to recycling facility		12	Assume 50 miles return empty
CRT dismantling		2.49	Assume 15 kWh/tonne of CRT glass (40 CRT units)
Glass processing		10	
Transport to brick works		0.35	Assume 15 miles return empty. No transport for clay, on site extraction
Brick production firing	142.85[1]	49.83	Lower firing temperature
	142.85	**74.67**	
Net CO_2 saving per tonne of brick		**68**	

Table 12. Comparison of CO_2 emission from standard brick and SU brick manufacture.

[1] Good Practice Guide 164, Department of Environment, Transport and the Regions

3.3 Innolasi Oy, Finland

Innolasi, Finland has developed a cladding tile made from waste glass that can incorporate or be entirely made from CRT glass and/or the CRT glass can be used to glaze the finished tile. However, this company has cease trading due to lack of sales and some production issues.

The company manufactured tiles from waste glass, the innovative process compacts crushed glass between 2 and 10 mm particle size, using a vibration forming technique, then it is fired to form a strong durable tile. The tiles produced were typically 300 x 400 mm with a thickness between 25 & 30 mm. The predicted Scandinavian market in 2003 for this product was 30,000 m^2/annum, which equates to 1200 tonnes/annum of waste glass. It is possible to solely use CRT for this product, however, to date Innolasi had only commercially trailed using CRT glass as a glaze, which would equate to 48 tonnes/annum of CRT glass if all the tiles were glazed, which is not the case.

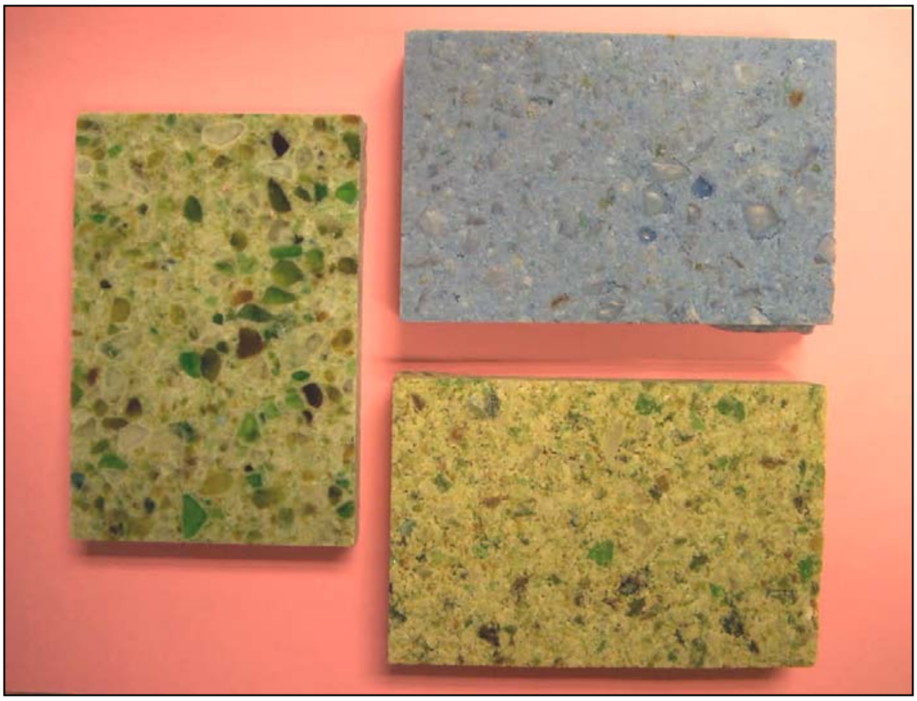

Figure 2. Selection of Innolasi tiles.

3.3.1 Technical barriers relating to manufacturing process

Due to closure of the plant no detailed information on the process was obtained. However, it is understood that there were some production problems due to shrinkage cracking that reduced production output of the plant.

3.3.2 Size and value of current and potential markets for this application in the UK

There is no known market research for the UK market, however, for the basis of this report it was assumed that 100,000 m^2/annum could be manufactured in the UK by two production lines.

3.3.3 Amount of CRT glass that could potentially be used in this process

The commercial limitation of the process is 50,000 m^2/annum per production line/factory. Therefore, based on the assumption of two lines at one production facilities in the UK, this would result in a total production of 100,000 m^2/annum, this would use 4,000 tonnes/annum at the very most, more likely to be 2,000 tonnes/annum if part mixed with container glass and if used for glazing only 80 tonnes/annum. The capital equipment for a 100,000 m^2/annum is in the order of €3 million.

3.3.4 Environmental impact of manufacturing process

The cladding tiles will be competing against natural stone products such as granite and marble. Due to the possible sources of natural stone, from around the world, it is difficult to estimate the environmental impact with respect to CO_2 emissions. Based on the energy consumption of the manufacturing process, it would emit 450 kg CO_2/tonne (1800 tonnes CO_2/annum) of product. The high energy use is due to the long curing and firing time, over 20 hours.

3.4 Next steps

The Staffordshire University brick product shows considerable potential to use large volumes of CRT glass. If the whole of the UK's annual arising of CRT screen glass were to be used in bricks, this would make some 20 million standard-sized units and account for less than 1% of the UK's annual brick production. The challenge however is to develop a niche market for this type of brick product. There is not enough waste CRT glass to make bricks to compete with standard bricks. Substantial further work is required to research the potential market, understand the competition and undertake a complete business appraisal.

4. Flux in brick and/or ceramics manufacture

Glass can be used in brick manufacture and/or ceramic manufacture as either a flux or glaze, respectively. Two possible applications for CRT panel glass were reviewed and investigated, namely:

- brick flux
- ceramic glaze

4.1 Flux in Bricks

4.1.1 Description of application

This application is based on research undertaken by CERAM with WRAP support; the investigation of waste container glass as a fluxing agent to reduce the brick firing temperature. CERAM has recently been commissioned to undertake an investigation on the suitability of CRT glass as a brick flux; this work has now been completed and the results will be fully described in the third interim report.

The work to date completed by CERAM on container glass has indicated that the use of container glass as a brick flux at a 5% addition could possibly save between 3 and 5% energy in the firing process.

4.1.2 Technical barriers relating to manufacturing process

The results of the CERAM study indicate that there are potential advantages with the use of CRT panel glass as a brick flux. The viscosity versus temperature relationship was studied as part of this investigation and the results are shown in Table 13.

	Container	**Mixed panel**	**Panel 1**	**Panel 3**
	wt%	wt%	wt%	wt%
SiO_2	73.00	63.87	62.55	61.52
Al_2O_3	1.00	3.26	3.58	3.86
Na_2O	12.80	8.06	7.86	8.86
K_2O	0.10	9.35	7.86	10.64
Li_2O	0.00	0.00	0.00	0.00
CaO	11.50	2.18	3.18	3.40
MgO	1.60	1.04	0.00	0.00
BaO	0.00	7.99	13.70	0.20
ZnO	0.00	0.00	0.00	0.00
PbO	0.00	0.00	0.00	0.00
B_2O_3	0.00	0.00	0.00	0.00
SrO	0.00	3.89	0.00	10.45
Total	100.00	99.64	98.73	98.93

Log viscosity	**Temperature (°C)**			
	Container	**Mixed panel**	**Panel 1**	**Panel 3**

Melting	2	1450	1483	1495	1416
	2.5	1309	1332	1339	1276
	3	1197	1213	1217	1166
Gob temp.	3.5	1108	1117	1119	1078
Working	4	1034	1038	1038	1005
Litt. Soft.	7.65	736	715	714	712
Mg	11	614	582	583	593
Annealing	13	567	532	533	548
Strain	14.5	540	502	503	521

Table 13. The viscosity temperature relationship for different panel glass compositions.

It can be seen from Table 13 that the difference between the mixed and two randomly picked panel glass compositions is that they have a similar Littleton softening point, within a few °C. Also, the viscosity temperature relationship of container and CRT glass is very similar. Therefore, from a thermal properties issue CRT glass could be used as a brick flux as it would soften at a slightly lower temperature than container glass. Hence, further possible energy savings could be achieved if CRT glass was used as a brick flux. The Littleton softening point is the temperature when glass is soft enough to deform and react. Therefore, it is a relative comparison of the suitability of glass as a fluxing agent.

Another consideration is the fluxing reaction of the glass, the alkali content of the glass is a major consideration. The alkali content of glass is primarily due to the oxides of potassium and sodium. CRT glass tends to have between a 20 and 50% greater alkali content than container glass. Indicating that CRT panel glass could be an effective fluxing agent in brick production. Therefore, considering the thermal and chemical properties it is likely that CRT glass will be at least as effective as container glass as a brick fluxing agent.

4.1.3 Likely production cost

Table 14 shows a cost comparison for traditional bricks vs. bricks incorporating glass flux. It is reported that glass flux will save up to 5% energy, assuming gas firing; there is a saving of fuel cost and CO_2 tax (based on Climate Change Agreement. It is reported that the glass (in the case of container) needs to be less than 100 µm and preferably between 20 and 40 µm to be an effective flux, the cost to process to this size again is reported to be approximately £40 for large scale processing.

	Traditional Bricks			Bricks with glass flux		
Glass addition	0%			5%		
Glass cost	n/a			£0	/t	£0.00
Glass processing cost	n/a			£40	/t	£2.00
Glass PR credit	n/a			£0	/t	£0.00
Brick clay cost	£1	/t	£1.00	£1	/t	£0.95
Energy saving	0%			5%		
Brick production	860	kwh/t		817	kwh/t	
Gas cost	£0.0100	£/kWh	£8.60	£0.0100	£/kWh	£8.17
CO_2 tax (gas)	£0.0015	£/kWh	£1.29	£0.0015	£/kWh	£1.23
CO_2 rebate CCA	80%		-£1.03	80%		-£0.98

		£9.86	£11.37

Table 14. Cost comparison of glass processing and energy cost for the production of traditional bricks and bricks incorporating glass flux.

4.1.4 Size and value of current and potential markets for this application in the UK

The potential market is hard to predict as the brick flux research and development project has not yet been complete and no results have been published. UK brick production is approximately 3 billion bricks per annum, which equates to 7.5 million tonnes per annum of bricks. Based on a 5% addition and if full adoption by the brick manufacturers then 375,000 tonnes per annum of glass would be consumed. It is unlikely that this level of adoption would be achieved, bearing in mind that there is potentially only 70,000 tonnes per annum of CRT panel glass waste arising. However, there could be a potential market for CRT panel glass in brick manufacture.

4.1.5 Amount of CRT glass that could potentially be used in this process

If the brick manufacturers start to consume glass as a brick flux, then there is the potential to use CRT panel glass. The technical barrier will be assessed as part of the work commissioned to CERAM. Also, the commercial aspect of using CRT panel glass will need to be addressed.

4.1.6 Environmental impact of manufacturing process

The addition of 5% glass in place of the virgin clay will save virgin clay extraction and energy. For every tonne of brick there is potential to reduce clay extraction by 5% (based on dry). Table 15 compares an estimate of CO_2 emission from brick production of a traditional composition and bricks with 5% glass flux. The CO_2 emission from glass processing is thought to be in the region of 10 kg CO_2/tonne of glass (20 kWh/tonne). Therefore, the overall energy saving could be in the region of 4.5 %, this analogy does not taken account of the energy of clay extraction as this figure will be relatively low and will not greatly influence the overall CO_2 emission.

Process	CO_2 Emission(kg CO_2 / tonne of bricks)	
	Traditional Bricks	Bricks with glass flux
Glass processing		0.5
Brick Firing	143[2]	136
Total	143	136.5
Saving		6.5

Table 15. A comparison of the estimated CO_2 emission for the production of traditional bricks and bricks incorporating glass flux.

4.2 Ceramic fluxes and glazes

4.2.1 Ceramic ware flux

The use of waste CRT glass as a fluxing agent in ceramic ware is one possible application. CERAM research is currently undertaking research to investigate the use of waste container glass as a flux in sanitary ware. Again CERAM is committed to undertaking the WRAP project and were not in a position to investigate the use of waste CRT glass. Based on the same logic as for the brick flux, CRT glass has similar properties to container glass, if not better in terms of viscosity temperature relationship and chemically reactivity (high alkali content). However, this requires further practical research to confirm the suitability of CRT glass as a ceramic ware flux.

[2] Good Practice Guide 164, Department of Environment, Transport and the Regions

4.2.2 Ceramic glazes

In the literature ceramic glaze is often referred to as a possible application for waste CRT glass. However, to date no commercial products that incorporate waste CRT glass could be found. With the demise of the UK glass frit industry there is how only a few producers of glass frit in the UK.

4.2.3 James Kent, Stoke on Trent

James Kent manufactures a range of glass frits and one glass frit that requires Ba and Sr is for stainless steel extrusion lubricants. The compositional range of panel was sent to JK and they were concerned that the Ba and Sr could range from 1.9 wt% to 14.2 wt% and 0 wt% to 11.6 wt% respectively. They believe that incorporating the waste CRT panel glass would require variable additions of the other raw materials to achieve the required composition. Requiring analysis of every batch of waste CRT glass and then recalculating the batch recipe to achieve the required composition. Practically this would not be viable, bearing in mind that the UK market is <1000 tpa. Theoretically, 25 wt% waste CRT glass could be incorporated, but practically it would probably be a faction of a percent.

4.2.4 Production of samples

Due to lack of samples, a series of frit glazes were developed based on commonly used non-leaded glazes.

	Mixed Panel	Glaze Composition	CRT Addition	Oxide Addition	Final Glaze composition	
SiO_2	54.00	53.1	20.77	29.92	50.69	
Al_2O_3	1.96	12.4	0.75	10.78	11.53	
Na_2O	6.76	2.6	2.60	0.00	2.60	
K_2O	8.77	4.1	3.37	0.67	4.05	
CaO	0.95	3.6	0.37	2.99	3.36	
MgO	0.14	2.6	0.05	2.36	2.41	
BaO	9.24	6.7	3.55	2.91	6.47	
ZnO	0.30		0.11		0.11	Over range
PbO	0.04		0.02		0.02	Over range
B_2O_3	0.00	14.9		13.79	13.79	
SrO	12.95		4.98	0.00	4.98	Over range

Table 16. Composition of Glaze 1, ratio of 37% CRT glass to 63% virgin materials.

	Mixed Panel	Glaze Composition	CRT Addition	Oxide Addition	Final Glaze composition	
SiO_2	54.00	50.8	11.69	37.74	49.43	
Al_2O_3	1.96	15.1	0.42	14.16	14.59	
Na_2O	6.76	3.3	1.46	1.77	3.24	
K_2O	8.77	5.5	1.90	3.48	5.37	
CaO	0.95	1.6	0.21	1.35	1.55	
MgO	0.14	2.4	0.03	2.29	2.32	
BaO	9.24	2	2.00	0.00	2.00	
ZnO	0.30		0.06		0.06	Over range

PbO	0.04		0.01		0.01	Over range
B_2O_3	0.00	19.3	0.00	18.63	18.63	
SrO	12.95		2.80		2.80	Over range

Table 17. Composition of Glaze 2, ratio of 21% CRT glass to 79% virgin materials.

	Mixed Panel	Glaze Composition	CRT Addition	Oxide Addition	Final Glaze composition	
SiO_2	54.00	49.7	24.76	22.55	47.32	
Al_2O_3	1.96	7.2	0.90	5.70	6.60	
Na_2O	6.76	3.1	3.10		3.10	
K_2O	8.77	4.6	4.02	0.52	4.54	
CaO	0.95	5.8	0.44	4.85	5.29	
MgO	0.14	0.7	0.06	0.58	0.64	
BaO	9.24	27.9	4.24	21.40	25.64	
ZnO	0.30	1	0.14	0.78	0.92	
PbO	0.04		0.02		0.02	Over range
B_2O_3						
SrO	12.95		5.94		5.94	Over range

Table 18. Composition of Glaze 3, ratio of 43% CRT glass to 57% virgin materials.

The above glazes (Table 16, Table 17 and Table 18) are currently being prepared and will be used to glaze white ceramic tiles, then the properties will then be assessed such as colour, durability etc.

As illustrated in the above examples, it is very difficult to match the composition without exceeding the quantity of one or more oxides. This is due to the fact that CRT glass compositions, especially mixed waste are very complex, even more so than ceramic glaze compositions. If waste CRT glass is to be used in the manufacture of ceramic glazes, then a series of specially adapted compositions need to be developed though a programme of research and development.

4.3 Next steps

4.3.1 Use as flux in brick manufacture

This application has particularly good potential for the use of large volumes of CRT glass. CRT screen glass shows even greater potential than waste container glass for reducing the firing temperature and may prove a better fluxing agent because of its higher alkali content.

One barrier to using CRT glass in flux in the near term is getting a reliable supply of CRT glass. In order for the brick and ceramics industry to consider switching to CRT glass they need to be assured of a constant supply processed to the required quality standards. To address this a suitable collection and processing infrastructure needs to be in place in the UK.

Further work is needed to:

- substantiate the results of the research already carried out
- raise awareness amongst brick manufacturers of the potential for using CRT glass as a flux
- consider the possibilities of blending CRT glass with flat and container glass

- explore in detail the collection and processing infrastructure that needs to be in place to assure brick manufacturers of a consistent supply

4.3.2 Use as flux in ceramics manufacture

Technically there is a similar potential for CRT glass to be used as flux in the manufacture of ceramics. Further research is necessary to confirm this, to quantify demand.

5. Foam glass

5.1 Description of products

Foam glass (also referred to as cellular glass) has been commercially available since the 1930's. Originally it was manufactured from a specially formulated glass composition using virgin glass only. Currently, there are a number of foam glass production plants that are using up to 98% post consumer waste glass in their product. The basic principle of foam glass manufacture is to generate a gas in glass at a temperature between 700 and 900°C. The gas expands thus producing a structure of cells to form a porous body. The foam glass can be either made from a molten glass or sintered glass particles. The latter process requires ground glass (below 100 μm) to be mixed with a foaming agent, then on heating the foaming agent releases a gas and expands the molten glass mass.

From a previous study undertaken by GTS for WRAP, all the commercial foam producers in Europe were identified and some were re-approached with regard the inclusion of CRT glass in foam glass production.

5.1.1 Misapor, Switzerland

They produce foam glass primarily made from waste container glass. However, they know that it is possible to use waste CRT glass. They made the comment that from experience a low level of waste CRT glass <5% has no effect on the process or product. Also, they commented that CRT panel glass would be the optimum waste component of CRT's, as the other components contain lead. They had no samples of foam glass that contained known quantities of waste CRT glass and were not in a position to produce any samples.

5.1.2 Hasopor, Norway

They currently produce foam glass in Norway that incorporates many different glass waste streams. As part of this project a visit to Hasopor was undertaken to witness their foam glass manufacturing process. At the time of the visit they were producing foam glass from a mixture of 10% lamp, 45% container and 45% flat glass. They have also manufactured foam glass using CRT panel glass, however, due to lack of supply they were not producing foam glass with CRT glass at the time of the visit. However, in the past they have produced foam glass of similar properties and specification has their standard production. They produce a loose fill aggregate for insulation and ground stabilising applications.

Currently, they are expanding their foam glass production throughout Europe and reviewing the market for a plant in the UK.

Figure 3. Foam glass merging from the furnace at Hasopor, Norway.

Figure. 4 Loose aggregate foam glass manufactured by Hasopor, Norway.

5.1.3 Millcell, Switzerland

Millcell are in a similar position as Misapor, in that they know that waste CRT glass can be part of their feedstock. But presently do not make any conscious additions of waste CRT glass. Again, it is viewed that panel glass can be incorporated into foam glass.

5.2 Physical and Chemical Durability Testing

None of the above European foam glass manufacturers were in a position to offer foam glass samples that incorporated CRT panel glass. Therefore, GTS manufactured a number of foam glass sample for chemical durability testing (Figure 5). From the various foam glass manufacturers there is sufficient data on the physical properties of foam glass and from Hasopor the physical properties do not vary significantly with the composition. Table 19 shows some of the reported physical properties of Hasopor foam glass. Hasopor are working towards European Technical Approval (EOTA) for their foam glass products and are hoping for approval by the end of 2003.

Figure 5. Foam glass samples produced at GTS for chemical durability testing.

Properties	®HASOPOR Light	®HASOPOR Standard
Gravel size from production	10 to 50 mm	10 to 50 mm

Dry weight	ca. 180 kg/m^3	ca. 225 kg/m^3
Slide angle in loose form	ca. 45°	ca. 45°
Heat conductivity [λ], dry and compressed 20%	0.11 W/mK [NBI ISO 8301]	0.11 W/mK [NBI ISO 8301]
Heat conductivity [λ], wet and uncompressed	0.14 W/mK [NBI ISO 8301]	0.17 W/mK [NBI ISO 8301]
Capillary absorption after 50 weeks, compression = 20%	4,4 kg/m^2 [EN 1097-10]	13 kg/m^2 [EN 1097-10]
Average compressive strength	6 N/mm^2	> 6 N/mm^2

Table 19. Physical Properties[3] of Hasopor foam glass.

Table 20 shows the range of compositions produced for the chemical durability testing. The same glass feedstock as in the brick samples was used (Table 1). The same leachate testing methodology as for the brick samples was used for the foam glass samples.

Series Number	Panel wt%	Container glass wt%
F1	100	0
F2	66.7	33.3
F3	33.3	66.7
F4	0	100

Table 20. The composition of the series of foam glass samples produced for chemical durability testing.

Analyte	F1 (ppm)	F2 (ppm)	F3 (ppm)	F4 (ppm)	Blank (ppm)
Ti	0.80	0.05	0.04	0.05	<0.01
Cr	<0.03	<0.03	<0.03	<0.03	<0.03
Ni	<0.02	<0.02	<0.02	<0.02	<0.02
Cu	<0.03	0.04	<0.03	<0.03	<0.03
Zn	0.28	0.15	0.11	0.08	<0.03
Fe	1.35	1.62	1.88	2.20	0.02
Sr	8.92	4.43	1.67	0.04	<0.01
Zr	0.66	0.21	0.13	<0.01	0.02
Cd	<0.01	<0.01	<0.01	<0.01	<0.01
Sb	0.29	0.11	<0.10	<0.10	<0.10
Hf	<0.10	<0.10	<0.10	<0.10	<0.10

[3] Data from Hasopor Presentation 2003.

Hg	<0.10	<0.10	<0.10	<0.10	<0.10
Pb	<0.10	<0.10	0.11	0.10	<0.10
Ba	9.44	4.39	1.64	0.19	0.01
Bi	<0.10	<0.10	<0.10	<0.10	<0.10
Ce	0.13	<0.10	<0.10	<0.10	<0.10

Table 21. Analysis results for leachate testing on the foam glass samples, all results in ppm. Orange cells above the water drinking limit and blue cells not specified.

5.2.1 Summary of results

To put the results in Table 21 into context, the results have initially been compared to current UK limits for leaching from food contact glassware and drinking water as detailed in Table 10 & Table 11. Considering these limits as the extreme and therefore probably not suitable for the foam glass application; then referring to Table 21, only barium and iron were above the drinking water limit, 1 ppm barium and 0.2 ppm iron is permitted. Strontium is not specified in the drinking waste limits. Therefore, the only elements from a toxicity point of view that may warrant further investigation are strontium and barium. The analysis for heavy metals, lead and cadmium were below the levels set for food containers and lead cadmium, mercury and chromium were below the levels for drinking water.

5.2.2 Conclusion

The brick chemical durability result were very similar with the same conclusion, that the chemical durability testing indicated that the likely levels of toxic leachates from the foam glass samples under the experimental conditions were below the levels set for drinking water. Barium and strontium were at a level that was considered low enough for not to be of concern whilst in service or at the end of life disposal of the foam glass.

5.3 Technical barriers relating to manufacturing process

The commercial process of manufacturing foam from different sources of very low quality glass has been proven by a number of foam glass manufacturers. Therefore, technically there are no known barriers for the production of foam glass from CRT glass mixed with other glass types.

5.4 Likely production cost

The net production cost for foam glass manufacture was reviewed for the WRAP report (WRAP Report) 'A UK market survey for foam glass', it was reported that the net production cost could vary between £30/m^3 and £60/m^3 depending on the size of production. This cost excludes profit, tax, licence fees etc.

5.5 Size and value of current and potential markets for these products in the UK

The potential market is hard to predict as foam glass is not currently used in the UK on any significant scale. As part of the WRAP report (WRAP Report) 'A UK market survey for foam glass', it was envisaged that the UK could sustain a production plant of up to 225,000m^3/annum, consuming up to 45,000 tpa of waste glass. It was also assumed that the foam glass would be marketed as loose fill aggregate and aggregate replacement for concrete products.

5.6 Amount of CRT glass that could potentially be used in these products

Based on Hasopor experience, it would be technically feasible to include up to 20% CRT panel glass in foam glass manufacture, which based on a 225,000m^3/annum production plant would consume 9,000 tpa of CRT panel glass. However, it is likely that early production of a UK foam glass plant would be somewhat lower, probably between 50,000 and 80,000 m^3/annum, therefore, only using up to 3,000 tpa of CRT panel glass.

5.7 Environmental impact of manufacturing process

The glass would require processing which would consume energy, the CO_2 emission from glass processing is thought to be in the region of 10 kg CO_2/tonne of glass (20 kWh/tonne). It has been reported (WRAP

Report) that the CO_2 emission from the foam glass process in the order of 2.5 kg CO_2/m^3. Therefore, the overall impact will be 4.5 kg CO_2/m^3 ($\approx$1 kg CO_2/tonne of glass). In addition, to CO_2 production, foam glass is a replacement insulating aggregate that will save on the extraction of virgin aggregate. Furthermore, an important factor is the CO_2 emission during the lifetime of the foam glass whilst in service compared to traditional aggregate. As foam glass is many more times insulating than traditional aggregate, for example foam glass used in building construction will save CO_2 during construction (less weight to transport and handle) and during the life of building due to a lower energy requirement. A life cycle analysis of foam glass was undertaken and reported in the 'A UK market survey for foam glass' (WRAP Report).

5.8 Conclusion and recommendations

There is good potential for use of CRT screen glass in foam glass but demand for CRT glass for this application is likely to be low – between 3,000 and 9,000 tonnes per annum in the UK. In order to take this application forward a manufacturing facility would be needed in the UK. Hasopor is already conducting market research into likely demand and production costs and no further research is recommended at this time.

6. Use of waste CRT glass in new CRTs

6.1 Components of CRT glass

CRTs contain two types of glass — barium/strontium glass in the screen section and leaded glass in the funnel and neck components. The different components are joined together with a lead glass frit. There is approximately twice as much barium glass by weight as leaded glass within a CRT. The inside of the screen is coated with a conductive material and a mix of phosphors. The inside of the funnel is coated with iron oxide. A graphite layer is stuck on the outside of the funnel. Other components include the electron gun, metal mask and deflector coil, as well as metal pins and cable.

6.2 Manufacturing process for CRT glass

The manufacturing process is similar for both screen and funnel glass. Although the material content differs, the main raw materials for both are silica sand, sodium carbonate and barium/strontium carbonates. Sand is the single largest ingredient and must be of high purity. Other materials may include oxides of aluminium, potassium, magnesium, zinc, zirconium and either barium and strontium or lead, depending on whether it is screen or funnel glass that is being manufactured.

Raw materials are converted to a homogenous melt at high temperature and then formed into screens, funnels or neck components. The dry materials are first blended and then added to the furnace where melting and other reactions (dissolution, volatilisation and redox) take place. The next phase — fining — removes bubbles from the molten glass melt. The most commonly used fining agents are potassium nitrate and antimony oxides. The melt is then homogenised and cooled to the temperature at which it can be formed into screen or funnel components.

The inside of the screen is coated with a conductive material and with luminescent material consisting of three layers of phosphors - blue, red and green. The inside of the funnel is coated with iron oxide.

6.3 Technical barriers to using waste CRT glass in new CRT glass components

6.3.1 Contamination

Screen glass has no added lead because this would cause it to discolour under X-radiation i.e. when electrons hit the screen. Therefore the only waste CRT glass that can be used in the manufacture of new screens is screen glass that is not contaminated with leaded glass. This means that the screen must be separated from the funnel glass in such a way that no leaded glass or glass frit remains attached to the non-leaded fraction. There are several separation techniques that can achieve this (see section 8).

Because the manufacturing process is very sensitive to contamination, waste screen glass also needs to be free of any other material which could affect the process and therefore the physical properties of the new screen glass. The main areas of concern are colour tint of screen, transmission, physical strength, and flaws i.e. defects and cracks in the glass. Screen glass must meet the highest quality standards in all these respects. Bubble specifications, for example, are critical. LG.Philips specifies a maximum size of 0.3 mm for imperfections in the central part of the screen, and 0.5mm for imperfections in the outer part of the screen[4].

In order to avoid contamination, all screen coatings must be removed from the CRT glass[5]. One way of doing this is to wash the separated screens in a caustic solution such as sodium hydroxide, followed by water, though it is not necessary to use a caustic solution to clean panel glass. Physical contaminants, such as stickers, metal components and pins, and any other non-glass waste also have to be removed. Care must also be taken to avoid contamination by iron oxide since this discolours the glass and causes

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[4] LG.Philips Display Units, Simonstone – verbal 2003
[5] NEG – verbal 2003

transmission problems. Some manufacturers are satisfied if all reasonable steps have been taken to ensure that contact with ferrous material has been minimised, others prefer waste screen glass to avoid all contact with ferrous metal.

6.3.2 Glass of different specifications

Even if waste screen glass is free of all chemical and physical contamination, there may still be barriers to using it in the manufacture of new screens if it is of a significantly different specification to the new glass manufactured. Screen colour, for example, can be varied by adding amounts of nickel and cobalt to the melt. It takes a very small amount of these substances to dramatically alter the colour of a screen, i.e. grams added to a batch of tens of tonnes[6].

Another factor which can present a barrier to using recycled glass is the level of fluoride in the glass. Some manufacturers add calcium fluoride to the melt where it acts as a melting agent (flux). Manufacturers who instead use electric boosting to increase tank temperature may not want to use waste glass containing fluoride because of possible corrosion problems with the electrodes[7].

There are two possible approaches to dealing with waste glass of different specifications. One is to set up quality control systems which will identify and reject waste glass from producers whose glass is incompatible. Screens normally carry a manufacturer's identification mark[8]. A second approach is to blend large quantities of glass from different sources into a homogenised mix which will be compatible with the specifications of the new glass being produced. This effectively overcomes problems such as colour differences but if used in lager quantities can reduce the transmission of the resulting glass. This can only happen if the manufacturer produces glass with very high transmission (more than 60%) because the mean transmission of panel glass is well below 60%.

For those manufacturers utilising cullet in the production of new screens, the quantity that can be incorporated into the manufacturing process will vary between different manufacturers reflecting quality and quantity of cullet supply and their own expertise in blending with the virgin input materials.

6.3.3 Barriers to use of waste glass in new funnel glass

The technical constraints on using waste glass in new funnel glass are less than for screens because the funnel is not visible to the consumer. However, funnel glass must still meet high standards of both physical strength and radiation shielding. Therefore waste glass for use in new funnels must be free of contaminants such as coatings, cleaning residues, plastics and other organic material.

It is possible to use mixed waste CRT glass (i.e. screen and funnel glass) in funnel glass manufacture but separated funnel glass is preferred because of its higher lead oxide and lower barium oxide content.

6.3.4 Technical specifications for waste glass to be used as feedstock for new CRTs

Manufacturers who use waste glass in new CRTs have set their own quality standards for glass that they are prepared to accept. These standards cover levels of contamination, grain size, load size, storage and transportation requirements. The technical specifications for different manufacturers are being collated and will be submitted as part of Milestone M.

6.4 Potential for using waste CRT glass in new CRTs

This project has looked at the potential for using waste CRT glass in the UK and in other EU states, now and over the next 10 years.

6.4.1. In the UK

There are two CRT glass-manufacturing plants in the UK, Nippon Electric Glass (NEG) in Cardiff and LG.Philips Display Units in Simonstone. Both manufacture screen glass only. There is no funnel glass manufacturing capability in the UK. The LG.Philips plant is scheduled to close in spring 2004.

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[6] LG.Philips – verbal 2003
[7] NEG, Schott – verbal 2003
[8] NEG – verbal 2003

Nippon Electric Glass (NEG)
NEG has one furnace and manufactures 90,000 tonnes of screen glass per annum. It also finishes some 18,000 to 20,000 tonnes of funnel glass per annum. It has recently become a stakeholder in a venture with Schott to develop a funnel glass manufacturing facility (STVG) in the Czech Republic with a capacity of some 50,000 tonnes a year.

It has considerable experience of using post production waste screen glass in the manufacture of new screens. This waste glass is normally of known source and composition, but has not necessarily been manufactured by NEG.

Waste glass used by NEG is separated and cleaned by The Mann Organisation, a recycler which has worked closely with NEG for many years to develop processes to separate and clean waste glass. The Mann Organisation also has in place quality controls to identify and reject glass which may be incompatible with NEG's manufacturing process.

The screen is first separated from the funnel glass using the hot wire technique (see section 8). The separated screens are then cleaned with sodium hydroxide and water and stored and transported to NEG in open skips. The screen glass arrives at NEG intact or in large pieces. It is then tipped on to floor from a 3 metre height so that it breaks further and is mechanically shovelled into an auger grinder where the glass is crushed into 20 millimetre diameter cullet. The grinding machine uses 55KWh and is capable of processing 120 tonnes a day.

In 2002, NEG used 2,200 tonnes of post-production waste screen glass. It aims to increase this to 3,000 tonnes in 2003 but has been unable to get sufficient waste glass from the UK. Possible reasons for the inability to obtain sufficient glass from the UK are:

- insufficient availability of production waste in the UK and lack of routes to obtain post-consumer waste
- market imperfections i.e. potential processors of waste glass are unaware of NEG's demand for glass
- the costs of obtaining and processing waste glass to NEG's quality requirements exceed the price that NEG is prepared to pay.

NEG has therefore imported samples of waste screen glass from EU sources to assess whether this material closer help achieve its target.

Building on its experience of blending clean waste glass with virgin materials, NEG aims to use 10,000 tonnes of waste screen glass in 2004. This amounts to 11% of total production and will require significant quantities of post consumer waste CRT glass.

NEG can also take waste funnel glass to send to its funnel manufacturing plant in the Czech Republic. It is unable at this point to estimate the quantities that can be taken.

NEG expects to be manufacturing screen glass for the foreseeable future in the UK and to produce similar quantities of glass. Although as sales of LCD and plasma screen TVs increase, the number of screens manufactured will fall, the overall weight of glass required is expected to stay the same as TV manufacturers produce more "jumbo" 32, 34 and 36 inch televisions.

LG.Philips Display Units
LG.Philips has one furnace and produces between 80,000 and 85,000 tonnes of screen glass per annum. It manufactures three or four different coloured screen glasses each year, all of high transmission. Because this glass is extremely sensitive to contamination, it recycles only glass from the same production run. The plant will close in spring 2004.

6.4.2 Throughout the EU
There are five manufacturers of CRT glass in the current 15 EU member states:
- Nippon Electric Glass, UK (screen glass)
- Schott, Germany (screen and funnel glass, soon to be only screen)
- LG.Philips Display Units, UK (screen glass) and Germany (screen and funnel glass)

- Samsung Corning, Germany (screen and funnel glass)
- Thomson Video Glass, France (screen and funnel glass)

There are also manufacturing facilities in Poland, the Czech Republic and Lithuania.

According to the EC Joint Research Centre[9], these five companies have between them 13 furnaces with capacity for CRT glass ranging from 70 to 360 tonnes a day. The average capacity is 185 tonnes a day, giving a total capacity of 880,000 tonnes a year. Of this capacity, 69% is in Germany, 21% in the UK (screen glass only) and 10% in France. In 2000, actual production was 525,000 tonnes, i.e. 61% of capacity. Of this, approximately two-thirds were screen glass and one-third was funnel glass. Industry sources[10] indicate that current production is at a similar level to that of 2000.

Three of the five producers currently use or are prepared to use waste post consumer CRT glass in the manufacture of new glass. These are NEG, UK; Schott, Germany; and Philips, Aachen. Thompson and Samsung Corning are currently trialling the use of small quantities of post production glass.

NEG

See section on UK, above.

Schott

Schott operates three furnaces in Mainz, Germany — two for screen glass (120,000 tonnes per annum), the other funnel glass (50,000 tonnes per annum). The funnel glass facility will close before summer 2004 and production is moving to STGV, jointly owned by Schott and NEG, in the Czech Republic. Schott receives waste CRT glass from many small suppliers and has two bulking up facilities, one in Germany and one in Holland. It used 20,000 tonnes of waste glass in 2002. This included post production and post consumer waste, some of it mixed and some of it separated. Schott estimates it has a potential to use 55% waste glass in funnel production and 30% in screen production. There is no time-line for this. To reach the target of 30% waste glass in the production of screen glass, it will need to acquire 36,000 tonnes of waste screen glass. To meet the target of 55% for funnel glass, it will need 27,500 tonnes of waste funnel glass.

Currently Schott is finding it difficult to get hold of sufficient quantities of glass which has been separated, cleaned and transported in a way that meets its very high standards.

Schott requires screen glass to be separated, free from all coatings, and more or less intact (apart from transport breakages). The glass must not be crushed, ground or shredded. This is because Schott wants to ensure there is no contamination from iron oxide resulting from the glass being in contact with metal knives or containers. Funnel glass must also be free of coatings but can be crushed. Detailed technical specifications for different types of glass will be covered in Milestone M of this project.

LG.Philips Display Units

For the UK, see above.
In Aachen the company has three furnaces, two for screen glass and one for funnel glass. It also has screen and funnel glass production facilities in Brazil. It uses up to 7.5% mixed waste CRT glass in funnel production. It does not use any waste glass in screen production. In the longer term there are plans to use up to 35% waste funnel glass in funnel production, and up to 25% waste screen glass in screen production. There is no timetable for this. Like Schott the main barrier to increasing the amount of waste glass used in manufacture is obtaining glass of suitable quality and at the right price.

The mixed waste glass currently used by LG.Philips in Aachen is cleaned, processed and crushed by recycler MIREC which has worked closely with LG.Philips since 1993 to develop systems for processing waste CRT glass to meet the feedstock requirements. In addition to using waste glass in Aachen, in 2000 Philips began to export processed waste glass as a raw material for use in its Brazilian production facility.

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[9] The IPPC reference document on best available techniques in the glass manufacturing industry, October 2000, published by the EC Directorate-General Joint Research Centre
[10] NEG – verbal 2003

Samsung-Corning and Thompson

It is understood that Samsung corning and Thompson are currently trialling the use of waste CRT glass.

6.4 3 European capacity to use waste CRT glass

Three of the five manufacturers say that between them they could in the short-term use 50,000 tonnes of waste screen glass (NEG 11% of production, Schott 30%, Philips 10%) if it were available at the right price and quality. According to Schott, the maximum amount of glass cullet that can be used in the production of new screen glass is 30%. If all manufacturers used 30%, the amount of waste screen glass that would be used is 105,000 tonnes (30% of current screen production estimated at 350,000 tonnes which is two-thirds of total CRT production of 525,000 tonnes). Similarly, the maximum amount of funnel glass that could be used is 96,000 tonnes, assuming total funnel glass production of 175,000 tonnes. In practice, however, it is unlikely that all manufacturers will be able to use this high level of waste glass and it is likely to take some years to develop the experience to use it in large quantities. Some additional economic incentive may be required to encourage manufacturers to develop the necessary skills and technology.

Schott estimates that arisings of waste CRT glass exceed 1,000,000 tonnes per annum across the EU. If 55% glass cullet were to be used in the production of new funnel glass and 30% in the production of new screen glass this would amount to some 201,000 tonnes of waste CRT glass per annum. This amounts to approximately 20% of arisings of waste CRT glass in the EU, using Schott's estimate of 1,000,000 tonnes of waste CRT glass per annum across the 15 current member states. In practice, because most manufacturers have limited experience of using post consumer glass, it is likely to take several years before such high levels could be achieved. It should also be noted that EU arisings of waste glass will increase significantly as the EU expands in 2004 but glass manufacture will not.

In the longer term— 10 to 15 years — both Schott and NEG expect CRT glass production to continue in Europe at similar levels (see 6.4.1, above) though Philips says that much will depend on whether European import duties are abolished in 2006. If import duties are abolished this will improve the competitiveness of CRTs manufactured in Asia and cheaper imports could seriously threaten European production. Subject to this, however, the use of waste glass in the manufacture of new CRTs in Europe can be considered a viable long-term recycling route.

CRT production is also expected to continue at least a further 10 years in the far east and other non-OECD countries but it is unlikely that this will be a market for waste glass from the EU partly because waste glass will be available locally and partly because of restrictions on the transfrontier shipment of waste.

6.5 Economics of using waste CRT glass in new CRTs

None of the glass manufacturers were prepared to discuss in detail the economics of using waste glass compared to virgin materials but all agreed that cost savings could be made. These include energy savings because less energy is required to melt glass cullet compared to raw materials. However, using waste glass can, if not done properly, ruin a whole batch and the cost of the resulting down-time would far outweigh the savings from using recycled material.

The main drivers for glass manufacturers to use waste glass are environmental considerations and standards e.g. ISO 14001 as well as the anticipation that their customers will soon require it because of the WEEE Directive.

6.6 Environmental implications of using waste CRT glass in new CRTs

The following environmental benefits arise from using waste glass in the manufacture of new CRTs:

- less energy is required to melt waste glass rather than raw materials (none of the manufacturers currently using waste glass had quantified these energy savings but for estimates see section 6.5 above)

- less environmental impact from mining and processing raw materials (none of the manufacturers using waste glass were prepared to disclose their "recipe" for manufacture and it is therefore not possible to quantify the materials substituted and the resulting environmental benefits
- less transport energy is required if the waste glass is sourced locally – some of the raw materials used in glass manufacture are imported from large distances.

6.7 Conclusion and recommendations

There is good potential for using significant amounts of post-consumer waste glass in the manufacture of new CRTs. In the UK alone, the current demand for waste screen glass for the manufacture of new screens amounts to some 10% of total UK CRT glass arisings. There is a similar level of demand (8-10% of arisings) across whole EU (15 member states). This demand covers both screen and funnel glass and could increase over time to as much as 20% of arisings across the current 15 EU member states if it proves technically feasible to use the high levels of cullet currently proposed by one manufacturers. According to both Schott and NEG, one of the main barriers to using waste CRT glass at the moment is lack of supply. It is therefore important to raise awareness among WEEE processors and end-users of the potential demand for waste glass for this application. Further work with glass manufacturers may also be needed to explore the technical limits for incorporating post-consumer waste cullet in new glass.

7. Flux in smelting

7.1 Overview of potential for using CRT glass as flux in metal smelting

Smelting is a high temperature process in which molten metal is separated from the impurities in metal-bearing material and recovered. Primary smelting extracts metal from ores or concentrates and secondary smelting recovers metals from scrap material. Most smelting operations use a fluxing material to fuse with impurities and form a liquid slag. This helps in the extraction of the metal.

In smelting operations which use sand as flux there could be potential to substitute CRT glass for all or some of the required sand provided that the metals contained in CRT glass, particularly lead, are compatible with the process and can be recovered. When considering the use of CRT glass in smelting it is also essential to ensure that the chemical composition of the resulting slag (which is where the bulk of the CRT glass will end up) is such that it can be used in new applications e.g. construction aggregate. The weight-based recycling targets for equipment containing CRTs set by the WEEE Directive will only be met if the slag and therefore the glass itself can be recycled for use in other applications.

Metals can be considered in three broad groups – ferrous metals (iron and steel), non-ferrous metals (such as copper, lead, zinc) and precious metals (such as gold, silver, platinum and palladium).

7.1.1 Ferrous metal smelting

There is no potential for using CRT glass in the smelting of ferrous metal since neither iron nor steel smelting uses sand. Silicon is a contaminant to steel and the steel smelting process is designed to reduce levels of silicon in order to keep the steel ductile.

7.1 2 Copper smelting

Primary copper smelters have in principle the potential to take CRT glass because they require substantial silica inputs and can in most cases tolerate lead input. Silica is used to flux iron oxide. The amount of silica needed is determined by the amount of iron in the infeed. Primary concentrates typically generate 1 tonne of slag (at approximately 30-35% silica) per tonne of concentrate. If the flux contains other oxides reporting to the slag, the amount of slag may increase.

The lead along with other volatiles report mostly to air pollution control dusts which can then be processed in a further smelting operation to recover the lead. Some secondary copper smelters can take CRT glass but only those that use silica and that also have the capability to recover lead. Because of the copper contained in the yoke of a CRT, this part of the CRT is an attractive feed for a primary copper smelter and for those secondary copper smelters that are in a position to recover this material. Companies that would compete for the yoke material include Boliden (Sweden), Umicore (Belgium), Metallo-Chimique(Belgium), Norddeutsche Affinerie (Germany) and Noranda (Canada). All except Norddeutsche (which does not use large quantities of silica) could also in principle deal with the CRT glass.

7.1.3 Lead smelting

Primary lead smelters could also be an option for CRT glass since they recover lead and may use some sand as flux. However, high levels of lead and other heavy metals in the slag from primary smelters may prevent the slag being used in other applications. There is no benefit from processing CRT glass in secondary lead smelters since these largely do not use sand as flux. Introducing CRT glass would increase energy requirements and could increase the volume of slag produced which, because of its hazardous content, must then be landfilled.

7.1.4 Zinc smelting

Modern furnaces use electrowinning technology which is not appropriate for CRT recovery since they do not require silica to control slag chemistry and viscosity. Adding CRT glass would impose an energy penalty, dilute the feed and increase the volume of slag. The recovery of lead would be limited with much of it reporting to the leach residue.

The older type of zinc smelter - known as an Imperial Smelting Furnace (ISF) - employs a conventional blast furnace approach. This type of furnace uses silica and could recover lead from CRT glass while making beneficial use of the glass to replace mined silica. However, the metal content of slags from this type of smelter are usually too high for it to be used in secondary applications such as aggregate. This is because the costs of treating the slag to bring metal levels down to acceptable limits would make the whole operation uneconomic. Four ISF smelters around the world have already closed this year because they are uneconomic to run compared to the electrowinning processes.

7.1.5 Precious metals smelting

Lead is a by-product of precious metal smelting and can therefore be recovered from CRT glass in the smelting process. The glass itself can partially substitute for bought silica used as flux but is not a perfect substitute because its silica content is lower than that in the sand normally used. Precious metal smelting is however carried out on a small scale compared to other smelting operations such as copper.

7.2 Case studies relating to use of CRT glass in smelting operations

Each smelting operation is unique. Smelters dealing with similar in-feed may have different types of furnaces and operate different processes: they may therefore have very different capabilities for processing CRT glass. In order to assess EU capacity for using CRT glass in smelting operations it will be necessary to explore the technical and economic issues with individual smelting operations. It was not possible to do this within the scope of this study so the following smelters were selected as case studies.

7.2.1 Boliden, Sweden

Boliden's Rönnskär smelter in northern Sweden processes copper and lead concentrates as well as copper and lead-containing scrap material. Its main activity is copper smelting and Rönnskär processes some 700,000 tonnes of concentrate per annum. Lead production is smaller. The "Kaldo" furnace used for lead has a capacity to process 80,000 tonnes of infeed per annum. Only 50,000 tonnes of this comes from lead concentrates. The remaining capacity is taken up with electronic scrap which can be processed in the same furnace (though in a separate campaign) and is more profitable to process. Rönnskär's main products are copper, lead, gold, silver and zinc clinker.

Boliden already treats some CRT glass at Rönnskär but does not take CRTs on their own on a commercial basis. CRT glass is taken largely because it accompanies higher value material. Boliden is however evaluating the technical and economic implications of offering a recycling service for CRTs and is therefore processing them for testing purposes.

There are two possible routes for processing CRTs at Rönnskär– through the copper smelter with copper concentrates or through the lead smelter with lead concentrates.

Processing CRTs with copper concentrate

The Rönnskär primary copper smelter uses more than 50,000 tonnes of silica sand per annum. Crushed CRT glass can be used as a substitute for silica sand but because CRT glass is on average only 50% silica, some two tonnes of CRT glass are needed to replace each tonne of sand. This creates more slag which in turn reduces the profitability of the smelting process partly because more copper is lost in the slag as the volume of slag increases and partly because the greater the volume of slag the more it costs to treat it. Although slag from the smelting process is sold as an aggregate for construction purposes, its sale value does not fully offset the costs of cleaning it to the standards required by the Swedish EPA.

In the copper converter, nearly all of the lead is evaporated during the smelting process. It is recovered from the process gases by treatment in several stages. Most of the metals in the process gases, including the lead which by then has re-oxidised, are captured as dust by the filter system. Boliden reports that that 99.9% of the lead that follows the process gases is trapped by the gas cleaning process and independent calculations indicate 99.2% is collected[11]. The filter dusts are then sent for further processing to recover lead, zinc and precious metals. Until last year dusts from the Rönnskär plant went to Britannia Zinc in the UK. This ISF plant has now closed and Boliden is currently exploring other options for recovering metals from the dust.

[11] Boliden – verbal 2003

Any lead which has not been evaporated is deposited in the slag. Some 300,000 tonnes of slag are produced by Boliden each year. This is marketed as Iron Sand for use in the construction industry. Its lead content is less than 0.03%.

In order to use the slag as aggregate in the construction industry it must first be treated to reduce heavy metal content. The liquid slag is formed at a temperature of 1200C and is then poured into the fuming plant. Carbon and air are used to reduce residual zinc and lead oxides to metal which is then fumed off at temperatures of around 1400C. On leaving the plant the vaporised metals immediately re-oxidise and are collected in the filter dust. The refined dusts are sent for zinc recovery at Bolden's Norzink smelter in Norway. The clean slag is then poured into a settler furnace where remaining copper alloy droplets and copper sulphide droplets settle out leaving slag on top. This is removed and shock-cooled using large quantities of water so that it forms granules which have a molecular structure similar to glass. This is important because it is less likely that any heavy metals remaining in the slag will leach out from slag which has this "closed" structure rather than a crystalline structure. The slag product from the Rönnskär smelter is marketed under the name "Iron Sand". It is a black, coarse-grained vitreous material which is used as a filler in road construction and house foundations and it replaces natural gravel resources. Iron sand has a lead content of approximately 0.5%. Its composition is currently being tested for certification by the Swedish EPA.

Initial estimates are that up to 25,000 tonnes of CRT glass could be processed each year in the Rönnskär copper converter but a charge would have to be made to cover the additional costs of processing higher volumes of material and treating higher volumes of slag. Boliden were unable to quantify costs at this stage but indicated that costs would be reduced if only separated screen glass were used in this process.

Processing CRTs with lead concentrate

CRT glass can also be processed with lead concentrate in the Boliden "Kaldo" furnace. This takes around 50,000 tonnes of lead concentrate per annum. It is, however, an alkaline process in which CRT glass can sometimes be useful (for example if there is too much magnesium in the in-feed) but for which silica is mostly not required. Although most of the lead will be recovered from the process gases or the slag, as described above, there is unlikely to be the potential to use significant quantities of CRT glass in this process. Initial estimates are that between 5,000 – 15,000 tonnes a year could be used and this will vary according to the silica and other mineral content of the in-feed. Because mixed CRT glass has a relatively low lead content (typically 5%) the additional costs resulting from processing increased volumes of material and treating increased volumes of slag and other wastes will not be offset by the value of the recovered lead. It would be more economic to use separated funnel CRT glass (typically 13% lead) in the lead smelting process. It may also be useful to explore the use of smelting technology to create a dedicated facility for recovering lead from leaded CRT glass

7.2.2. Metallo-Chimique, Belgium

Metallo-Chimique operates a secondary copper/tin/lead smelter at Beerse, Belgium. Metallo processes 22,000 tonnes of scrap and waste material each month to produce 9,000 tonnes of copper anode, 800 tonnes of tin and 2,000 tonnes of lead ingot. The metals are refined with an iron-silicate slag for which 2,500 tonnes of sand are needed each month. CRT glass could be substituted for at least 1,500 tonnes of this.

CRT glass has advantages over sand because of its lower melting point, its immediate good fluidity during refining and the fact that it can be added in any ratio to the slag without risk of forming a high melting point transient. However, for small, "in-process" adjustments to the silica content of the slag, sand is preferred because it can be pneumatically injected without losing furnace time for charging.

The CRTs are ventilated and removed from their plastic casing before arriving at the smelter. Metallo then uses the whole CRT, complete with iron and copper yoke (unless this has been previously removed because of its value), in the furnace. The glass is not crushed but is broken into large pieces by being transported and unloaded. It is charged to the furnace together with scrap in the ration of 5 tonnes of glass per drop. Metallo has a daughter company – Elmet – in Bilbao which operates a similar process and has a similar capacity to use CRT glass.

Metallo says that the lead from CRT glass is almost fully recovered. At the end of the refining process the resulting slag is granulated to a size of 2-4mm and marketed as Metamix. It is similar in appearance to the "Iron Sand" produced by Boliden. Metamix is allowed by OVAM to be used by the construction industry in the local Flemish market as a substitute for gravel. This slag contains the full silica content of the CRTs.

7.2.3 Umicore, Belgium

Umicore's core business is precious metal smelting but they also process copper, lead and nickel containing materials. They have the technical capability to recover lead from CRT glass and have done so in the past, partly for goodwill. They do not currently take CRT glass on a commercial basis because CRT glass adds volume and therefore cost to the smelting process. Although Umicore uses sand as flux, CRT glass is not a perfect substitute because of its lower silica content. Umicore believes the amount they would need to charge would make them uncompetitive with other options for CRT glass such as landfill. They were unable estimate what the charge might be.

Before entering Umicore's lead blast furnace the CRT glass must be crushed to fist size pieces (no smaller because of the dust). Copper-bearing material associated with CRTs is welcome as are precious metals in the circuit board or glass coatings. The smelting process produces a slag whose lead content is less than 0.5% and which is used in the fortification of dykes and road construction. It has undergone a series of tests by the Flemish EPA and is certified accordingly.

Umicore confirmed that it has capacity to process CRT glass but capacity will vary according to other material in the in-feed. Umicore processes 250,000 tonnes of material per annum and has made an initial estimate that some 25,000 tonnes of CRT glass could be taken each year. It was unable to give any indication of costs at this stage but thought that costs would be lower if they received separated funnel glass rather than mixed CRT glass.

7.2.4. Norddeutsche

Norddeutsche has a primary copper smelting facility and associated lead smelter in Hamburg – Norddeutsche Affinerie, Germany and a secondary copper smelter – Huttenwerke Kayser – at Lunen also in Germany. The Norddeutsche copper smelting process requires only small amounts of silica. They perceive their capacity to take CRT glass to be very limited. Their main interest in CRTs is to obtain the copper bearing yoke – they have no facility to cope with the glass. Norddeutsche produces a slag which the German authorities deem fit for use in maintaining river banks. Its lead content is less than 0.5%.

7.2.5 Britannia Refined Metals Ltd, UK

Xstrata Zinc operates a lead refinery in Kent, which processes bullion smelted from ore in Australia. There is no primary lead smelting in the UK. Silica is not used in the refining of lead though it is used in primary smelting. However, although CRT glass could in principle be used to substitute for sand in the primary smelting process, levels of lead in the resulting slag are typically 6-7%. According to Xstrata it is not normally economic to treat the slag in order to reduce these levels.

7.2.6 Britannia Zinc, UK

Until last year, Britannia Zinc operated an Imperial Smelting Furnace (ISF) at Avonmouth. This facility processed zinc and lead-containing concentrates as well as recovering zinc and lead from secondary sources such as the filter dust produced by Boliden.

In an ISF process, sulphidic concentrates of lead and zinc are first sintered. The sinter is then smelted at high temperatures to separate lead, liquid slag and gaseous zinc. CRT glass could substitute for the sand used in the smelting process but the resulting slag is likely to contain high levels of zinc and lead which could limit its use in secondary applications.

7.2.7 H.J. Enthoven, UK

Enthoven is the UK's only remaining secondary lead smelter. Its process does not offer a viable option either to recover the lead from CRT glass or to recycle the glass in a useable slag.

Enthoven's in-feed is largely lead acid batteries (90%) and therefore contains large amounts of sulphuric acid. It uses sodium carbonate rather than sand as flux and smelting is carried out at 900 – 1000C. If sand or CRT glass were to be introduced, smelting temperatures would have to be increased. This would increase energy consumption and be difficult to achieve in Enthoven's rotary furnace which has been designed to operate at lower temperatures. A second reason why Enthoven's process is unsuitable for CRT glass is that it would not recover much of the lead from the glass. Enthoven estimates that if CRT glass containing 5% lead were put through the smelting process, at least 50% of that lead would remain in the resulting slag. A third reason why CRT glass could not be used in the Enthoven process is that the process produces a hazardous slag that could not be used in secondary applications and must be disposed of in hazardous landfill site. Because of the high concentrations of sulphur bearing material in the in-feed, secondary smelters such as Enthoven are keen to fix sulphates in the slag to reduce emissions of sulphur dioxide. The resulting alkaline slag contains iron, sodium and lead sulphide, is estimated to contain 3 - 5% lead and must be disposed of in hazardous landfill.

7.2.8 Britannia, UK

Until earlier this year Britannia operated two secondary lead smelters in the UK, one at Britannia Refined Metals Ltd in Northfleet, Kent, the other at Wakefield, West Yorkshire. Britannia had been considering using CRT glass to in their processes to provide silica and produce slag that would pass leach tests and satisfy the requirements of the new Landfill Directive. Initial tests had shown that operating temperatures would not need to be greatly increased and their existing rotary furnaces would be suitable. However, the resulting slag would still have gone to hazardous landfill. Therefore this method of processing CRTs would not have contributed to the recycling targets of the WEEE Directive. Moreover, both of the secondary lead smelters operated by Xstrata in the UK have now been closed.

7.3 Amount of CRT glass that could potentially be used in smelting

7.3.1 UK

The UK has very limited metal smelting capability. There is no primary copper production and only a very small amount of secondary smelting (one company in the midlands). There is no primary lead smelting, one lead refiner and one remaining secondary lead smelter in Derbyshire. There is no zinc smelting capability – Britannia Zinc's Imperial Smelting Furnace at Avonmouth closed last year. There is some precious metal refining capability but this is small. Apart from this there is no potential for using CRT glass in smelting operations in the UK.

7.3.2 EU

The main opportunities for processing CRT glass are in copper smelting (primary and secondary), primary lead and zinc smelting (in an ISF furnace), and precious metals smelting.

Copper

Both primary and secondary copper smelting facilities have potential for using CRT glass and there is significant copper smelting capacity in the EU. The main facilities include:

- Boliden, Sweden
- Outokumpu, Finland
- Norddeutsche Affinerie, Germany
- Huttenwerke Kayser, Germany
- MKM, Austria
- Elmet, Spain
- Rio Tinto, Spain
- Cie Generale du Palais, France
- Enirisorse, Sardinia
- Metallo-Chimique, Belgium
- Umicore, Belgium

Initial estimates are that 90,000 tonnes of mixed or separated CRT glass could currently be taken by four of these facilities between them (Metallo, Elmet, Boliden and Umicore). It is not possible to gross up from this to estimate capacity for the copper smelting industry as a whole since operations can differ dramatically. Norddeutsche Affinerie, for example, though a major copper producer has no capacity for handling CRT glass.

Total potential capacity in copper smelting however is likely to be much greater than this. Across the current 15 EU member states, smelter production of primary copper is 1.5 million tonnes. The new EU states will contribute a further 700,000 tonnes. Boliden estimates that total demand for silica is likely to be in excess of 500,000 tonnes if typical copper concentrates are processed. This would equate to 250,000 tonnes assuming CRT glass contains 50% silica.

Lead and zinc

According to Boliden, primary lead production capacity in the EU is approximately 400,000 tonnes per annum. There are three remaining ISF furnaces in the EU (though one is under threat of closure) and a fourth facility in Poland. Boliden estimates that there is a potential to use some 70,000 tonnes of CRT glass in primary lead production. It is essential to establish however that the level of lead and other metals in the resulting slag is sufficiently low to allow the slag to be used in secondary applications. This could be achieved by sending slag for further treatment by other smelters who have the technology and capacity to treat and clean slag generated by other smelting operations.

7.4 Environmental impact of using CRT glass in the smelting process

Provided the lead is recovered, there is no additional environmental impact of using CRT glass in smelting than using sand. In fact, energy requirements may be reduced because CRT glass requires less energy to melt than sands. It is likely that a key adverse environmental impact is energy consumption in transport (depending where the CRTs are processed). It is estimated that 99% of the vaporised lead is trapped and recovered by scrubbers – with the resulting dusts processed further to recover the lead, zinc or other precious metals.

7.5 Conclusion and recommendations

The use of waste CRT glass as flux in smelting operations is an important application for waste glass, particularly for funnel glass which contains lead. Recycling options for funnel glass are limited to the manufacture of new funnel glass and use in smelting operations. The European smelting industry has the potential to use significant quantities of CRT glass but further work is needed to assess the capacity of each individual smelting operation. It will also be important on a case-by-case basis to ensure that the lead in CRT glass is largely recovered and that the resulting slag can be used in secondary applications.

8. Methods of separating CRT screen and funnel glass

8.1 Current separation techniques

There are two approaches to separating leaded funnel and non-leaded screen glass in a CRT. The first involves splitting intact CRTs and is a semi-automated process. Although the actual cutting process can be automated, the CRT has to be manually removed from its plastic casing. The second approach involves shredding whole TVs and PC monitors to produce different material streams, including leaded and unleaded. This is fully automated mechanical process.

With either approach it is critical that no leaded glass remains with the non-leaded fraction. This is because there is no tolerance for lead in the manufacture of new screen glass. The other applications being investigated for screen glass in this project also require it to be lead-free. There is, however, some tolerance for funnel glass to have a small amount of screen glass with it.

A literature search was carried out to identify and evaluate possible methods of splitting CRTs. Discussions on the pros and cons of different methods were then held with WEEE dismantlers who have either already invested or are about to invest in screen-splitting technology. Information was sought on the nature of the process, any technical barriers to overcome, costs (both capital and labour) and environmental and health and safety considerations. A similar literature search was conducted to identify methods of separating shredded leaded and unleaded from CRTs and discussions on the practicality of these techniques were held with shredding companies in the UK.

Six techniques have been identified for splitting intact CRTs. Three techniques have been identified for separating broken or shredded CRT glass. In evaluating these techniques, the following issues have been taken into account:

- operator safety — including the risks from sharp/jagged edges, respirable dust, the use of high voltages or hazardous materials
- effectiveness of separation — whether the method is capable of making a clean separation between panel and funnel
- time taken to separate the glass
- cost — both initial capital investment and labour costs.

8.1.1 NiChrome hot wire cutting

When a NiChrome wire or ribbon is wrapped round a CRT and electrically heated it causes a thermal differential across the thickness of the glass. The wire needs to be in contact with the glass surface for approximately 30 seconds. The area is then cooled (e.g. with a water-soaked sponge) to create thermal stress which results in a crack. When this is lightly tapped, the screen separates from the funnel section. One potential problem with the hot wire technique is the risk of sharp edges on the separated fractions. A second is the difficulty in getting clean separation between screen and funnel glass if the wire is incorrectly placed. To position the wire, the usual approach is to score the CRT with a diamond glass cutter at the point where the wire is to go. The CRT may be placed on a suction bed, levelled and spun round against a diamond etching blade. This can, however, make it difficult to accommodate CRTs of different sizes because of the need to change the height of the etching blade. A third problem with this approach is that the glass does not always break along the wire line. This is particularly so when dealing with CRTs of different sizes since larger TVs have thicker glass.

Many of these technical challenges have been overcome. One company in the UK, the Mann Organisation, successfully uses hot wire separation to deal with post-production waste CRTs and separate the glass for use in the manufacture of new CRTs. It has recently further developed this process to take any colour post-consumer waste monitor or TV.

8.1.2 Thermal shock

The CRT tube is subjected to localised heat followed by cold air. This creates stress at the frit line where the leaded funnel glass is joined to the non-leaded screen glass and the tube comes apart. Because the frit joining the two types of glass contains high concentrations of lead, care must be taken to clean all lead from the screen glass. This approach has been successfully used by KoTech in the UK to recover post-production waste glass and can be applied in the same way to post-consumer CRTs.

8.1.3 Laser cutting

The laser method works on a similar principle to the thermal shock method. A laser beam is focused inside producing a molecular level separation. This heats up the interior of the glass and is immediately followed by a cold water spray that cools the surface of the glass and causes it to crack along the cut line. Potential problems with the laser approach include reforming of the glass after the laser beam has passed through, difficulty in cutting thick glass and sharp edges on the separated fractions. It also uses more power than other cutting techniques and requires significant capital investment. The technical problems with this technique have now been overcome

8.1.4 Diamond wire method

This uses a wire that is embedded with industrial diamonds. The wire diameter is usually very small. A continuous loop of wire cuts into the glass as the CRT is passed through the cutting plane. The main problem with this approach is that it is very slow. It also generates dust which needs to be controlled. This research has not identified any companies who are currently using this technique or thinking of using it.

8.1.5 Diamond saw separation

Diamond saw separation can be undertaken either wet or dry. Wet saw separation involves rotating the CRT in an enclosure while one or more saw blades cut through the CRT around its entire circumference. Coolant is sprayed on to the surface of the saw blades as they cut to control temperature and prevent warping. The wet saw method can produce clean separation without exposing operators to hazard so long as the CRT is correctly aligned with the saw blades.

8.1.6 Waterjet separation

This technology is commonly used in cutting many different types of material, particularly metal. It uses a high-pressure spray of water containing abrasive directed at the surface to be cut. The water is focused through a single or double nozzle spraying configuration set at a specific distance. It is currently being trialled in the US for cutting CRT glass.

8.1.7 Separating shredded CRT glass

An alternative to screen-splitting is to shred either whole CRTs or whole TVs and PC monitors and then separate out the different types of glass. The advantage of shredding the whole TV or monitor is that it removes the need for manually removing the CRT from its casing. If a sufficiently high degree of separation can be achieved, this approach is potentially more cost effective than screen splitting. It is not yet , however, in commercial operation because the separation techniques discussed below need further development.

If the whole unit is shredded, the glass is mechanically separated from the other material streams, such as metals, plastics, circuit board and cable. The next step is to use either sizing or liquid density separation to separate the leaded glass from the unleaded. Sizing relies on the fact that screen glass breaks into thick flat pieces when shredded but funnel glass breaks into smaller thinner pieces. Density separation, however, has shown the best potential. This relies on floating the mixed glass in a liquid medium that has a density between that of the two types of glass. The more dense material then sinks to the bottom. The density of screen glass is 2.7gcm^{-3} and the density of funnel glass 3.0gcm^{-3}[12].

A major problem with density separation, however, is separating glass from CRTs of different ages. The density of old funnel glass is similar to screen glass i.e. 2.7 - 2.8 gcm^{-3} and it is therefore not possible to separate the two using density separation.

[12] DEER2 Final Information Report, February 2002, prepared by National Defense Center for Environmental Excellence, US

A second problem with density separation is dealing with combined cullet i.e. shredded screen glass which has some leaded frit glass attached to it. The density of this is somewhere between the density of screen and funnel glass.

Separation of shredded glass, whether by density or sizing, is at very best only some 95% effective. An additional process would therefore needed to get the 100% separation required if the glass is to be used in the manufacture of new CRTs or other zero lead tolerant applications.

Possible secondary processes involve using UV light, visible light and X-ray fluorescence. In the US, X-ray fluorescence has been trialled to sort broken pieces of glass but was perceived to have several technical problems such as being able to provide only a point or line measurement though it is an area measurement that is needed. Further problems include the need for consistent spacing between glass pieces as well as potential health risks to operators. Light sorting systems have the best potential but the capital costs of such systems are expected to be very high involving specialist conveyors, multiple spectrophotometers, reject mechanisms, software and individual computers to operate the system.

8.2 What's happening in the UK

There is very little separation of post-consumer CRT glass currently taking place in UK because the costs outweigh the price that could be achieved for separated glass and until the WEEE Directive takes effect, end-users have no incentive to pay for recycling. Therefore most operations are in the pilot and development stage.

Until this year the only separation activities in commercial operation were focusing on post-production CRTs, mainly from TVs, for the manufacture of new CRT glass. They included the Mann Organisation in Ross-on-Wye and KoTech in Cardiff. The Mann Orgnisation is now offering to recover glass from post-consumer CRTs, both TVs and monitors. The Electrical Recycling Company is also offering a commercial service for recycling post-consumer TVs and monitors by separating the glass to use in the manufacture of new CRTs. Other facilities planned for the UK are a laser cutting operation and a CRT shredding plant.

9. Next steps

The next stage of the project will be to put together a Business Development Plan. This will set out technical specifications for each of the end-use applications listed below and identify commercial operators who may be interested in developing these applications further. The end-use applications selected for business development are those which can take significant quantities of the UK's waste CRT glass. These have been identified as :

- brick manufacture (for screen glass)
- flux in brick and ceramic manufacture (for screen glass)
- manufacture of new CRTs
- flux in smelting

Consideration will also be given to the use of CRTs in foam glass although the volumes of CRT glass likely to be used in this application are relatively small.