C A R E

C O N S O R T I U M F O R
A U T O M O T I V E  R E C Y C L I N G

G L A S S  R E C Y C L I N G

An Automotive Perspective

February 1999
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ABBREVIATIONS

ACORD  Automotive Consortium on Recycling and Disposal
CARE  Consortium for Automotive Recycling
ELV  End of Life Vehicle
FEVE  Federation Europeene du Verre d’Emballage
Kta  Thousand tonnes per annum
mta  Million tonnes per annum
PET  Poly ethylene terephthalate
PVB  Poly vinyl butyl

ACKNOWLEDGEMENTS

The author wishes to thank Mr Derek Wilkins (CARE Programme Manager, Rover Group), Mr. Peter Pennells (Consultant, Pilkington Glass) and Mr. David Richardson (Director, Richardson’s Glass) for their constructive comments.
Glass constitutes just one fraction of societies’ complex waste stream. Every year the UK alone produces more than 435 million tonnes of rubbish, only a relatively small proportion of which is glass. About 75% (possibly 1.5 million tonnes/ annum) of the glass waste arises as containers from post-consumer sources. The proportion contributed by automotive fractions is small (about 0.06 million tonnes).

Glass has been amongst the most successfully recycled components of the municipal waste stream. From humble beginnings in 1977, when the first ‘bottle bank’ was opened in the UK, the amount of container glass recovered annually has risen steadily to over 440,000 tonnes in 1997. At this time, all 436 UK Local Government Authorities (and many private companies besides) had bottle banks in place, adding up to more than 22,000 sites. However, the UK still recovered less than 25% of all the waste glass estimated to be available. Within the EU as a whole, this proportion is currently about 58% (7.5 million tonnes/ annum), with only Turkey recovering a smaller proportion than the UK. Astonishingly, eight EU member states manage to recover more than 70% of their post-consumer glass arisings.

The rapid increase in glass recovery rates is, in no small measure, the result of a number of important factors, including: the technical feasibility of recycling this material; the cost advantage of doing so; the commitment of the glass industry to accept post-consumer material and to invest in and develop the technology required to process the material. Never the less, there have been, and continue to be, problems associated with glass recycling in general. These are primarily due to contamination of the glass by: mixing of incompatible glass types (such as bottles, window panes, light bulbs and ovenware); mixing of different colours of glass; and the presence of non-glass ‘inclusions’ (especially stones). All of these problems are being addressed by the glass recycling industry in attempts to improve the quality (and hence value of the recovered material) and to reduce the rejection rate of unacceptably contaminated loads.

On top of these technical problems, the glass industry is beset by economic and political pressures. The UK suffers from an acute imbalance in the availability and demand for different colours of waste glass – a result of the preferences of the packing and filling industries and the consumer. In addition, EU-wide legislation on the recovery of packaging waste, coupled with more efficient material utilisation in the manufacturing process (‘lightweighting’) and significant reductions in the prices of the virgin raw materials have meant that there is now a surplus of recovered glass. This has driven down the demand for, and value of, recovered glass, most notably in the UK with regard to green glass.

It is against this backdrop, of market saturation and depressed prices, that the proposed EU Directive, concerning End of Life Vehicles may impact. This is envisaged to set limits upon the proportion of an ELV that could be landfilled, and the burden to meet these targets will inevitably fall, in part, upon glass. This is not, by any means, a predicament unique to glass amongst the ELV materials; most of the other materials that are not currently recovered during the shredding process (predominantly non-metallics such as plastics) are or will be subject to the same economic and political pressures. The recovery of ELV glass is much more complicated than that of post-consumer container glass. The major cost here is the time and labour expended in collecting the material from a heterogeneous waste origin (bottle bank schemes generally rely upon the public to segregate the material and pubs/ clubs deal with a largely homogeneous waste stream). Attempts to achieve this by structured vehicle dismantling would probably be prohibitively expensive. Although the recovery and re-utilisation of manufacturing scrap is well established, the only significant example of post-consumer flat glass recycling in the UK is that of in-service vehicle windscreen replacement, which is estimated to yield about 15,000 tonnes/ year.

With annual UK ELV arisings of approximately 1.5 million, the 45,000 tonnes/ year of automotive glass theoretically available would appear to be a relatively small amount, in relation to the UKs’ overall glass waste stream. Field studies by CARE, however, suggest that in practice even this level of recovery is unlikely to be achieved. This figure assumes that ‘scrapped’ vehicles retain their full complement of glass, and that all of this is recovered. This clearly is not the case. Many ELVs are accident damaged, some of the glass is sold by the vehicle dismantlers as replacement parts, and a significant proportion of that remaining (up to 50%) may be lost using unsophisticated recovery procedures. Bearing in mind that the cullet market is already saturated, and that future moves are likely to increase this substantially, ELV-derived cullet will have to compete not only with virgin raw materials but also packaging waste. Under these circumstances, with virgin raw material prices at about £30/ tonne, cullet prices hovering between £10-£15/ tonne and Packaging Recovery Notes (PRNs, proof of compliance with the packaging waste regulations) for glass retailing at about the same, there is little scope to expect ELV-glass recovery to be economically viable in the UK at present.
Above and beyond those problems normally associated with container glass re-processing, there is the potential for significantly higher contamination levels and waste by-product disposal from processing front and rear vehicle windscreens. Most front and rear glazing is nowadays directly bonded into the vehicle body apertures, contributing significantly to body shell rigidity. The edges of these windscreens are printed, in order to mask the presence of the polyurethane adhesives, and protect the adhesive from UV light induced degradation, but this constitutes a significant potential contaminant in itself. The same is true of the silver heating elements in rear windscreens. Furthermore, the poly vinyl butyral (PVB) plastic laminate interlayer renders the front windscreen much more difficult and hence expensive to process. Not only does the glass have to be separated from the interlayer, but there is currently no market for the residual plastic, which therefore has to be discarded (entailing further cost). The emergence of a market for this plastic, which as a virgin material is very expensive, might go some way to offsetting the cost of windscreen recycling.

Very careful consideration will have to be given as to the eventual preferred glass ‘disposal’ route. Glass recycling, where viable, should be promoted but a balance has to be found between recycling and disposal, a view taken on the grounds of ‘best practicable environmental option’ (BPEO). The technique of life cycle analysis may play a crucial role in this procedure. The current wide distribution of ELV dismantling facilities in the UK could alone render the recycling option redundant. The energy usage, pollutant production and cost of running a fleet of collection vehicles could negate any environmental benefit. Of critical importance is the development of additional and/ or alternative end uses for the recovered glass. This may aid the economics of the situation but doesn’t improve the logistics problem per se. This applies equally to PVB; the BPEO may well be incineration with energy recovery. Never-the-less exploration of the feasibility of utilising re-extruded polymer should not be overlooked, and importantly the process should be transparent, otherwise the outcome might be susceptible to misinterpretation as the influence of ‘vested interests’.

Any cost associated with such developments should, however, not be confined to any single sector (such as the glass re-processors) but should be spread amongst all the economic operators. Furthermore, this should not exclude the consumer. It can be argued, with some justification, that ‘the consumer rules’ philosophy is flawed and just reflects the prevalence of the ‘consumer society’ in which we live. If we, the consumer, want the benefits of high mobility and freedom of movement, we must be prepared to accept, within reason, responsibility for the consequences of these activities and of any remedial action (and hence cost) necessary. This argument extends, of course, to those other facets of automobile usage, such as fuel consumption, exhaust emissions, air and water pollution and maintenance of the road infrastructure.

*Ford Escort Van Mk5, CARE Hulk Standards Trial, Universal Salvage (Paddock Wood), August 1998*
**WHAT IS GLASS?**

Glass, as everybody knows, is hard, brittle and transparent. Although there is no scientific consensus, glass is thought to have been first discovered in the ‘near east’, probably in Syria or Egypt, as long ago as 1200 BC, where it was used for decorative purposes. The first clear glass dates from around 800 BC, with glass blowing being developed about 300 BC. Glass manufacture then spread rapidly, first appearing in the UK in Roman times where it was heavily taxed. It subsequently went into a period of decline, to re-emerge as a near monopoly in Venice in about 1200 AD, from whence the technology was gradually disseminated. The first automated bottle making plant was opened in 1903 in the USA.

Glass plays a very important role in today’s society and is widely used as a packaging material in bottles and jars, as a structural component in buildings and automobile windows, and in other domestic applications (e.g. cookware, light bulbs) and for specialised technical applications in science and engineering (e.g. glass fibre, glass ceramics and optical communications).

Certain chemicals, known as ‘network formers’, when in combination with oxygen or other anions form ‘glasses’. The most common and familiar is that formed by silica. Although glass behaves like a solid at normal temperature, it has no crystalline structure, its atoms are arranged like a liquid. Indeed, evidence of glass flow can often be seen in old window panes that have been exposed to high summer temperatures, where unevenness is caused by the glass thickening at the bottom of the pane.

Contrary to popular belief, there is more than just one type of glass, and each differs according to its required function. These include:
- soda-lime glass (typified by bottles and jars, and automotive applications)
- lead alkali glass (e.g. crystal glassware and television screens)
- borosilicate glass (glass fibre, ovenware, glass wool insulation)
- other specialised small volume technical glasses (e.g. scientific and optical)

The most common types of glass are sand (silica) based. The most important, soda-lime silica glass (constituting over 90% of all glass made), is typically made up of four main ingredients:
- 61% sand (SiO₂, with an iron content of <0.03%)
- 18% soda (Na₂CO₃) – an alkali, used as a fluxing agent to reduce the temperature at which the sand melts
- 13% limestone (CaCO₃) or lime (CaO), - acts as a stabiliser, giving the final product a greater durability
- 8% other components, mainly alumina (Al₂O₃), magnesia (MgO) and refining agents

Other additives are used to counter the effects of impurities in the raw materials or to produce special effects, e.g.:
- selenium-cobalt oxide mixtures may be added to decolourise the green tinting caused by iron oxide impurities
- fluor spar or oxides of tin or zinc may be used to give special colour effects or opaqueness
- colouring agents such as selenium (pink), cobalt oxide (blue), nickel oxide (brown), iron oxides (green, yellow, brown, blue) and iron sulphide (brown)

UK glass production currently stands at over two million tonnes per annum. Of this, approximately:
- 68% is used in the manufacture of bottles and jars (it has been estimated that more than 6 billion glass containers are used annually in the UK alone)
- 25.2% in flat glass (e.g. windows, including automotive applications)
- 1.6% as tableware
- 4.8% as glass fibre and
- 0.2% in crystal glass
HOW IS GLASS MADE?

There are four basic stages in glass manufacture:
1. Melting (of the raw materials that are mixed before they enter the furnace)
2. Refining (the molten glass achieves homogeneity)
3. Working (of the molten glass into the desired shape)
4. Annealing (relieving the internal stresses within the formed shape that developed during working)

The raw materials (which may include waste glass, or cullet) are mixed before entry into the furnace, heated and melted, and the molten glass supplied directly to high speed automated container making machines. Due to its relative purity, any cullet that is present in the mix melts at a lower temperature than any of the other raw materials and speeds the overall melting process. In soda lime glass chemical reactions start to occur at 600°C to 900°C forming bubbles of carbon dioxide in the partially formed glass. The homogeneity of the molten glass is ensured by completion of remaining chemical reactions and removal of the bubbles by the action of refining agents (e.g. sodium sulphate) which are added to the raw material mix and is facilitated by raising the temperature to about 1540°C. These also prevent the formation of a scum on the molten glass surface. ‘Network modifiers’ such as soda (Na₂O) and lime (CaO) lower the viscosity of the molten glass to more practical levels at more convenient temperatures; otherwise the fluid is too viscous for blowing or drawing at operating temperatures. Once homogeneity is achieved, the temperature is reduced to about 1000°C giving a viscosity suitable for working and shaping.

Large-scale production of glass is performed in tank furnaces that run continuously. The raw materials enter at one end and the molten glass emerges from the other at a rate of up to 2000 tonnes/ day. Modern furnaces are modified steel making open hearth blast furnaces, being of oil or gas-fired regenerative type, where the hot waste gases are re-circulated for burning fuel (allowing significant fuel cost savings). In 2.5 minutes, 3.5 tonnes of raw materials are mixed together and heated to 1540°C. Most modern glass containers are made (i.e. shaped) when a portion of molten glass is dropped into a mould and then blown into the required shape. Portions of molten glass (known as ‘gobs’) are formed into ‘parisons’ – hollow balls of molten glass which are still malleable but stiff enough to retain their shape. These are then enclosed in the final mould and compressed air is blown through the neck of the parison, forcing the glass out against the surface of the mould forming its final shape. All this takes only about one second, the glass’s temperature dropping to 550°C in that time. The rapid cooling creates stresses in the glass, which are relieved by re-heating and then allowing it to cool more slowly. One and a half litre wine bottles are typically made at a rate of 150/minute, with a plant producing up to 2.5 million bottles per day.

Flat glass (including automotive) is made by the ‘float glass process’ which first appeared commercially in 1959 and superseded all other methods due to the superior results obtained. Here the continuous flow of glass leaving the melt furnace is floated on the surface of a molten tin bath. The glass is held at a high temperature for a sufficient length of time to allow any irregularities in the glass to melt out and the surfaces to become flat and parallel. The glass is then cooled on the bath surface to a point where the surfaces are hard enough not to be marked by rollers. If allowed to flow naturally, surface tension and density determine a natural thickness for the resulting glass sheets of about 6 mm, but techniques have been developed which allow variations in thickness between 1.5 – 25 mm.

GLASS AS WASTE

Glass, in reflecting its abundant use today, is one of the major components of the waste stream, accounting for about 8-10% by mass of the domestic (household) waste arisings in Europe (5% in the USA). Approximately 25 mta of household waste are generated in the UK (including that collected from Civic Amenity Sites, estimated to be approximately 5 million tonnes/ year), most of which is currently landfilled (see Table 1). Glass, therefore, contributes about 1.6-2.0 mta. Most of this is in the form of packaging as bottles and jars. On top of this, potential glass waste arising from ELV sources (assuming approximately 1.5 million vehicles per year, with an average glass weight per vehicle of 30 kg) has been estimated at 45,000 tonnes/ annum. Further waste arisings from in-service windscreen replacements are thought to be in the region of 15,000 tonnes, equating to approximately 1.5 million units/ year (Peter Pennells, Pilkington Glass, personal communication). In addition to this there is the glass originating from pubs, clubs and restaurants, as well as other commercial sources. We can, therefore, estimate (with some degree of certainty) that at least two million tonnes of glass waste arises every year. FEVE estimates the UK container glass recycling rate, at a level of 441,000 tonnes in 1997, to be about 23%.
The residence of glass in landfill sites is not problematic in terms of its decomposition. Being of mineral origin (i.e. inorganic) landfilling doesn’t lead to methane or leachate generation. But it does occupy valuable void space and is a waste of resources, which are fairly easy to recover and recycle.

### Table 1. Estimated Annual UK Waste Arisings For 1990 (Making Waste Work, 1995)

<table>
<thead>
<tr>
<th>Proportion (%)</th>
<th>Weight (mta)</th>
<th>Source</th>
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<tr>
<td>18</td>
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<td>Mining and quarrying</td>
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<td>70</td>
<td>Construction and demolition</td>
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<tr>
<td>16</td>
<td>70</td>
<td>Other industrial</td>
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<td>35</td>
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<tr>
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<td>35</td>
<td>Dredge spoils</td>
</tr>
<tr>
<td>Total</td>
<td>435</td>
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</tbody>
</table>

NB. Controlled waste (as defined in EPA90) 245mta (excludes mining, quarrying and agricultural)

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**THE CHANGING ROLE OF GLASS PACKAGING IN THE UK**

The UK’s glass packaging is primarily of ‘single trip’ type; examples of the ‘returnable’ bottles (familiar to us all as, for instance, milk bottles) are few and far between these days. However, such schemes are still much more common in mainland Europe (and indeed, still dominate in some sectors), for example beer bottles in the Netherlands and wine bottles in France. Single trip packaging is of a lighter, and hence ‘weaker’ construction than returnable containers (and therefore are not suitable for re-use), this change having evolved from efforts to optimise the economics and logistics of product transportation. The benefits of returnable and re-usable glass packaging is a fine balance between the costs associated with:

- more rugged construction of the container (necessary to withstand the greater amount of wear and tear associated with repeated use, transportation and cleaning)
- using more raw materials and making the product heavier and thus more expensive to manufacture and transport
- the ‘trippage rate’ (i.e. how many times the container goes through the return cycle)
- large amounts of detergent and water are also consumed in order to meet the stringent hygiene requirements.

The higher the trippage rate, the more economically favourable the scheme. The average UK glass milk bottle, for example, is used 20 times. It has been reported (Warmer Bulletin No 49 May 1996) that in Denmark beer bottles have an average life of four years and a trippage rate of 30. Similarly Japanese beer bottles are reused an average of 24 times. Interestingly, it was also reported that Carlsberg have experimented with refilling plastic PET drink bottles in Denmark, but had experienced problems with residual tastes with some soft drinks precluding their use for certain other types of drink (e.g. water).

High trippage ‘returnable’ schemes are the best option if recovered and refilled locally, ideally by collection ‘backfilling’ on delivery vehicles. However, even in non-returnable containers, the actual amount of glass used in their construction has been declining over the last 50 years in line with improvements in the manufacturing processes. Between 1940 and 1990, the average weight of a one pint glass milk bottle dropped by almost 55%. Despite this extensive ‘lightweighting’ glass is still both heavy and fragile compared to other packaging materials. The decline of the returnable bottle in the UK is exacerbated by the fact that the raw materials used in the manufacture of glass are relatively abundant and cheap. Never the less, the quarrying of raw materials does lead to extensive environmental degradation and the manufacturing process consumes enormous amounts of energy and water.
The advantages of recycling glass are both economic and environmental. According to the glass industry and environmental pressure groups, these include:

- glass can be recycled indefinitely without the quality significantly deteriorating
- the conservation of finite natural raw material resources (for each tonne of recycled glass used 1.2 tonnes of natural raw materials are saved)
- reduces the demand for the raw materials and hence the detrimental effects upon the environment associated with their quarrying (reducing the by-production of quarrying waste by up to 80%)
- reduces the water consumption of the manufacturing process by up to 50%
- energy savings; for every tonne of recycled glass used the equivalent of 130 litres of oil are saved, as cullet melts at a lower temperature than the raw materials - in 1993 this amounted to a saving of 65 billion litres of oil and is equivalent to a 20% energy saving. An LCA analysis of automotive ELV glass recycling (Simon Dawes MSc thesis, October 1997) suggested a possible 7% energy saving; a report in Warmer Bulletin No 43 November 1994 suggested a 13% advantage for container glass
- reduces pollution, over the whole life cycle, by up to 20%
- reduces operating waste disposal costs by reducing both the weight and volume of waste requiring storage, transportation and disposal
- valuable void space in landfills is saved by diverting the glass for recycling, thus easing the pressure to develop new landfill sites (it was estimated by FEVE that in 1997 over 7 million tonnes equivalent of landfill space was avoided)
- creates employment in the glass industry

**WHAT PROGRESS HAS BEEN MADE IN RECYCLING GLASS?**

As a result of public concern regarding the escalating wastage of the earth’s natural resources and the disposal of society’s waste material there have been considerable efforts made to improve the recovery rate of this domestic resource in the last fifteen years or so. Many of the advances made in material recovery levels during this time have been achieved as a result of the threat of legislative action by Government. Household waste came under particular scrutiny due to its high visibility, and the fact that it’s a waste stream familiar to everyone and for which we all have responsibility. In addressing the aforementioned concerns both the current and previous UK Governments favoured ‘producer responsibility’ initiatives to ‘kick-start’ a demand for the recyclates. A European Union Directive on Packaging and Packaging Waste (Directive 94/62/EC) became European law in 1994 and came into effect in the UK on 1st January 1998. This addresses not only glass but also paper, steel, aluminium, cardboard and plastic waste streams. This directive stipulates ‘valorisation’ of the individual waste streams (in other words the recovery of value from it) by setting distinct recovery and recycling targets. Significantly, recovery could encompass not only mechanical recycling but also chemical recycling and incineration with energy recovery. However, as far as glass is concerned, mechanical recycling is the only option. Each of the materials must meet minimum recovery and recycling targets within five years of implementation, currently envisaged, depending upon the specific waste stream, as 50-65% recovery by weight with this including 25-40% by weight being recycled and a minimum of 15% of each different material being recycled. On an EU-wide scale, the glass industry is currently the only packaging industry sector to meet, and indeed exceed, the recycling targets (in 1997, 12 of the 17 individual FEVE member states already exceeded the 2001 target for recovery).
The critical underpinning strength of any recycling system is a sufficient demand for the recyclate produced. This is why glass recycling, despite the current depressed market values, has become so widespread. The lack of defined end markets for the materials collected within the German Duales System Deutschland (DSD) resulted in widespread ‘dumping’ of cheap material onto the markets of other European states, which in turn had the effect of depressing their internal recycling initiatives.

**HOW IS GLASS RECYCLED?**

Immediately upon arrival at the re-processing centre all loads are visually inspected to ensure they meet the appropriate quality standard, especially with respect to foreign materials (known as inclusions) and colour contamination. Non-glass contaminants present in cullet as a result of their forming part of the packaging (e.g. paper labels or metal caps) are not regarded as ‘inclusions’ as far as the initial quality control is concerned. Loads that are deemed to contain an unacceptably high proportion of inclusions are rejected at this point and usually have to be landfilled. Loads that are accepted are stored colour segregated.

When required the cullet is then fed into a reception hopper linked to a variable speed conveyor belt; the rate with which this moves controls the rate of the whole process - the heavier the contamination level the slower the processing rate, to maximise the efficacy of contaminant removal. The conveyer belt passes under overband magnets that remove any ferrous metal items, and on to the crusher, via manual picking stations to allow removal of other large contaminants such as incompatible glass objects, bricks and concrete.

After crushing the cullet is fractioned depending upon the fragment sizes. This is accomplished by means of a vibrating ‘two deck’ screen. The crushed glass enters on to the top screen, over which are positioned vacuum hoods. These remove light materials such as paper, plastic and aluminium caps. Glass which is too large to pass through the first screen (with a diameter greater than 28 mm) is directed back to the pre-manual picking stage. Glass dropping through the top screen lands on a second, finer, screen. Fragments with a diameter of less than 8 mm drop through this; the remainder again passing back to the manual picking stage.

The ‘fines’ then pass through a microprocessor controlled ‘automatic colour separator’ which analyses the material passing by via laser or infrared. Non-transparent opaque materials, such as ceramics and crockery are rejected by activation of a high-pressure air jet, blowing the offending articles into a reject stream. Non-ferrous metal detectors are also incorporated here and further material maybe rejected in the same way. The biggest problem is the presence of small stones; they roll under the influence of the air jet and don’t

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### Table 2 European Glass Recycling (data source FEVE/ British Glass)

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<td>NA</td>
</tr>
<tr>
<td>Portugal</td>
<td>117</td>
<td>120</td>
<td>71</td>
<td>50</td>
<td>62</td>
<td>46</td>
<td>44</td>
<td>42</td>
<td>32</td>
<td>30</td>
<td>30</td>
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</tr>
<tr>
<td>Spain</td>
<td>521</td>
<td>456</td>
<td>371</td>
<td>310</td>
<td>312</td>
<td>304</td>
<td>37</td>
<td>35</td>
<td>31</td>
<td>27</td>
<td>27</td>
<td>NA</td>
</tr>
<tr>
<td>Sweden</td>
<td>134</td>
<td>120</td>
<td>95</td>
<td>57</td>
<td>76</td>
<td>50</td>
<td>76</td>
<td>72</td>
<td>56</td>
<td>58</td>
<td>44</td>
<td>NA</td>
</tr>
<tr>
<td>Switzerland</td>
<td>259</td>
<td>242</td>
<td>199</td>
<td>212</td>
<td>189</td>
<td>91</td>
<td>89</td>
<td>84</td>
<td>72</td>
<td>71</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Turkey</td>
<td>72</td>
<td>44</td>
<td>54</td>
<td>54</td>
<td>52</td>
<td>58</td>
<td>20</td>
<td>13</td>
<td>22</td>
<td>25</td>
<td>28</td>
<td>NA</td>
</tr>
<tr>
<td>UK</td>
<td>441</td>
<td>420</td>
<td>492</td>
<td>386</td>
<td>459</td>
<td>372</td>
<td>23</td>
<td>22</td>
<td>28</td>
<td>26</td>
<td>21</td>
<td>NA</td>
</tr>
<tr>
<td>Total</td>
<td>7648</td>
<td>7639</td>
<td>7320</td>
<td>5967</td>
<td>6459</td>
<td>5226</td>
<td>57</td>
<td>58</td>
<td>53</td>
<td>46</td>
<td>46</td>
<td>NA</td>
</tr>
</tbody>
</table>

NA, Not available
follow a normal sliding trajectory into the reject material stream. The remaining fine cullet then passes on to the ‘product bay’ without any further processing.

Samples of crushed cullet are taken every hour from the product bay and examined manually. Any failing the specification tests at this stage results in all of the previous hours' product being returned to the reception bay for re-processing.

**PROBLEMS ASSOCIATED WITH RECYCLING GLASS**

The problem with recovering the glass fraction of domestic waste, in the absence of ‘returnable’ schemes, is that household waste is a very heterogeneous mix of materials (Table 3). The glass industry’s solution has been to promote ‘bring systems’ where drop off points are provided for the public to deposit their used glass packaging. Such ‘bottle banks’ are now commonplace. The bottle bank scheme was developed on economic grounds. Two of the leading companies (Rockware Glass and United Glass) formed the British Glass Recycling Company in 1993 to procure and distribute cullet. It undertook to accept all cullet that was generated, as long as it met certain quality standards, at a fair price reflecting the costs of collection, transportation, and market prices. The first bottle bank (defined as a bottle depositing site, usually consisting of three containers, one for each colour of glass) was established in 1977 and by 1990 there were 5000. Prior to 1977 new glass was made almost entirely of virgin raw materials – the only recycling was that of manufacturing scrap. In 1990 the glass industry was asked by the Government to double the number of bottle banks and since then the number has multiplied enormously. The 16,000th bottle bank was officially opened in 1995 by the then Secretary of State for the Environment, John Gummer. The total currently stands at about 22,000.

The glass bottle bank scheme has become the most successful programme for the recycling of post-consumer packaging in the UK and Europe. Every UK Local Authority now has at least one bottle bank. In 1997 the UK glass industry recycling rate was about 23%, but this was still amongst the lowest in Europe; the average here was about 57% with the Netherlands, Germany, Sweden, Norway and Switzerland recovering over 70% of their domestic waste glass.

About three quarters of all UK cullet is now collected from bottle banks, and this post-consumer stream is known in the trade as ‘external’ or ‘ecology’ cullet (as opposed to ‘English’ or ‘domestic’ cullet for manufacturing waste). Most glass is collected by Local Authorities and is passed on to glass re-processors who clean it to the standards demanded by their customers (the glass manufacturers). However, ‘ecology’ cullet also includes glass collected from pubs, clubs, and restaurants. Currently less than 10% of the glass available from pubs, clubs and restaurants is recycled, but this has the potential to pose a serious contamination risk from the likes of drinking glasses, ashtrays and crockery. The glass manufacturing process is extremely sensitive to even very low levels of such contaminants which, due to differences in their melting points, result in irregularities and distortions in the molten glass. This can lead to initial load rejection or worse, production scrappage and wastage due to quality shortfalls.

There have been significant problems with cullet collections over the last few years, due mainly to wide fluctuations in the market prices, reflecting price reductions for the raw materials. In addition, the increasing proportion of cullet used in the manufacturing process has lead to a demand for much higher quality standards, and more sophisticated technologies for processing reclaimed

<table>
<thead>
<tr>
<th>Material</th>
<th>% by weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper and cardboard</td>
<td>33.2</td>
</tr>
<tr>
<td>Plastic film</td>
<td>5.3</td>
</tr>
<tr>
<td>Dense plastic</td>
<td>5.9</td>
</tr>
<tr>
<td>Glass</td>
<td>9.3</td>
</tr>
<tr>
<td>Ferrous metal</td>
<td>5.7</td>
</tr>
<tr>
<td>Non-ferrous metal</td>
<td>1.6</td>
</tr>
<tr>
<td>Textiles</td>
<td>2.1</td>
</tr>
<tr>
<td>Putrescibles</td>
<td>20.2</td>
</tr>
<tr>
<td>Misc.</td>
<td>16.8</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
</tr>
</tbody>
</table>

containers. This applies both to Local Authorities/ independent bottle bank operators and re-processors. Cullet prices are currently very low, in the region of £10-15/ tonne (delivered) and although Local Authorities are probably not benefiting from income from glass recycling itself, they are from savings associated with reduced landfill disposals.

There is, in the UK, a distinct imbalance in the types of cullet produced, a problem not so acute in mainland Europe. This arises due to the high proportion of coloured glass that is imported into this country, mainly in the form of wine and beer bottles. This results in over 60% of the cullet collected from bottle banks in the UK being coloured, even though 70% of the glass production in the UK is clear (flint), whereas in France (for example) the proportion is about 50%. The consequences of this are that there is a shortage of flint and amber cullet but an excess of green in the UK. In 1994 reclaimed flint cullet could only satisfy 18% of the demand, compared to 20% for amber (brown) and 80% for green. To put it another way, every green bottle made in this country contains up to 80% recycled cullet.

Interestingly, analysis of household waste has revealed that nearly 60% of glass discarded is clear, whereas less than 35% of all glass collected is clear. In addition, more than half of all the glass recycled in this country is green (flint), but constitutes only one quarter of glass discarded. This suggests that there may be a misunderstanding amongst the general public as to what types of glass can be recycled via bottle banks - its not just bottles, but all glass containers.

When using cullet in the melt furnace, which in the UK currently averages about 20% by mass, it is important that only the correct materials enter. Extensive efforts have to be made to exclude the wrong types of glass (the wrong types depending upon the type of glass being manufactured, but for example include mixing of different colours, flat, technical or ceramic glasses) and contaminants such as metal and stones. Major contaminants are picked out of the cullet, often by hand, when it first reaches the reprocessing plant. This is then crushed and metallic impurities removed by magnetic and eddy current methods.

In 1996 the glass re-processor T. Berryman and Sons were supplied with 185 kt waste glass (equating to 30 lorry loads/day). In 1994 6 kt were rejected due to contamination problems. A grading system has since been introduced in order to relate price to quality. This company was also the first glass reprocessor to introduce an automated optical scanning device to detect and remove contaminants, to below the 20 g/ tonne specified by their customer Rockware Glass. In 1996 Rockware Glass produced about 30% of the glass manufactured in UK, using approximately 105 kta cullet at just one UK plant.

Contamination problems with ecology cullet fall into three main categories:

- foreign materials
- colour mixing
- incompatible glass types

Post-consumer cullet, whatever the source, is always contaminated to some degree with unwanted materials, known in the industry as ‘inclusions’. These usually arise as a result of the functional origin of the cullet source. For example, automotive glass may well be contaminated by adhesive/sealant residues, and flat glass by window frame fragments and fixings. The presence of inclusions in the cullet feedstock leads to visual blemishes and irregularities, weakening the final structure and allowing the formation of stress fractures in the finished product, reducing the quality of the product.

The most important bottle bank cullet inclusions are:

- metal (ferrous and non-ferrous) from bottle/ jar tops, lids and closures
- organics, from paper labels, plastic closures, food residues and oils
- soil, stones, concrete and bricks (usually picked up en route at transfer stations)

Many of the inclusions can be removed. However the higher the degree of contamination, the greater the amount of subsequent quality refinement required (and hence expense entailed by the processor) and consequently the lower the value of the cullet. As the pressure to utilise an increasing proportion of ecology cullet in glass manufacture has mounted, so too has the demand by the manufacturers and re-processors for higher quality cullet. Heavily contaminated loads may even be rejected, the only remaining disposal route being landfill.

FOREIGN MATERIALS

The tables below illustrate the typical level of inclusions in ecology cullet delivered to glass reprocesors in the UK (Table 4), and the origins and effects of some of these inclusions (Table 5).
Many of the inclusions present in the glass when it arrives at the processing site are removed by hand. This particularly applies to incompatible glass types and colour mixing. Once the glass is broken, it is not possible to separate these materials, therefore it is essential to minimise the level of breakage prior to sorting. The greater the degree of breakage the more difficult it is to assess the level of contamination and under these circumstances, preventing the entry of such contaminants into the cullet must be the overriding priority. Although most ecology cullet is collected via bottle banks, it is cullet derived from ‘kerbside’ collections (where recyclables are source segregated by householders and the drivers) which yield the highest quality.

<table>
<thead>
<tr>
<th>Inclusion type</th>
<th>Float cullet Max. permissible (g/t)</th>
<th>Container cullet Max. permissible (g/t)</th>
<th>Typical container cullet levels (g/t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferrous metal</td>
<td>2</td>
<td>50</td>
<td>20-40</td>
</tr>
<tr>
<td>Non-ferrous metal</td>
<td>0.5</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>Ceramics and stone</td>
<td>No particle&gt;0.3 mm</td>
<td>20</td>
<td>5-10</td>
</tr>
<tr>
<td>Organics (paper, card)</td>
<td>50 (No particle&gt;2 g)</td>
<td>3000</td>
<td>1000-1800</td>
</tr>
</tbody>
</table>


INCOMPATIBLE GLASS TYPES

There are many different types of glass, their exact compositions being tailored to suit their primary function. These include lead-alkaline silica glass (the second most important in commercial terms, after soda-lime silica glass) which is used in tableware such as crystal glass; and borosilicate glass used in oven/ cookware (e.g. pyrex), industrial piping, and high wattage lighting applications. For recycling purposes these different glass types cannot be mixed, and as far as bottle bank cullet is concerned the major problem sources are:

- glass saucepans
- pyrex cookware
- crockery (plates, cups and saucers)
- pottery
- plate/ mirror glass
- laboratory glass and light bulbs
- crystal glass, drinking glass and ashtrays

COLOUR MIXING

The third type of cullet contamination is caused by glass colour cross-mixing. This arises for a number of possible reasons, including the fact that:

- some of the banks may be full, so the glass is deposited in one of the other receptacles
- the public do not understand the consequences of mixing the different colours
the public assume or think that extensive sorting occurs at some later stage

There are fairly tight colour contamination limits regarding what is acceptable for re-processing, and these are illustrated in Table 6.

<table>
<thead>
<tr>
<th>Glass colour</th>
<th>Acceptable level of other colours (w/w)</th>
<th>Typical level observed (w/w)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear (flint)</td>
<td>2%</td>
<td>0.5%</td>
</tr>
<tr>
<td>Green</td>
<td>5%</td>
<td>0 - 10%</td>
</tr>
<tr>
<td>Brown (amber)</td>
<td>5%</td>
<td>0 - 10%</td>
</tr>
</tbody>
</table>

**THE FUTURE OF GLASS RECYCLING?**

There is some scope, in the UK at least, for further increases in the proportions of ecology cullet used in glass manufacture. Never the less there are significant problems which remain to be overcome. As both the demand for higher quality glass and external (environmental and political) pressures to increase cullet incorporation escalate, the requirement for higher quality feedstock will continue to grow. The three aforementioned areas of concern (minimisation of inclusions, better colour separation and reduced glass breakage) need to be addressed to accomplish this.

The key issue in all three areas is education, both of the public and commerce. There has already been much success; there have been consistent improvements in cullet quality with 95% of ecology cullet now being colour segregated at source. However, there are indications that further increases in the use of post-consumer cullet will result in an increasing incidence of inappropriate glass types and inclusions.

With regard to those glass loads which are too heavily contaminated, whether it be due to colour mixing, inclusions or type contamination, there are currently no suitable large-scale disposal options other than landfill. There have been reports of research into other possible avenues to increase glass recovery rates, such as the:

- use as an aggregate substitute, in asphalt, bricks, clay pipes, cement or foamed building products such as breeze blocks (usually made from coal-fired power station ash) in the construction industry (recently highlighted in Material Recycling Weekly 23rd October 1998). In the USA glass has been used as an aggregate substitute in road construction (at up to 30% level) for over 20 years (where it’s known as ‘glassphalt’). The Ends Report (No 236 September 1994) mentioned that glassphalt was trialled, at a 17% level, in Westminster (UK) road structuring.
- standardisation of glass containers to facilitate re-use via a ‘returnable’ system, allowing different ‘fillers’ to use the same shape/colour container. However, most consumer goods packagers are unwilling to use such standardised containers – preferring their own distinctively shaped/coloured articles.

**GLASS IN AUTOMOBILES**

Vehicle manufacturers are faced with many specific, and often conflicting, requirements when designing and constructing automobiles. Every component, and the material from which they are made, must adequately perform its primary function, must be durable, must contribute to the appearance, comfort and style of the vehicle, and above all must be safe. Recently, issues such as weight savings and recyclability of the component at the end of its useful life have become contentious. All these have to be attained within tight budgetary limitations. With regards to glass, it must satisfy all of the above criteria by having excellent impact resistance and breakage predictability, whilst being completely unobtrusive in terms of optical clarity.

Motor vehicles contain two different types of safety glass:
All of the glass fitted to motor vehicles must satisfy very stringent safety criteria – both national and international – and the appropriate standards are marked on all pieces of glass on the vehicle:

- how glass breaks when hit by various objects from both inside and outside the vehicle (e.g. a 10kg dummy human head or large stone)
- resistance to heat, abrasion, humidity, temperature changes
- optical clarity (distortion and double image)
- resistance to fire and chemicals

As occurs in other industrial situations, under circumstances where significant volumes of a relatively homogenous waste stream arise, the economics of recovery and recycling are often beneficial. The re-processor Richardson’s Glass is based in St. Helens, very close to the glass manufacturers Pilkington Glass, themselves major suppliers to the automotive industry. There is considerable interaction between the two companies. Richardson’s has about 80% of the UK market share for recycling flat glass (or ‘float glass, that made by the float process) amounting to 10-20% of its annual throughput (approximately 140 kta). All of this is post-manufacturing, mostly from known sources (primarily Pilkington). There are very few facilities in the UK which reprocess post-consumer float glass. T.Berryman & Sons. developed a nationwide collection and reprocessing scheme for scrap automotive windscreens from the replacement industry, but the effects of the increasing volumes of container glass being recovered and the plummeting cullet prices has recently halted this activity.

Car manufacturers and their suppliers have, as mentioned, very tight specifications due to safety and appearance constraints. Automotive glass is thinner (typically 3 mm for body glass) than constructional flat glass (generally 6 mm) and therefore intrinsically more fragile (although it is toughened to improve durability and safety). This compounds the effects of any defects in the pane. Although safety is the primary consideration, one of the major reasons for using thinner glass is that car manufacturers are under constant pressure to minimise the weight of their vehicles. All materials and components have to contribute to this. In addition automotive glass is subject to very close scrutiny. In the vehicle occupants sit very close to the glazing, often for extended periods of time. For this reason any defects will be much more apparent – especially in front windscreens which must be completely unobtrusive in terms of transparency.

Another reason is, of course, that customers often pay a lot of money for their vehicle (often their second largest purchase, after a house) and even minor defects would probably not be acceptable. Even very small optical defects can cause structural weaknesses and hence premature failure. Any float glass with optical defects of greater than 0.5 mm diameter is automatically rejected; in practice this means cullet used in float glass manufacture containing any foreign particles of diameter greater than 0.3 mm has to be excluded.

Normal float glass contains up to 20-25% cullet, reclaimed from the manufacturing line itself or downstream processing (e.g. due to breakage, off-cuts from shaping or manufacturing changes in glass tinting or thickness etc.). In automotive applications, such wastage arises during the production of shaped side glasses and windscreens. For example, the construction of the two slightly different shaped halves of a laminated front windscreens necessitates production of glass of between 1.5 - 2.5 mm thick (2.1 mm being standard), meaning that the glass ribbon has to be ‘stretched out’. This is achieved by rollers that grip the edges of the glass ribbon. These sections are marked by this action and are trimmed off and recycled.

In the production of (constructional/ architectural) patterned float glass, where the optical clarity is not of such critical importance and slightly lower quality specifications can be accepted up to 60% cullet can be safely accommodated. However, the critical feature of such recycled float cullet is that, in both cases, it all arises from known sources with extremely low contamination levels.

As representatives of automobile manufacturers and dismantlers, the primary interest for the Consortium for Automotive Recycling (CARE) lies with automotive glass fractions, and more specifically with that of end of life vehicles (ELVs). Very little work on the recovery of these waste streams has been performed to date. Apart from some modifications (e.g. laminating and heating elements) automotive glass is fairly similar, once processed, to flat glass arising from other domestic and commercial sources. Float glass, irrespective of the source, should not be mixed with container glass in bottle banks. Having said this, some glass re-processors have been adding float cullet, from known sources, to their own container cullet material streams in relatively low proportions for many years. However, glass from the packaging waste stream is now displacing this and the market for this material has collapsed. As there are no specific applications for the
automotive fraction (the float glass industry insists that post-consumer float glass is not suitable for recycling back into float glass applications) it has to compete with the far larger volumes recovered from other sources. It should not, therefore, be considered in isolation from the wider glass waste arisings.

In common with glass waste in domestic arisings, glass forms only one part of the overall material profile in end of life vehicles, estimated to be in the order of 3% by mass (Table 7). Nationally, this could amount to as much as 45,000 tonnes annually (assuming an annual ELV arising of 1.5 million) most of which is currently landfilled. Reliable figures regarding the proportion of ELV glass which is sold as second hand parts are not available, but is thought to be small (about 5-10%), meaning that the vast majority is not recovered, reused or recycled. However, compared to the UK’s current total annual post-consumer container glass recycling of over 440,000 tonnes, this would constitute only a relatively small additional amount.

**THE ELV DISPOSAL CHAIN**

At the end of its useful life, the majority of motor vehicles in the UK pass from their last owners into the hands of vehicle dismantlers (more frequently known as ‘car breakers’). It has been estimated that there are between 3500 and 5000 vehicle dismantlers operating in the UK (*Find-A-Part, personal communication*). However, since the introduction of more stringent licensing conditions following on from the implementation of the Environmental Protection Act 1990, only 60% of this number are currently thought to be licensed or registered exempt (*i.e.* conform to higher environmental operating standards). Accurate data concerning these statistics appears not to be readily available due to the lack of a central database of vehicle dismantling sites and their registration/licensing status. This is a major problem in the UK.

In general, the UK vehicle dismantling industry, despite its name, has not (in the past) systematically ‘dismantled’ vehicles to any great degree *per se*. Dismantling has been limited to those parts that could be sold directly as ‘used’ (or second-hand) parts, and those composed of valuable raw materials. The latter have, historically, been the metallic fractions (*e.g.* cast iron, aluminium alloy, and copper). It is probably true to say that many dismantlers still operate simply by storing their vehicles, more or less complete, until a particular item is required, at which point it is removed either by the staff or the public. Having said that, there are a growing number of more professional dismantlers who process their vehicles to a much greater extent and offer a more comprehensive service.

![Table 7. Composition of a Typical 1990 European Car (data source ACORD).](image)

<table>
<thead>
<tr>
<th>Material</th>
<th>Typical mass (kg)</th>
<th>% by mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>478</td>
<td>53</td>
</tr>
<tr>
<td>Cast Iron</td>
<td>72</td>
<td>8</td>
</tr>
<tr>
<td>Non-ferrous metal</td>
<td>86</td>
<td>9.5</td>
</tr>
<tr>
<td>Plastics</td>
<td>104</td>
<td>11.5</td>
</tr>
<tr>
<td>Glass</td>
<td>27</td>
<td>3</td>
</tr>
<tr>
<td>Rubber</td>
<td>45</td>
<td>5</td>
</tr>
<tr>
<td>Other non-metals</td>
<td>90</td>
<td>10</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>902</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

*NB. Figures previously provided by ACORD indicate that the proportion of glass in European motor vehicles has remained more or less constant, between 1975 and 1995, at about 3%*

That part of the glass fraction which can be re-used in its original function, is sold by vehicle dismantlers. This varies from model to model and depends upon a multitude of factors such as age of the vehicle; in newer vehicles all of the glass may be sold; in older vehicles, such as MOT failures, no glass may be sold. There has not been much research into the proportion of ELV glass that is reused/resold but in general, is thought to be low. One only has to visit a dismantling site immediately before the individual vehicles are finally destroyed to realise that most of the glass is still in place. Data contained in the ACORD First Annual Report (1998) suggests a ‘reuse’ rate of about 14% by mass, but opinion within the glass and dismantling industries suggests a figure closer to 5%. In
addition, it must be borne in mind that many ELVs are accident damaged, and therefore, contain less than their full complement of glass (and indeed other parts).

When the vehicle dismantler decides that an ELV is ready for final disposal, the remains are crushed for transportation to the ‘fragmentiser’ or ‘shredder’. The vehicles are flattened simply to allow the logistics of transportation to be optimised. Any intact glass remaining prior to this stage is, obviously, now broken. It may be that only 50% of the remaining glass falls inside the vehicle and hence is passed directly on to the fragmentisers. A lot of the glass fragments fall onto the ground in the flattening area, where it either gradually becomes incorporated into the construction of the floor, or is later collected up and put inside empty shells immediately before they are flattened. This is, in fact, the standard method of clearing yard surfaces and disposing of the results. Changes in landfill prices and practices are putting this operation, of including ‘dirt’ in the car hulks, under increasing pressure. Many shredders operators now penalise merchants who use the shells as a disposal route for ‘rubbish’.

At the fragmentiser or shredding facility, of which there are currently approximately 45 in the UK, the crushed vehicle shells join a complex incoming stream of metal items, including white goods, such as refrigerators and freezers. In the UK ELVs typically constitute about 50% by mass of the fragmentiser infeed. These metal items are then loaded by crane, into a massive ‘hammer mill’ which basically tears everything into fragments. These fragments are subsequently sorted into different material streams depending upon the physical characteristics of the individual materials. Magnetic, eddy current and density techniques are used to recover the valuable ferrous and non-ferrous metal components, which account for about 75% by mass of the infeed. The remainder, predominantly rubber, foam, plastic, glass and other miscellaneous materials is currently disposed of to landfill in the UK.

The most straightforward method of recovering ELV glass is simply to break it and collect the fragments in a container which can then be emptied into a suitable skip. This is practical for toughened glass, predominantly side and rear units (including doors and sunroofs), bearing in mind that the alternative method, removal in one piece, may require extensive dismantling of the vehicle structure. However, this is not the case for laminated glass units. These are specifically designed not to fragment upon impact and have therefore to be manually removed in, more or less, one piece.

Some automotive glazing is already recycled by the larger companies in the aftermarket replacement industry (e.g. Autoglass) when the customers’ damaged item is replaced. These are then collected and recycled by specialist re-processors (e.g. T.Berryman). The major differences between this and the dismantler scenario are:

- specialist glass replacement/ re-processors deal with a uniform waste stream derived from their core business
- the glass replacement industry expends no extra labour (cost) in obtaining the material, as it obviously removes the damaged item in the course of the replacement (the cost being borne by the customer or their insurance company)

Neither of these conditions exist for vehicle dismantlers. ELVs could be regarded, in some respects, as similar to household waste. Certainly
some of the same problems are encountered (wide variety of materials present, labour/ costs involved in segregating different materials, general lack of end markets especially for mixed/ contaminated material streams).

As in the wider glass recycling industry, the presence of contaminants (known as inclusions) in the ELV glass stream would be one of the major problems. ELV dismantling sites are not generally renowned for their good housekeeping, and it is to be expected that the presence of ‘foreign’ items such as stones, dirt and general site waste could pose significant difficulties with the quality and consistency of the material stream. Laminated windscreens which are ‘bonded’ into the vehicle aperture are very difficult to remove – in this case even when the vehicle has been crushed, the main bulk of the windscreen remains in place (Charlton Recycled Autoparts, Cambridge, 1998)

The recovery of vehicle-derived glass could also pose a number of other technical problems:

- it may be difficult to distinguish between clear and tinted glass. This has obvious consequences in terms of the ‘value’ of the colour-contaminated stream
- the use of rubberised (gasket) seals has, in recent years, been superseded by a ‘direct bonding’ method in which the glass is fixed into the body aperture by means of an adhesive. The glass, when finally removed, may be more heavily contaminated with adhesive/bonding material
- directly bonded glass is much more difficult and hence time consuming to remove. Even after the vehicle has been flattened, the glass often remains bonded in place (see above photograph)

Experience in the field has demonstrated that adhesive contamination might be of relatively little significance, depending upon the method employed to remove the windscreens. It is the time taken to remove the glass that is, in practice, most significant. This is confirmed by information provided by the vehicle manufacturers in the International Dismantling Information System (IDIS). Consider, for example, two of the current most common ELVs, the Ford Escort mark 3 (1980-86) and the Ford Sierra mark 1 (1982-86). Removal of all of the glass from the Escort takes just under 5 minutes, whereas it takes more than three times this to recover the glass from the Sierra (16.8 minutes). Indeed, the removal of the front windscreen from the Sierra takes longer than removal of all the glass from the Escort. The significance of this lies in the different bonding techniques used, the Sierra utilizing the direct bonding approach.

As part of a controlled experiment with 179 ELVs CARE recovered approximately 1.75 tonnes of glass. Interestingly, this equates to about 9 kg/vehicle on average – less than one third of that which should theoretically have been available. Those pieces of glass fixed with rubberised (gasket) seals (front, side or rear) were cut out; those fixed with hinges/ screws (side or sunroofs) were removed complete wherever possible. However, where this was not possible due to direct bonding into the body aperture, a fairly primitive removal method was employed – breakage with a hammer. In these instances the glass was collected by placing a canvas bag under the area where the broken glass was expected to fall. Using this approach it was estimated that up to 50% of the glass was lost as it either fell into the door or body cavity or outside the area covered by the bag. There is capacity for significant refinement in this respect. Neither of these techniques were appropriate for removing directly bonded front windscreens. Removal of these was time consuming and dangerous. The quickest and safest method of removal was found to be, by trial and error, to use a large disc cutter. This allowed most of the screen to be cut out in 2 to 3 minutes, but could, in turn lead to complications with contamination by grinding dust.

Having said this, it should be borne in mind that vehicles of typical ELV age maybe 13 years old. Therefore, even though methods of vehicle glazing may well be changing now, there could be a considerable time lag before these new glazing approaches predominate at dismantling sites. As the direct bonding method becomes increasingly common in ELVs this will render the recovery of such glass increasingly difficult and time consuming and hence costly. The type of fixing method used in what are currently amongst the most frequently dismantled ELVs in the UK are shown in Table 8.

Based upon an average weight of glass per vehicle of 30 kg, if 10% by weight is sold for re-use, and a
When a vehicle is crushed at a dismantling facility, prior to transportation to the shredder, much of the remaining glass falls outside of the vehicle. This may later be swept up and placed inside another shell prior to flattening.

Further 10% is allowed for breakage during accidents and transportation (as an average over the whole ELV population) it can be seen that more than 40 ELVs would need to be processed to recover one tonne of glass. This could have a value of about £20/tonne, equating to about £0.02/kg or £0.48/vehicle processed. Assuming a standard labour rate of £7/hour for a dismantler (excluding operating overheads), in order to break-even about 15 vehicles/hour must be processed (i.e. allows 4 minutes per vehicle processing time). This would yield about 350 kg of glass/hour. Based upon the illustrative figures provided by IDIS, the figure of 4 minutes per vehicle processed would be optimistic assuming that all ELVs utilised the ‘gasket’ seal method. However, when the implications of an increasing frequency of direct bonding in ELVs is considered, a more realistic processing rate might be 5 vehicles/hour. In terms of economics, this would result in a considerable negative cost balance for vehicle dismantlers; under such conditions a net loss of £4.60/hr/5 vehicles processed (i.e. each vehicle would ‘cost’ £0.92 to process in terms of glass recovery). In addition, this does not take into account the costs associated with delivering the glass to the reprocessing centre.
The recovery of ELV glass will only be economically viable, from a vehicle dismantlers’ and glass re-processors’ point of view, if: the price obtained per unit mass is significantly greater than the labour cost expended during its collection; and it is competitively priced against other recovered glass sources and virgin raw material, after it has been collected from the dismantling centres and processed to remove the main contaminants.

When considering glass values, in terms of mechanical recycling, there are several important aspects to consider. The raw materials from which glass is manufactured (predominantly sand and limestone) are both cheap and plentiful. This imposes an immediate economic restriction on the price competitiveness of recovered glass (if it is more expensive than ‘virgin’ glass there will be no financial incentive to use this material). Within this, there are a multitude of other factors to consider, such as collection, transportation and processing of the recovered glass. The current market value of post-consumer recovered container glass is in the region of £20/tonne, delivered to the reprocessing site.

Laminated front windscreens which are fixed into the body shell aperture by means of a rubberised seal are easily removed. They often ‘pop out’ when the shell is being flattened (CARE Hulk Standards Trial, Universal Salvage, Paddock Wood, August 1998)

One major difference between a significant portion of automotive and domestic glass (but in common with other types of safety glass) is lamination. Laminated glass is used extensively in safety applications such as automobile windscreens, aircraft glazing and bullet-proof glass. It is made up of a layer of clear plastic (usually Polyvinyl butyral, PVB) sandwiched under conditions of mild heat and pressure between two layers of glass. The strong plastic layer confers the safety advantage - glass adheres very strongly to it, so when it breaks it does not shatter - the screen remains in (more or less) one piece. The plastic interlayer is usually clear, even in tinted glass, where the tint resides in the glass. In some cases, however (e.g. where there is a tint gradient or patterning) the colour is contained in the PVB layer. A relatively new development in windscreen glazing has been the advent of ‘solar reflecting systems’. The idea here has been to address the problem of uncomfortably hot vehicle interiors during periods of hot weather. These windscreens differ from standard laminated units which incorporate a 0.76 mm PVB layer, in that a 0.05 mm layer of silvered Polyethylene terephthalate (PET, another type of plastic) is sandwiched between two 0.38 mm layers of PVB.

PVB, is an expensive, high performance thermoplastic polymer with relatively few applications. It is the most common lamination interlayer due to its:
- strong glass adhesion
- high impact resistance
- high flexibility
- excellent optical clarity
- high light (ultra violet) stability
- heat stability
- moisture insensitivity

PVB is not a new plastic; it was developed by Monsanto in the 1930s as the key ingredient in laminated glass. PVB belongs to a group of chemicals known as an ‘acetal’ i.e. is formed by the reaction of an ‘aldehyde’ with an ‘alcohol’, which proceeds via an unstable ‘hemi-acetal’ intermediate. For use in critical glass applications, such as automotive windscreens it needs to be very pure, which in turn determines the precise chemical method which is used to synthesise it (i.e. minimises the presence of by-product contaminants).

PVB has come to the attention of CARE as a result of its presence in scrap automotive front windscreens that arise from two broad sources - ELVs and in-service replacements. PVB, when used in windscreens at a standard thickness of 0.76 mm, constitutes about 10% by weight of a windscreen, amounting to approximately 1 kg/screen. Movement of designers and/or manufacturers towards incorporating laminated glass into side and rear glazing applications will have obvious repercussions with regard to the abundance of scrap PVB. At present, with the estimated annual UK ELV arisings of 1.5 million, this represents a possible source of 1.5 million kg/year of PVB (i.e. 1500 tonnes per annum). There is also estimated to be an additional 1500 tonnes of PVB available from in-service windscreen replacements annually (equating to an annual
replacement rate of 1.5 million units/year). This represents a considerable pool of material. Growth or shrinkage of the vehicle population, extension of laminated glass applications in vehicles and any vehicle scrappage schemes could have a considerable impact upon PVB arisings.

Homogeneous manufacturing scrap is, of course recovered and recycled by the 'virgin' polymer suppliers. The main PVB producers, world wide are:

- Monsanto (marketed as ButVar)
- Du Pont (marketed as Butacite)
- Huels Troisdorf
- Hoechst AG
- Sekisui
- Union Carbide
- Wacker Chemie

In response to the problem of waste PVB, arising at laminated glass reprocessing centres four of the main PVB producers (Monsanto, Du Pont, Huels Troisdorf, Hoechst AG) formed a 'waste PVB consortium' with the aim of finding a high value recycling route. To date, this has not been accomplished.

In common with PVB derived from non-automotive post-consumer laminated glass, there is currently no recycling of this valuable material in the UK. The current disposal route is landfilling, a result of the cost advantage for this disposal method. However, valorisation by incineration with energy recovery does occur in some EU states (PVB having an energy content similar to coal).

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The main technical issue then, with regard to PVB, is identification of suitable end markets (a problem shared with all other ELV-derived plastic waste streams). Many automotive polymers are valuable high specification materials, and the recyclate derived from these has been shown, by CARE, to be of a similarly high quality and specification. To use these in low grade applications can only be regarded as somewhat of a wasted opportunity (or value). The ideal solution must be to identify high value end markets such as those typified by the automotive sector.
As far as the ELV Directive and the glass industry is concerned, the problem is that glass is very easily targeted – much more so than many of the other ELV materials; it is relatively easy to recognise and remove. Therefore it is likely to be subject to considerable political pressures. Broadly speaking, post-consumer glass (although significantly not float glass) is already widely recycled by, and is familiar to, consumers in the form of bottles and jars. The problems lie in the very low value of the resulting material and the probable misunderstanding that ‘all glass is the same’.

Recovering glass from ELVs is a labour and energy intensive activity. The question has to be asked – considering the overall energy consumption and pollutant generation, is it environmentally beneficial to collect and process ELV glass from an extensive network of vehicle dismantlers? Clearly, recovering ELV glass within the existing vehicle dismantling infrastructure is not financially viable at present, and may not even be of significant environmental benefit.

Technically, ELV glass is almost certainly recyclable, but the cost penalty is so large at present as to render it unacceptable. Not only do relatively small amounts of glass have to be manually removed from a widely distributed ELV population, but the resultant material would then have to be stored, appropriately segregated with minimal contamination, until it can be transported to a reprocessing centre. There are additional technical problems with re-processing automotive glass. In heated rear windscreens the silver heating elements are ‘fired’ into the glass. In addition, the trend away from the gasket sealing technique towards using ‘direct bonding’ to fix glass into body apertures (an arrangement that contributes significantly towards car body strength and rigidity) has further ramifications. Here the glass is ‘glued’ into place using a very strong polyurethane adhesive. This not only renders the glass extremely difficult to remove in one piece but under certain circumstances could lead to problems with adhesive contamination of the cullet. To further complicate matters, the thick layer of adhesive is hidden from view by the outer sections of the glass panes being ceramically printed to render them opaque. This introduces another contamination problem. These problems are not insurmountable but the downstream processing and sorting techniques required are sophisticated and expensive.

There may be some limited scope for absorption of post-consumer float glass in lower specification automotive or construction/architectural applications. However, with the forecast increases in the recovery of container glass there is small chance of channelling ELV glass into the container glass stream. The development of appropriate sorting and segregating techniques may go some way to reducing the specification ‘cost penalty’ of post-consumer material.

Even if the technical sorting issues were overcome, the issue of logistics of collection and transportation would be daunting. For illustrative purposes, consider 1.5 million ELVs being dismantled at 4000 separate locations. Assuming an even distribution each dismantler might potentially handle 375 vehicles/year. Using a not unrealistic recovery efficiency of approximately 50% by mass (taking into account some sales as replacement parts and some breakage during vehicle transportation) and assuming that each vehicle initially contains 30 kg of glass on average, it can be seen that each dismantler might produce about 5.5 tonnes of waste glass annually. This would take up a disproportionate amount of space in what are typically small and often disorganised dismantling facilities, even discounting the possibility that it might need to be colour segregated. The introduction of unacceptably high levels of contamination would be a probability, verging on a certainty.

One approach to tackling the issue of logistics could be the development of compartmentalised material collection vehicles, of the type which are now being used to collect segregated components of household waste. Such vehicles are used by many local government authority-run kerbside schemes, to collect paper, aluminium and steel cans, glass, plastic and in some cases putrescible organic wastes.

As long as float glass recycling is driven predominantly by economics, and the glass manufacturers and their customers are not forced to accept reclaimed post-consumer cullet, such waste glass arisings will have to be disposed of by other routes. The effect of environmental and, probably most significantly, political factors may change this. However, it must be stressed, under prevailing conditions, there is no straightforward solution.
REFERENCES.

ACORD First Annual Report, Spring 1998
Automotive Glazing Executive. Information Pack 1995
British Glass Recycling Pack 1994
CARE Phase 1 Report Spring 1998
CARE Promotional launch brochure August 1995
Glass Gazette No22, FEVE, September 1996
Glass Gazette No23, FEVE, September 1997
Glass Gazette No 24, FEVE, September 1998
Improving Cullet Quality. Environmental Technology Best Practice Programme 1997
Is There A Net Environmental Benefit From Recycling PP, ABS and Glass From ELVs. Simon Dawes MSc Thesis, October 1997
Making Waste Work. HMSO 1995

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Further information on glass recycling, both in the UK and in Europe (including back copies of the Glass Gazette) can be found on the Internet at www.britglass.co.uk