2 Background information on waste glass reclamation and recycling

2.1 Glass and waste glass: terminology and characteristics

2.1.1 Identification and general description of glass

There is no exclusive definition of the term "glass", a term describing a variety of inorganic materials with different mechanical and optical properties. What all glass materials have in common is a vitreous or amorphous state, originated by the relatively fast cooling and solidification of an initial molten state. The fast cooling prevents atoms, molecules or ions to organize into a more thermodynamically favourable crystalline structure. Therefore, glasses are not arranged in an orderly repeating pattern in all three dimensions like crystals but are characterised by an amorphous structure. As a consequence, glass does not melt at a certain temperature like other solids but softens slowly when heated up.

The most common type of glass is formed by melting a mixture of silica (SiO$_2$), soda ash (Na$_2$CO$_3$), and lime (CaCO$_3$) at high temperatures, followed by cooling during which solidification occurs without crystallization (Siddique, 2008). In the glass industry the term "glass" is predominantly used for silicate glasses, i.e. materials containing a high share of silica (SiO$_2$), formed under ambient cooling conditions from the molten state into an amorphous glass structure.

The main raw material for glass production is sand or quartz, which is the crystal form of silica (SiO$_2$). It consists of a continuous framework of SiO$_4$ silicon–oxygen tetrahedra, with each oxygen atom being shared between two tetrahedra. In amorphous glass structures, the bonds within each silica tetrahedron have a similar length as in the crystal form (same short-range order), but the three-dimensional distances between different tetrahedra are irregular (no long-range order).

2.1.2 Chemical-physical properties of glass

In its simplest chemical form, glass can consist of pure silica, in which case it is called “quartz glass” or “fused quartz”. However, the production of amorphous glass from pure silica is highly energy intensive, requiring temperatures of around 1900 °C. As such, quartz glass is only produced for applications requiring high chemical resistance and hence belongs to the special glass types (MGS, 2010).

In order to lower the energy requirements for glass production, most of the glass is composed of silica (SiO$_2$) plus other compounds. Silicon has the role of a so-called "network former", and it is the main element used as network former. Alternative network formers are boron or germanium. The network formers create a highly cross-linked network of chemical bonds.

Aside from network formers, glass contains also "network modifiers", which are alkali-oxides added as fluxing agents for lowering the melting point of glass (sodium, potassium, lithium, etc.), alkaline earth metal oxides (calcium, magnesium, barium, strontium, etc.), and other metal oxides (i.e. aluminium oxide). The network modifiers change the bonding relationships and structural groupings, resulting in changes in the physical and chemical properties of the glass. The modifiers are usually present as ions, compensated by nearby non-bridging oxygen atoms, bound by one covalent bond to the glass network and holding one negative charge to compensate for the positive ion nearby.
Glass may also contain other added substances (e.g. lead, titanium, aluminium, zirconium, beryllium, magnesium, zinc), which may act both as network formers (e.g. Pb\(^{4+}\) replacing Si\(^{4+}\)) and as network modifiers, depending on the glass composition.

The main types of glass, according to physico-chemical composition, are:

1. Soda-lime glass
2. Lead crystal and crystal glass
3. Borosilicate glass
4. Electric glass, also called E glass

The first three categories account for more than 95% of all glass produced. The physico-chemical compositions of the most frequent glass types (soda-lime, lead crystal glass, borosilicate, and E glass) are summarized in Table 1, and are described more in detail below.

**Table 1: Major components of soda-lime glass, lead crystal glass, borosilicate glass, and E glass (BREF 2009)**

<table>
<thead>
<tr>
<th></th>
<th>Soda-lime glass</th>
<th>Lead crystal glass</th>
<th>Borosilicate glass</th>
<th>E glass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Siliceous dioxide (SiO(_2))</td>
<td>71-75%</td>
<td>54-65%</td>
<td>70-80%</td>
<td>52-56%</td>
</tr>
<tr>
<td>Boron trioxide (B(_2)O(_3))</td>
<td></td>
<td></td>
<td>7-15%</td>
<td>0-10%</td>
</tr>
<tr>
<td>Lead oxide (PbO)</td>
<td></td>
<td>25-30%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soda (Na(_2)O) or Potassium oxide (K(_2)O)</td>
<td>12-16%</td>
<td>13-15%</td>
<td>4-8%</td>
<td>0-2%</td>
</tr>
<tr>
<td>Lime (CaO)</td>
<td>10-15%</td>
<td></td>
<td>16-25%</td>
<td></td>
</tr>
<tr>
<td>Aluminium trioxide (Al(_2)O(_3))</td>
<td></td>
<td>7%</td>
<td>12-16%</td>
<td></td>
</tr>
</tbody>
</table>

**Soda-lime glass**

Glass industry mainly produces “soda-lime” glass. It is composed of:
- 71-75% silicon dioxide (SiO\(_2\) derived mainly from sand)
- 12-16% sodium oxide (Na\(_2\)O derived from soda ash – Na\(_2\)CO\(_3\))
- 10-15% calcium oxide (lime, CaO, derived from limestone – CaCO\(_3\))
- Low levels of other components

Sodium carbonate (Na\(_2\)CO\(_3\), “soda”) is added to lower the melting point of silica to about 1500 °C. However, soda addition leads to glass corrosion (Fearn *et al.*, 2006). To provide for a better chemical durability of the glass, calcium oxide (CaO, ‘lime’), magnesium oxide (MgO) and aluminium oxide (Al\(_2\)O\(_3\)) are added. Soda-lime glass is commonly used for the three major glass applications: container glass (packaging bottles, jars), flat glass (windows of buildings, automotives) and domestic glass (drinkware, dishes).

**Lead crystal and crystal glass**

Lead crystal and crystal glass are types of glasses that contain varying amounts of lead oxides, as defined in the Council Directive 69/493/EEC of 15 December 1969 on the approximation of the laws of the member states relating to crystal glass.

The typical lead crystal composition is:
- 54-65% SiO\(_2\)
- 25-30% PbO (lead oxide can be partially or totally replaced by barium, zinc or potassium oxide in glasses known as crystal glass)
- 13-15% Na\(_2\)O or K\(_2\)O
- various other minor components
Lead oxides (PbO and Pb₃O₄) are used to improve the sonority and to increase the refractive index of the glass. This creates the high brilliance of domestic lead crystal and crystal glass products. Lead oxides ease the workability of handmade glass, because they lower the working temperature and the viscosity. Barium, zinc, and potassium oxide have similar properties as lead oxide, but they produce lower levels of brilliance and density, and therefore have disadvantages in the workability of handmade glass. As will be explained later, lead could be a source of environmental impact if it leached out of the glass material.

**Borosilicate glass**

A typical borosilicate glass composition is:

- 70-80% silicon dioxide SiO₂
- 7-15% B₂O₃
- 4-8% Na₂O or K₂O
- 7% Al₂O₃

If silicon is partly substituted by boron ("borosilicate glass") as a network former, superior durability and resistance against chemicals, water and heat are achieved. Boron changes the viscosity and liquidity to ease fibreisation. Borosilicate glass is used for laboratory equipment, as syringes, ampoules, vials and cartridges for pharmaceutical use, cookware, lighting (as bulbs for high-power lamps), windows for fire protection, and insulation mineral wool.

**Electric glass, or E glass**

Electric glass or E glass is a special type of borosilicate glass where part of the boron trioxide has been replaced by aluminium oxide, and is also characterized by a low alkali content (<2%). E glass has high electrical resistivity and it was developed for stand off insulators for electric wiring. E glass is mainly used for continuous filament glass fibre production (BREF, 2009).

### 2.1.3 Glass production and use

The European glass industry is very diverse and covers a variety of very different types of products and technologies, including bottles & jars, flat glass, continuous filament glass fibres (CFGF – not to be confused with insulation mineral wool), flämmage, tableware, insulation mineral wool, optical fibres and special glass (cathode ray tubes, glass for televisions and monitors, lighting glass, optical glass, laboratory and technical glassware, borosilicate and glass ceramic cookware, etc). The specific products that the glass industry can produce are very diverse, ranging from tiny jewellery products to huge swathes of architectural flat glass for buildings. The common factor among these industries is that they all need glass melting furnaces to manufacture their products. The raw materials they need, the size and type of furnace, the amount of energy needed, the type of fuel used, the amount of cullet that can be used, the length of time needed to melt and produce a finished product vary considerably from one sector to another.

Glass can be applied for the production of various products. A typical classification is based on the six broad sectors of the glass manufacturing industry. Numbers in parentheses indicate their approximate shares of the total EU-27 production. For each sector, specific products or applications are listed below.

1. **Container glass or packaging glass (~56%)**: Bottles and other containers (for packaging of food, drinks, pharmaceuticals, cosmetics, etc.).

2. **Flat glass (~25%)**: Mainly windows in buildings and vehicles. The flat glass products can be roughly categorised into two types: float glass and rolled glass. Float glass is used for a huge number of applications including glazing for building and transportation, industrial applications, electronics, furniture, appliances, etc. Rolled glass is used principally in the manufacture of glass doors, partitions,
shower enclosures, and photovoltaic panels. Float and rolled glass are produced with different manufacturing processes. Rolled glass installations have much smaller furnaces than float glass, with lower load.

(3) Continuous filament glass fibres (~2%). Continuous filament glass fibres are produced and supplied in a variety of forms such as mat, chopped strand, roving, yarn, tissue or milled fibre. The main end use (approximately 75%) is the reinforcement for many polymer materials. The main markets for the resulting composite materials are the building industry, the automotive and transport sectors, and the electrical and electronics industry. Continuous-filament glass fibres are predominantly made of E glass.

(4) Domestic glass, also called tableware (~4%). Used for tableware, glassware, decorative glass, etc. Most important components are soda-lime, lead crystal, crystal glass, and opaque and glass ceramics.

(5) Insulation mineral wool (~10%). Insulation mineral wool is made of short fibres of glass (typically borosilicate glass or alkaline earth – alumina-silicate stonewool) and ceramic materials. It is used for insulation, filtering and firestop applications.

(6) Special glass (<3%). The category of special glass covers a wide variety of glass, for example: optical/ophthalmic glass, glass in laboratory equipment (partly made of borosilicate glass), glass in tubing, glass ceramics, lighting glass, glass composing cathode-ray tubes (CRT) in computer monitors and TVs, as well as glass in other electronic equipment such as in TFT LCD screens (thin film transistor-liquid crystal display). There is no more production of CRT glass in the EU, but there is some recycling activity of CRTs (companies such as GRIAG and CRT Recycling Ltd).

Table 2: Sectors of the glass manufacturing industry, applications, types of glass they are made of, and approximate production volumes in the EU-27 in 2007 (data compiled from BREF, 2009)

<table>
<thead>
<tr>
<th>Glass manufacturing sector</th>
<th>Application or use</th>
<th>Type of glass</th>
<th>Production in the EU-27 in 2007</th>
<th>Share of total production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Container glass or packaging glass</td>
<td>75% beverage packaging, 20% other food packaging, 5% packaging cosmetics, pharmaceuticals and technical products</td>
<td>Soda-lime glass</td>
<td>~21 Mt</td>
<td>~56%</td>
</tr>
<tr>
<td>Flat glass</td>
<td>95% float glass: 75-85% buildings industry, 15-25% automotive industry, 5% rolled glass (wired or patterned)</td>
<td>Soda-lime glass</td>
<td>~9.5 Mt</td>
<td>~25%</td>
</tr>
<tr>
<td>Continuous filament glass fibre</td>
<td>Roving, mat, chopped strand, textile, tissue, milled fibre (90% used for composite materials)</td>
<td>E glass</td>
<td>~0.7 Mt</td>
<td>~2%</td>
</tr>
<tr>
<td>Domestic glass</td>
<td>Tableware, cookware, vases, ornaments</td>
<td>Soda-lime glass, lead glass</td>
<td>~1.5 Mt</td>
<td>~4%</td>
</tr>
<tr>
<td>Mineral wool</td>
<td>Insulation material</td>
<td>Borosilicate glass</td>
<td>~3.7 Mt</td>
<td>~10%</td>
</tr>
<tr>
<td>Special glass (CRT not produced in EU anymore)</td>
<td>75% monitor glass, 25% light bulbs/tubes, ceramic glass, high-temperature domestic glass</td>
<td>Soda-lime, borosilicate glasses</td>
<td>~1 Mt</td>
<td>~3%</td>
</tr>
</tbody>
</table>

Total | ~37.4 Mt |

2 The production of special glass has dropped in the last few years, partly because of the downturn of CRT production (in particular, there is currently no CRT production left in the EU-27).
2.1.4 Waste glass terminology: cullet

In general, the word cullet can be used to refer to either "broken glass" or to "waste glass". A distinction should be made regarding internal vs. external cullet: this distinction is important because internal cullet is not regarded as waste, while external cullet (which can be pre- or post-consumer) is classified as waste. When using the word "cullet" in the context of end-of-waste it will always refer to external cullet.

Internal cullet is composed of defective products detected and rejected by a quality control process during the industrial process of glass manufacturing, transition phases of product changes (such as thickness and colour changes) and production offcuts. The basis of the definition of internal cullet is the fact that these materials are immediately absorbed by the respective industrial process as a raw material for a new melting operation, not leaving the glass manufacturing plant. Internal cullet cannot be considered as waste as it was never a product.

External cullet is "waste glass that is collected and/or reprocessed with the purpose of recycling". External cullet can be of two types: (1) pre-consumer, also called post-industrial glass cullet, and (2) post-consumer glass cullet.

(1) Pre-consumer cullet is waste glass resulting from the manufacturing of products that contain glass as one of their components, and which leaves the specific facility where it was generated, becoming waste but not reaching the consumer market. An example of pre-consumer cullet is the glass cullet constituted by offcuts and pieces from defective manufacturing of e.g. the production of car windows from flat glass, which leave the car window manufacturing facility and are re-melted in the flat glass manufacturing facility.

(2) Post-consumer cullet is waste glass originated after the use of the glass products at the consumer market.
The majority of cullet is container glass and flat glass cullet. However, cullet can also come from insulating mineral wool, or from continuous-filament glass fibres. In these cases, especially for the case of High Temperature Insulation Wools (HTIW), the waste glass has a fibrous structure rather than the crushed-glass appearance that is usually associated with the word cullet.

The term **cullet** will be used in this document to refer to **reprocessed cullet**, that is, external cullet that conforms to a set of minimum quality criteria; and the objective of this project is to define the minimum quality criteria for reprocessed cullet to obtain the status of end-of-waste. Some types of reprocessed cullet may have reached a quality that is considered high enough that no additional sorting or cleaning steps are needed for its direct input into a glass furnace; in this case, some studies refer to the reprocessed as **furnace-ready cullet**.

The report sometimes will also make reference to **collected cullet**; in this case, it is a type of cullet that generally conforms to lower quality specifications than reprocessed cullet and may not be suitable as direct input for re-manufacturing into new glass products.

### 2.1.5 Waste glass: classification

There are two possible classifications of waste glass. On the one hand it can be classified according to its source, on the other hand according to the European Waste Catalogue.

**Classification of waste glass according to its source: pre- and post-consumer waste glass**

Pre-consumer waste is generated during manufacturing (before reaching the consumer), and has exclusively an industrial origin. It represents approx. 25% of waste glass generated in the EU³.

Post-consumer waste is generated after the manufactured products are used by the consumers. The approximate share of waste glass from this origin is approx. the remaining 75%. The main sources of post-consumer waste glass are:

- Municipal solid waste (from household and commercial waste collection)
- Industrial waste
- Construction and demolition waste (C&D)
- End-of-life vehicles (ELV)
- Waste from electric and electronic equipment (WEEE)

In general, pre-consumer glass is more homogeneous. Waste glass from post-consumer origins will almost always need different degrees of sorting, collection and treatment, while some pre-consumer streams may not need any treatment at all.

**Classification of waste glass according to the European Waste Catalogue**

An alternative classification of waste glass can be made following the European Waste Catalogue (EWC), which classifies waste glass according to five different sources:

- I. Mixed municipal solid waste and bulky waste (20%)
- II. Glass packaging and other waste glass from municipal, commercial or industrial sources (67%)
- III. Construction and Demolition (C&D) waste glass (5%)
- IV. Industrial sources (7%)
- V. End-of-life vehicles (ELV) waste glass (1%)

³ This figure has been estimated from data in (IPTS, 2009) and feedback received from experts (FERVER, FEVE)
2.1.6 Glass cullet contaminants

Contaminants are materials present in glass cullet that are unwanted for its further use. Contaminants can be classified in two groups: non-glass material components, and glass material components that are detrimental for new glass manufacturing.

**Non-glass material components**
- Metals (ferro-magnetic and non-ferro-magnetic)
- Non-metal non-glass inorganics:
  - Ceramics, Stones and Porcelain (abbreviated in Europe as “CSP” or “KSP”)
  - Glass ceramics, also called pyro-ceramics or vitro-ceramics: These are heat-resistant non-glass ceramic materials
- Organics (food remains, strapping, plastic, wood, textiles)
- Hazards (hazardous materials contained in bottles and jars, medical or chemical refuse contained within needles and syringes)

**Glass material components**
Glass product quality is severely affected by the presence in glass cullet of glass types different from the main glass cullet type. For example:
- To manufacture flat glass, only flat glass cullet can be used (flat glass manufacture does not accept for example container glass cullet)
- To manufacture container glass (of soda-lime physico-chemical composition), it is not possible to use non-soda-lime glasses that are sometimes deposited by mistake in collection banks, such as: domestic lead-crystal glass or special borosilicate glasses coming for example from light bulbs and tubes (which present an undesirable higher melting point).
- To manufacture flint container glass, there is a limit on what percentage of green container glass cullet is used. Above that limit, the green glass cullet is adverse for new flint glass manufacturing.
Of all the non-glass contaminants listed above, one of the most problematic is the contamination with non-metal non-glass inorganics, including ceramics (CSP) and glass ceramics\(^4\). These inorganic contaminants have a higher melting point than glass components and they might not melt depending on their size, thereby creating unacceptable defects in the final glass products. An increased incorporation rate of cullet for glass melting requires high CSP qualities to minimise the risks of interruptions in the production and of inclusions in the final products. From the start of glass collection in the early 1970s until mid 1980s, manual sorting (“handpicking”) was the only method to reduce CSP, achieving levels of about 400-500 g/tonne (i.e. 400-500 ppm, or 0.04-0.05%). Today automated optical sorting can achieve CSP levels of 25-50 g/tonne (i.e. 25-50 ppm, or 0.0025-0.0050%) (Van Santen and Beerkens, 2005). The contamination of glass by vitro-ceramics is a relatively new type of contamination. The recycling industry is concentrating on research towards sorting equipment for vitro-ceramics. These developments are rather new and immature. Therefore it is regarded as important to promote better collection schemes to minimize the inclusion of vitro-ceramic contaminants in the cullet.

The next problematic contaminants of glass cullet are metals. The effect of metal contaminants is that as they fall to the bottom of the glass furnace, they may cause damage to the furnace walls and bottom. Metals originate from caps or cans thrown into the waste glass collection banks. Table 3 presents the origin and effect of different types of metal contaminants in glass cullet.

<table>
<thead>
<tr>
<th>Metal</th>
<th>Origin</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead</td>
<td>Wine bottle caps (no longer used since the late eighties), reduction of lead oxide from domestic crystal glass</td>
<td>Furnace attack by furnace bottom damage caused by liquid metallic lead downward drilling (lead drops drilling into the refractory bottom of the tanks). Increased lead content in soda-lime container glass.</td>
</tr>
<tr>
<td>Aluminium</td>
<td>Cans or caps</td>
<td>Formation of silicon-inclusions by a reaction of the less noble aluminium with silica grains forming silicon metal spheres. ((4 \text{Al} + 3 \text{SiO}_2 \rightarrow 3 \text{Si} + 2 \text{Al}_2\text{O}_3))</td>
</tr>
<tr>
<td>Iron</td>
<td>Cans or caps</td>
<td>Less dangerous for the furnace or glass rigidity, although also causing inclusions and colour cords in the glass products from iron sulphides.</td>
</tr>
<tr>
<td>Copper</td>
<td>Wires</td>
<td>Possible inclusions of copper or lead (present in some copper alloys) in the glass.</td>
</tr>
</tbody>
</table>

Table 4 shows typical maximum permissible levels of major cullet contaminants for the use in container glass, flat glass, and insulation mineral wool production.

\(^4\) Glass ceramics are also referred to as pyro-ceramics, and they are also known as vitro-ceramics; these are heat-resisting inorganic materials. Amongst all types of inorganic contaminants, pyro-ceramics are considered by industry as one of the most difficult ones to detect and separate out because of their glass appearance. For their effective removal, specialized and innovative equipment is needed.
Table 4: Maximum permissible levels of typical contamination of cullet, for the production of container glass, flat glass, and insulation mineral wool (Glass for Europe, 2005; 2009; Eurima, private comm.)

<table>
<thead>
<tr>
<th>Contamination</th>
<th>Particle weight/size</th>
<th>Container glass maximum (ppm)</th>
<th>Flat glass maximum (ppm)</th>
<th>Insulation mineral wool (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferrous metals</td>
<td>&gt; 0.5 g</td>
<td>50</td>
<td>None</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(2 if &lt; 0.5 g)</td>
<td></td>
</tr>
<tr>
<td>Non-ferrous metals</td>
<td>&gt; 0.1 g</td>
<td>20</td>
<td>None</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.5 if &lt; 0.1 g)</td>
<td></td>
</tr>
<tr>
<td>Inorganics</td>
<td>&gt; 0.2 mm</td>
<td>20</td>
<td>None</td>
<td>25</td>
</tr>
<tr>
<td>Organics</td>
<td>&gt; 2 g</td>
<td>3000</td>
<td>None</td>
<td>3000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(45 if &lt; 2 g)</td>
<td></td>
</tr>
</tbody>
</table>

Quality requirements for cullet use in the flat glass production are much stricter than for container glass. Cullet impurities for container glass production in the range of 20 - 50 g of metals and ceramics per tonne of glass (20-50 ppm) are usually acceptable. For flat glass, impurities of ceramics and non-ferrous metals are practically not acceptable. For instance, ferrous impurities have to be lower than 2 g per tonne of glass (2 ppm). Thus, most of the cullet used in the production of flat glass is internal cullet, and it amounts to about 10-15% of the input raw materials. However, most flat glass manufacturers (in particular, float glass) use external cullet, but its quantity is limited because of limited availability of external float glass cullet.

**Colour**

There are four colours of cullet mainly used in container glass production: (1) clear or flint; (2) green; (4) brown or amber, and (4) mixed cullet. Colour requirements are related to commercial, not environmental, requirements.

Maximum accepted levels of false colours in a given coloured cullet differ according to the desired product quality by the manufacturer. The strictest requirements apply for the manufacture of flint glass, whereas mixed glass (followed by green glass) has the highest tolerance for other colours.

Typical maximum limits of colour contamination for the manufacturing of a given colour of container glass are (BSI/WRAP, 2003):

- Flint glass: < 4% to < 6% (according to FERVER, even a lower tolerance, estimated at <2%)
- Brown glass: < 5% to < 15%
- Green glass: < 5% to < 30%

For container glass production, particle size in general is between 5 and 50 mm. Intentionally ground cullet (even to < 1 mm) is an increasing trend.

### 2.2 Waste glass management

#### 2.2.1 Description of management options

Glass can for example be reused as returned bottles with deposit, in which case it is not defined as waste. Post-consumer waste glass can be recovered with the purpose of recycling in the glass
manufacturing industry, to make products such as container glass, flat glass or insulation mineral wool, and also for uses that do not imply re-melting, e.g.:

- Additive (fluxing agent) in brick and ceramics production
- Filter media (e.g. for water purification)
- Aggregate in civil works (loose fill, asphalt, backfill)
- Abrasive, e.g. for sandblasting
- Sports turf (rooting medium, top dressing)
- Decorative applications (tiles, flooring, synthetic marble).

The process of recycling consists of a series of steps to condition the waste glass for further use. Typical steps are collection, crushing, sorting, contaminant removal, transport, and final use. Some of these steps can, if appropriate, be by-passed. When no use is found for glass, it is stored or disposed of. The most frequent disposal options are landfills and incineration. Incineration implies that glass is mixed with other materials in slag, which then can be either used (e.g. in civil works) or landfill.

### 2.2.2 Waste glass generation

**Overall mass balance**

It is estimated (Ramboll/Ökopol, 2010) that the total amount of waste glass generated in the EU-27 in 2007 was 25.8 Mt. This resulted from a total production of glass in the EU-27 of 37.4 Mt in 2007. The extra-EU trade of manufactured glass represented only 5-10% of production. In addition, in 2007, extra-EU imports and exports of glass products approximately balanced each other, with a total imports volume of 3.6 Mt and total exports of 3.5 Mt (ECORYS, 2008).

![Mass balance diagram](image)

**Figure 3:** Mass balance of glass production, and consumption, and waste glass collection, recycling, traded, and disposed of (2007)
As can be seen in Figure 3, the difference between glass production (A) and waste glass generation (B) is \( A - B = 11.6 \text{ Mt} \). This difference is composed of long-life glass products, and the net extra-EU exports of glass products. In 2007, the next extra-EU exports of glass products was a small amount, representing only \(-0.1 \text{ Mt}\).

From the 25.8 Mt amount of waste glass generated, 14.85 Mt was collected for reuse/recovery/recycling. This gives a **collection rate of 58%**. Collection rates vary among member states, with collection rates higher than 80% in some countries.

Out of the total 14.85 Mt collected for reuse/recovery/recycling, around 11.8 Mt were actually recycled to replace raw materials in the manufacture of new glass products. This gives a **recycling rate of 46%** (of the total waste glass generated). As indicated in Figure 3, the difference between waste glass collected and recycled, \( C - D = 3.05 \text{ Mt} \), ends up disposed in landfills or results in a net extra-EU export of cullet. In 2007, the total extra-EU imports and exports of cullet were 0.21 Mt and 0.19 Mt, respectively. Therefore, the next extra-EU export of cullet was a small amount of \(-0.02 \text{ Mt}\).

Container waste glass is the largest part of the generated waste glass, with about 17 Mt.

Table 5 summarizes amounts of glass production, waste glass generation, waste glass collection with the purpose of recovery (mainly recycling), and waste glass recycled, for each of the six sectors of the glass manufacturing industry, whenever available. Data were collected from CPIV and FEVE statistics, as well as other references (ECORYS, 2008; Ramboll/Ökopol, 2010) and input from the TWG.

**Table 5: Statistics on EU-27 glass production, and waste glass generation, collection, and recycling (2007)**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Container glass or packaging glass</td>
<td>(~21 \text{ Mt})</td>
<td>(~17 \text{ Mt})</td>
<td>(~11 \text{ Mt})</td>
<td>(~8 \text{ Mt})</td>
</tr>
<tr>
<td>Flat glass</td>
<td>(~9.5 \text{ Mt})</td>
<td>(~5.1 \text{ Mt})</td>
<td>(~2.9 \text{ Mt})</td>
<td>(~2.9 \text{ Mt})</td>
</tr>
<tr>
<td>Domestic glass (tableware)</td>
<td>(~1.5 \text{ Mt})</td>
<td>(~0.8 \text{ Mt})</td>
<td>(~0.5 \text{ Mt})</td>
<td>(~0.5 \text{ Mt})</td>
</tr>
<tr>
<td>Mineral wool</td>
<td>(~3.7 \text{ Mt})</td>
<td>(~2.0 \text{ Mt})</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Continuous filament glass fibre</td>
<td>(~0.7 \text{ Mt})</td>
<td>(~0.4 \text{ Mt})</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Special glass</td>
<td>(~1 \text{ Mt})</td>
<td>(~0.5 \text{ Mt})</td>
<td>(~0.45 \text{ Mt})</td>
<td>(~0.40 \text{ Mt})</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>(~37.4 \text{ Mt})</td>
<td>(~25.8 \text{ Mt})</td>
<td>(~14.85 \text{ Mt})</td>
<td>(~11.8 \text{ Mt})</td>
</tr>
</tbody>
</table>

Notes regarding Table 5: Waste figures include both pre- and post-consumer waste glass. Total collection rate (C/B) is \(~58\%\); total recycling rate (D/B) is \(~46\%\). Data sources for the figures by glass type (sector of glass manufacturing industry) are given below:

- For container glass, statistics were mainly gathered from FEVE published data.
- For flat glass, most of the waste is pre-consumer. Estimates were derived from several sources, including glass manufacturers.
For domestic glass, estimates were provided by the European Domestic Glass Association. However, as recycling in the domestic glass sector involves mainly spot operations with pre-consumer cullet, rather than a continuous flow of post-consumer cullet, there are no official data or reliable statistics. The figures provided should be regarded as estimates and subject to some degree of uncertainty.

Regarding mineral wool, it is difficult to use mineral wool cullet for the manufacturing of new mineral wool products, because of its content of binding materials. However, Eurima reports that in the annual manufacturing of mineral wool in the EU (3.7 Mt), about 0.6 Mt of external cullet from container glass and flat glass sources were approximately incorporated. This means that the new mineral wool production incorporates about 16% of external cullet.

According to GRIAG, the amount of special glass that was recycled in 2007 was around 0.40 Mt (a slightly higher amount was collected, with the difference being approx. the next extra-EU exports of special glass cullet). The amount recycled today is estimated as higher, around 1 Mt.

In general there are no reliable available data on imports/exports of cullet per glass type but, given that the net trade of cullet for all types of glass combined is small compared to the total volume of waste glass generated, a similar trend is approximately expected when considering each type of glass individually. Because of cost considerations, cullet is generally not a material that is transported over long distances and therefore the imports and exports of cullet are small compared to the amounts recycled locally, near the point of waste glass collection.

In Table 5, the difference between glass production (A) and waste glass generation (B) is composed of long-life glass products and net extra-EU exports of glass products for each of the glass sectors. As was the case with overall glass statistics (Fig. 3), the net extra-EU exports of glass products are significantly small. The difference between waste glass collection (C) and waste glass recycling (D) mainly goes to landfill disposal and net extra-EU exports of cullet (this last quantity is significantly small due to the mentioned high costs of transport).

**Amounts of glass waste generation, collection, and recycling by sources**

**ELVs**

In Europe, about 9 million end-of-life vehicles (ELV) arise each year. Assuming an average vehicle weight of 1000 kg, about 9 Mt of this waste are annually generated. Glass composes ~3% of the weight of a car, that is, about 30 kg, so that the total waste glass from ELVs is around 0.27 Mt per year in the EU-27.

The ELV Directive (2000/53/CE) aims at reducing the amount of vehicle waste to be landfilled. In particular, one of its goals is preventing environmental emissions of four heavy metals: lead, cadmium, mercury, and hexavalent chromium. The ELV Directive sets a reuse and recycling rate target of 80% by 2006 and 85% by 2015 (recycling rate is defined as weight of vehicle waste recovered for re-manufacturing into new products but excluding energy recovery, per weight of vehicle waste discarded).

Annex I of the ELV lists minimum technical requirements for treatment of ELV. The ELV directive encourages the dismantling and selective removal of components such as glass before shredding. Some experts of the TWG have mentioned that ELV glass cannot be recycled into re-melting applications once is shredded together with the metal scrap. If high recycling rates of 90% or higher are to be achieved, the ELV glass needs to be removed before shredding. Experts indicated furthermore that there is the technical capacity in Europe to perform the selective dismantling of ELVs and the recycling of their waste glass fractions with the purpose of re-melting into new glass products.

At present most of the discarded vehicles end up in dismantling facilities, which on the one hand carry out decontamination operations (removal of battery, tyres, fuel, oils, etc.) and on the other hand collect spare parts which can be sold for reuse. The decontaminated and selectively dismantled ELVs are sent to automotive shredder facilities, where the ELV are shredded to recover the ferrous and non-ferrous metals. Many references agree that in current shredding plants, about 75% of ELV is recovered.
The remaining 25%, which is called auto shredder residue (ASR) or auto fluff, is a complex heterogeneous waste which contains many different plastics (thermoplastics and thermosets), elastomers, foams, remaining metals, wood, glass, textiles, etc. Being a very heterogeneous stream, its recycling is neither technically nor economically feasible and therefore up to now ASR have been in their majority disposed in landfills.

Little information is available, but some experts of the TWG indicated that only the Netherlands was removing almost all the automotive glass from ELVs; other countries do it partly (e.g. Germany, France, Italy, Portugal, UK), and the remaining EU countries do it rarely. Recent information (private communication from stakeholders) suggests that the producer’s responsibility scheme in the Netherlands has decided to stop removing the car glass before shredding the vehicles. Experts from the TWG suggested that more effort should be directed to support the recovery/recycling of car glass, including the preference for dismantling of car windows prior to shredding.

WEEE
Waste from electrical and electronic (WEEE) equipment means equipment which is dependent on electric currents or electromagnetic fields in order to work properly and equipment for the generation, transfer and measurement of such currents, such as computers, ovens, mobile phones, toys and hairdryers. Light bulbs, fluorescent tubes and low energy bulbs are also included in this category. In the collection systems for household waste, for example at apartment blocks, there is often a special place for electrical and electronic equipment, for example in the bulky waste room. Sometimes citizens can take WEEE to a recycling centre, or to hazardous waste collection points.

The WEEE directive (also discussed under legislation) puts the responsibility for reducing, reusing and recycling of WEEE on the producers, and requires removal of hazardous components.

WEEE consists, among other materials, of a mixture of metal, plastics and glass. Treatment may involve steps such as: shredding, granulating, magnetic separation, eddy current separation, and density separation. Some manual separation can also be involved. Glass constitutes about 5% of WEEE on average\(^5\). The percentage of glass in certain types of WEEE materials such as CRT screens is significantly higher as reported by experts from the TWG.

Construction and Demolition (C&D)
According to Glass for Europe (2005) the total waste glass from C&D waste in the EU is about 1.2 Mt yearly. Out of ca 180 Mt of C&D waste, this represents ~0.66% in weight.

Environmental regulations promote selective demolition, considered as the most effective method for recycling the various types of waste streams in C&D wastes. However, mainly for reasons of cost of transport and the low value of most of the C&D recyclates except metals, C&D in the EU follows no standardised practice for the selective dismantling of materials in C&D waste, and the separate collection of glass.

2.2.3 Collection and transport techniques

Post-consumer dry recyclables are collected in two main different ways: mono-material collection (optionally with colour differentiation), or mixed with other dry recyclables (multi-material collection). Both options have advantages and disadvantages, frequently not affecting the same sectors of society.

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Mono-material systems

Advantages:
- Normally results in higher quality. The amount of non-glass is significantly lower, making it easier to process and remove the lids, labels, foils, ceramics and any other impurities.
- Cullet has higher quality, and it is thus fit for a larger range of glass recycling uses. This is especially valid if there is colour separation.
- Increased added value over the recycling chain, also higher with colour separation.
- Lower costs of reject disposal (non-glass material fraction) or bad quality cullet batch disposal.
- In general, higher overall recycling rates (even though collection rates may not in all cases be higher).
- Better image to the public, as multi-material collection may result in the perception that glass is not being recycled
- Avoidance of gate fees for storage at material recovery facilities.

Disadvantages:
- Requires existence of a reprocessor with adequate sorting technology within reasonable transport distance, otherwise it is likely that the material will be used for open loop recycling applications, such as aggregates, resulting in virtually no environmental benefits.
- The additional stage of colour sorting may have a significant cost impact and even become economically not viable.
- More demanding for consumers.
- More costly in terms of collection than multi-material systems, especially if colour-separated.

Multi-material systems

Advantages:
- Easier for households, as less sorting space is needed.
- Cheaper collection.

Disadvantages:
- Higher reprocessing costs to achieve the same quality as mono-material collection, if at all achievable.
- Lower recycling rates because of high contamination.
- Higher glass loss during processing (typically 12-15% is wasted in material recovery facilities, compared to 1% for mono-material processing).
- Cullet frequently not suitable for further reprocessing with the aim of re-melting in glass manufacturing facilities. Experts reported that even in some cases the cullet is not suitable for use as aggregates because of its high organic contamination. As a consequence, the cullet from multi-material systems is sometimes rejected by aggregate companies.

It is currently a widespread opinion of the glass manufacturing industry that the best collection option for the long-term sustainability of the glass recycling industry is mono-material, if possible colour-separated. However, technologies for sorting continue to advance and in the near future it may be the case that multi-material collection may produce high-quality reprocessed cullet.

2.2.4 Reprocessing techniques

After collection and transport to the reprocessing facilities, waste glass is inspected visually, crushed and sorted, yielding cullet that is subsequently transported to a next step in the recycling chain.
Crushing and sorting of waste glass

The first phase of treatment upon arrival of waste glass at the reprocessing plant is visual inspection.

Visual inspection is undertaken by experienced staff with good knowledge of the processing technology of the plant. Lorries tip their load for visual inspection, to determine the processing needs. In some cases, the operator may decide that the contamination is too high for an economic treatment, and the load is disposed of without treatment.

If inspection results in acceptance, the material is crushed. Crushing reduces the glass piece size to the size suitable for further sorting or cleaning. Afterwards the organics may be dried at ambient air, or removed by washing, before the material passes sieves to reduce the organic content as well as magnetic separators and Eddy current separators to reduce the metal content. Highly contaminated materials may pass several times sieving as well as magnetic and Eddy current steps until they are clean enough to pass an optical sorting. In the different phases of the process, air suction removes lighter components such as paper and plastics.

Manual sorting can also be part of the sorting steps, removing by handpicking large pieces of foreign material such as plastics, paper, textiles, or ceramics/stone/porcelain. An increasing problem for container glass cleaning is the recent trend of using transparent thin foils attached to glass, instead of paper labels. Some adhesives of these foils lead to increased rates of waste because they cannot be separated from the glass (Pohl, 2010). Radio frequency identification (RFID) tags might also raise problems for recycling if their use will increase in the future, as suggested by members of the TWG.

The most complex process is optical sorting. Here, glass pieces are first sorted into different flows according to grain size. The flow passes through one or more optical sorting machines. Each sorting machine is equipped with cameras and sensors that use white light, laser light and infrared backlight. The opaque non-glass materials are detected. Different colours of glass can also be detected depending on how they transmit the different incident light beams. Detection triggers blowout commands. Blowout jets are used to eject target impurities at precisely the right moment. Regarding color impurities, this technique allows improving color separation, but not to the extent of a complete separation into single colour waste glass streams. In the last years, fast X-ray fluorescence detection systems combined with blow out techniques have become available as well. The X-ray system is able to sort out undesired glass fractions that cannot be detected with infrared technique, like lead glass, refractory glass and glass ceramic. Within milliseconds, material with defined characteristics is blown out of the cullet, independent from the size, shape, or colour of the particle (Mogensen, 2010; Pohl, 2010). Finally, automatic quality control is combined with manual quality control by qualified staff overseeing the final separation result. The outcome of these steps is cullet with a certain quality.

Pre-consumer glass waste, collected at a direct customer of the glass manufacturer, can spare some of the mentioned reprocessing steps. For example, a car manufacturing company buys flat glass from a glass manufacturer to be used in car windows. Some of the flat glass in the car manufacturing company ends up as waste during the production process of making car windows. This flat glass waste may be directly returned to the flat glass manufacturing company. It is a prerequisite for such direct return without processing that the waste glass has no contamination during its processing at the product manufacturing industry (in the example, the car manufacturing industry). Usually, this practice takes place in cases where long-term customer relations exist, e.g. within two steps of the glass supply chain that share ownership.

Transport of glass cullet to cullet users

Because of its relatively high density, low specific value, and frequent abundance of the raw materials that glass cullet substitutes, glass is mostly produced and consumed locally, and waste glass is collected and used locally. Transport takes place over relatively short distances, normally not more than 300 km. Still for certain types of glass cullet it is profitable to haul longer distances for collection or glass manufacturing.