EU-MERCI

EU coordinated **ME**thods and procedures based on **R**eal **C**ases for the effective implementation of policies and measures supporting energy efficiency in the **I**ndustry

HORIZON 2020 Project Nr. 693845

Technical analysis – Glass sector (NACE C23.1)

WP4: Picture of efficiency projects implemented by the Industry sector-by-sector and process-by-process

Table of Contents

1 Introduction

According to NACE classification, Glass manufacturing and processing covers sector 23.1 and can be split in the following subsectors:

- NACE C23.11 Manufacture of flat glass
- NACE C23.12 Shaping and processing of flat glass
- NACE C23.13 Manufacture of hollow glass
- NACE C23.14 Manufacture of glass fibers
- NACE C23.19 Manufacture and processing of other glass, including technical glassware.

The main products of glass manufacturing can be divided into 5 categories:

- Flat glass (NACE C23.11) – 25% of total EU glass production
- Container glass (NACE C23.13) – 70% of total EU glass production
- Continuous filament glass fiber (NACE C23.14) – 2% of total EU glass production
- Domestic glass (NACE C23.12 and C23.19) – 2% of total EU glass production
- Special glass (NACE C23.12 and C23.19) – 1% of total EU glass production

For details about the plants and Companies distribution in Europe please refer to next paragraph.

2 Glass manufacturing

Generally, glass manufacturing can be divided in 5 phases:

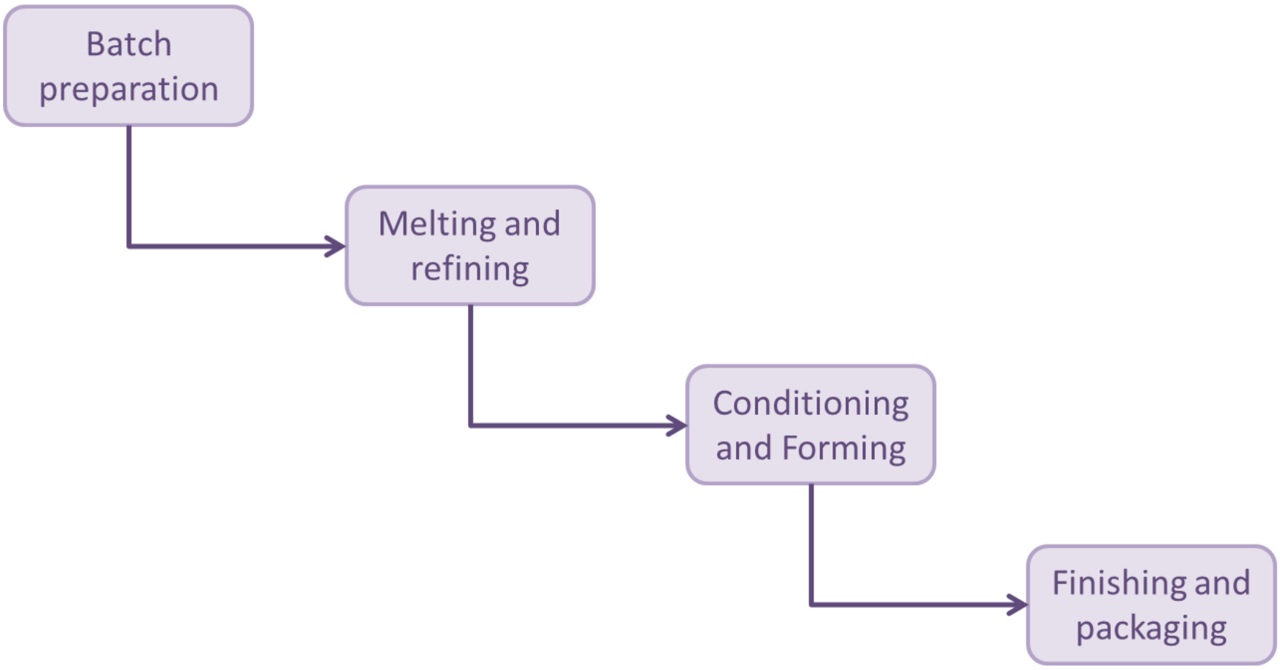

Figure 1: Glass general process.

- Batch mixing and preparation: raw materials (mainly sand, limestone, soda ash, dolomite, iron oxide and salt cake) stocking and processing, if necessary; delivery of raw material to the furnace;
- Melting in a furnace: raw materials are charged into a large furnace to be melted at 1,500-1,600°C. They are transformed to molten glass, that usually exits the furnace, after refining, at around 1,200°C;
- Forming process: depending on the final product, molten glass passes through different blowing and pressing methods;
- Finishing and packaging: finishing processes (also called secondary processes) are applied to release stresses and/or to give glass products some extra properties. Packaging is the last step of glass products manufacturing, when they are made ready for storing and/or shipping;
- Quality assurance: verification of glass quality and properties. To ensure the highest quality, inspection takes place at every stage. Modern systems allow to record 100 million measurements per second and to drive “intelligent” processes (e.g. cutters in the flat glass manufacturing), further improving product quality to the customer.

According to the final product, there might be more phases and some details of the main process can be different, starting from the forming process. This leads to the need to specify the manufacturing process for each product. When speaking about glass industry, it has to be reminded that glass recycling is an important part of it, contributing significantly to reduce energy consumption related to raw materials extraction and processing and in the melting phase. However, the amount of recycled glass that can be used in the different processes varies depending on the desired properties of the output product. Before being sent to the furnace, recycled glass shall be separated from extraneous parts (especially the ones that can't be melted like ceramics) and its quality shall be verified in order not to contaminate the molten glass bath.

2.1 Batch mixing and preparation

The main raw materials used in glass manufacturing can be divided in 6 categories:

- Glass-forming materials (Silica sand): the basis for glass manufacturing;
- Fluxing agents (Soda ash): Soda ash, added to the batch of raw materials, transforms into Sodium oxide through reaction with Silica sand (SiO_2); in this way, it helps the reduction in melting temperature of the mix (silica sand alone melts at 1,700 °C);
- Stabilizers (Limestone, Marble, Dolomite): give the required properties and the workability to the glass;
- Refiners (Sodium sulphate, Calcium sulphate): support the removal of waste gas from batch decomposition and the homogenization of molten glass;
- Colouring/decolouring agents: different materials, usually metals (e.g. Copper, Chromium, Cobalt) that remove colour from or give a certain colour to the glass;
- Cullet: depending on the colour and quality of the desired glass, it can be added in different amounts in the batch as a replacement for silica sand; it is responsible for reduction in energy consumption.

Depending on the kind of desired product, different other materials can be added to the batch. Just as example, a possible compositions of flat and hollow glasses is:

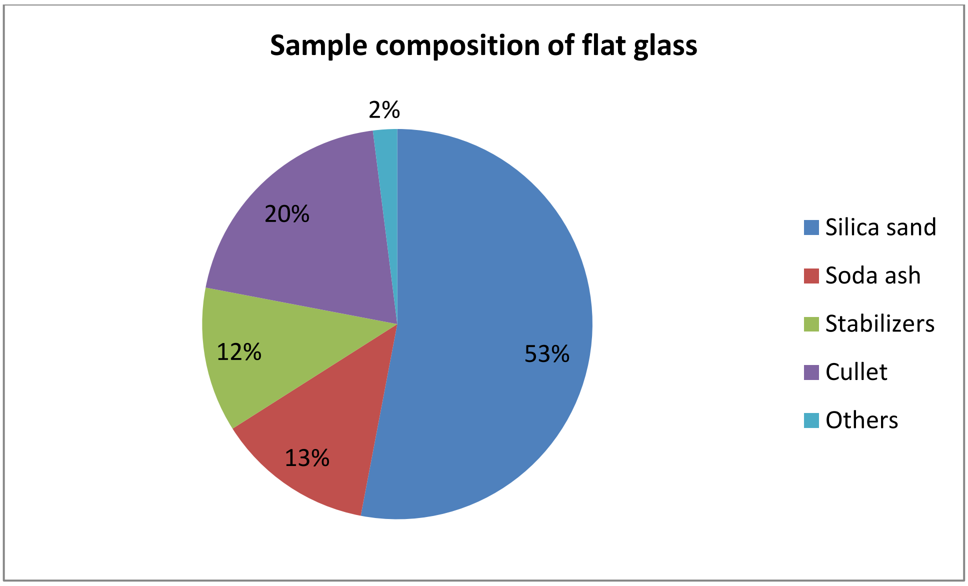

Figure 2: Sample composition of flat glass.

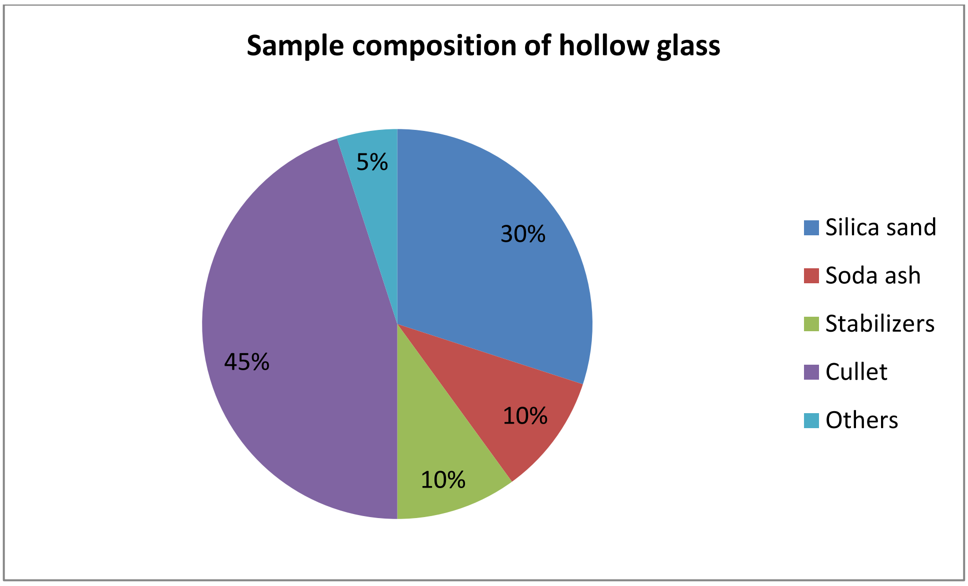

Figure 3: Sample composition of hollow glass.

Raw materials arriving to the plant are usually transferred to dedicated storage areas, through the use of pneumatic transport systems. They are then automatically collected, weighed and mixed and are sent to the furnace on a conveyor belt. Cullet, after crushing, is added directly to the mixture at furnace charging system.

2.2 Melting

Melting phase is a combination of chemical and physical transformations. It can be divided in several phases, of which the most important ones are:

- *Heating*: heating is usually accomplished by burning fossil fuels above the batch and above the molten bath. The temperature required to melt and refine glass is dependent on the composition of the batch; however it is usually between 1,300°C and 1,550°C. In furnace design, geometry is usually optimized to induce temperature differences in the molten glass bath, in order to have a continuous convective flow inside it. This ensures homogeneity in the glass fed to the forming process. The molten glass residence time in the furnace varies depending on the kind of glass, but it usually goes from 24 hours (container glass) up to 60-72 hours (flat glass);
- *Primary melting*: raw material has low conductivity, so the start of melting is usually very slow. The first phase of melting is moisture removal and decarbonisation, that occurs at around 500°C. The real melting starts between 750°C and 1,200°C, with the dissolution of sand under the influence of fluxing agents. Then several chemical and physical processes occur, that lead to a molten volume of around 35-50% of the starting batch, due to the release of gases and the reduction in the interstitial spaces;
- *Fining and homogenisation*: fining (or refining) process consists in the removal of bubbles from the molten bath; together with homogenisation it is fundamental to guarantee glass integrity and good quality. Fining happens in a first phase, with very hot molten glass where bubbles are formed, come out and are gas stripped and a second phase (secondary refining) during cooling, when bubbles are dissolved. The addition of fining agents (whose nature depends on the type of desired glass) to the batch supports these processes; the most common one is Sodium sulphate. Homogenisation can be achieved by introducing nitrogen, steam or oxygen bubbles from the bottom of the furnace, in order to increase the internal flow in the molten bath. For optical glass, also stirring in the melting tank can be used;
- *Conditioning*: after melting and fining, the glass is slowly cooled down to 1,350-900°C and the last bubbles are reabsorbed into the melt.

The main types of melting furnaces are:

- *Regenerative furnaces*, either with cross-fired or end-fired technology: the term regenerative refers to the heat recovery performed inside the furnace, that is done through the passage of exhaust gas through a refractory material, that absorbs heat and then releases it to the inlet air. The heat recovery process happens in two chambers, that are alternatively heated by waste gas and cooled by inlet air. In the cross-fired regenerative furnace the burners are positioned all along the furnace and the two chambers are on the sides of it. In the end-fired regenerative furnace the regenerative chambers are situated at one end of the furnace, each with one single port;

- *Recuperative furnaces*: in the recuperative furnace, the incoming air is pre-heated by the waste gas through the use of a traditional metallic (sometimes ceramic) heat exchanger. The pre-heat temperatures are lower than in the regenerative furnace. Sometimes, waste gases are used also to pre-heat raw materials or to produce steam. However, they are largely applied when high flexibility is required or when the production is too low to justify the use of a regenerative furnace;
- *Oxyfuel melting furnaces*: in oxyfuel melting furnaces, combustion air is replaced by oxygen (>90% purity). This allows to reduce the amount of fuel, because it is not necessary to heat all the nitrogen contained in air and to reduce the amount of produced waste gas, especially thermal NO_X. They are usually designed like the other furnaces, but don't use any heat recovery to pre-heat oxygen;
- *Electric furnaces*: in the electric furnaces, electrodes are inserted either from the top or the bottom of the furnace and the heat is provided through electrical resistance when electrical current passes through the melting bath. The raw materials are usually fed as a layer on the top of the bath, in order to slowly melt inside it (this type of furnace is also called "cold-top" furnace). The start of the furnace at the beginning of each campaign is done through the combustion of fossil fuels as support;
- *Combined fossil fuel and electric melting furnaces*: they can be either fossil fuel furnaces with electric boosting or electric furnaces with fossil fuel support. The heating principle of the electrodes is the same as in the electric furnace. Electric boosting is achieved by circulating electricity through electrode rods or plates positioned on the sides or on the bottom of the tank. This can either support the fluctuations in production (without requiring the replacement of the furnace) or to reduce waste gas emissions. Fossil fuel support in electric furnaces is less spread. The applied technique, called "over-firing", consists in firing flames over the surface of batch materials in order to aid melting;
- *Discontinuous batch melting furnaces*: this kind of furnace is used when the quantities of product don't justify the use of a continuous furnace. They can be either melting pots or day tanks, depending on the production cycle and on the timing. The pots can have open or closed top, with different temperature control (open pot furnaces are controlled through modulation in firing, closed pots have constant firing and modulation in the opening of the gathering port). The pots are heated 24 hours a day but with different temperatures depending on the phase of the melting process. The highest temperatures are reached during refining. Day tanks are a further development of melting pots, with higher production rates. They allow a fast change in the type of glass to be melted;
- *Special furnaces*: they are used either to reduce waste gas emission in atmosphere (e.g. low NO_X furnaces) or to accommodate flexibility of production in a more compact and efficient way than day tanks and melting pots (flex melters). There are several types, however they are less spread than the other types of furnaces.

2.3 Forming phase

The main difference among the glass manufacturing methods is the forming phase, that is differentiated according to the desired final product. The forming processes for the main products will be summarized in this section.

2.3.1 Flat glass

Almost all flat glass is produced in "Float glass plants", that are operated 24/7 without interruption for the whole furnace technical life (around 10-15 years). A float line can be half a kilometre long. Raw materials enter at one end and from the other end plates of glass emerge, at rates as high as 6,000 tonnes a week. In float bath, the molten glass flows gently over the surface of an enclosed bath of molten tin (about 3–4 m wide, 50 m long, 6 cm deep), from a delivery canal and is poured into the tin bath by a ceramic lip known as the spout lip. The amount of glass allowed to pour onto the molten tin is controlled by a gate called a tweel. The molten glass enters the float bath at around 1,100°C. The name "Float bath" derives from the fact that the molten glass literally floats on top of the tin. As it flows along the surface of the tin bath it forms a ribbon of uniform thickness, controlled by the speed at which solidifying glass ribbon (at 600°C) is drawn off from the bath and the sheet can be lifted from the tin onto rollers.

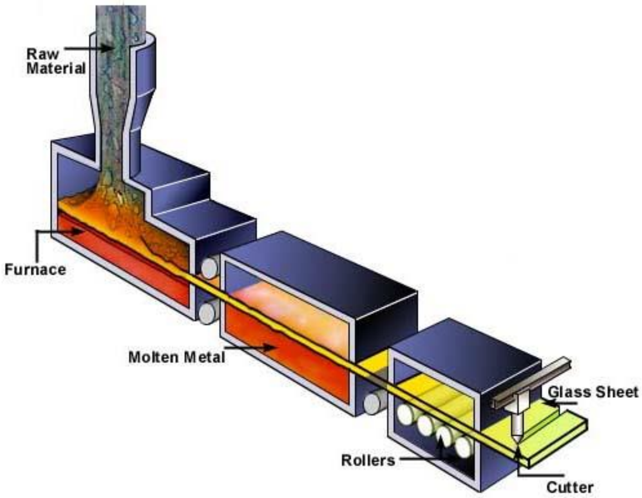

Figure 4: Float glass process.

The next phase is annealing, that is common to all glass products, even if it is performed with different furnaces. After annealing, the cooled down and solidified glass goes to the cutting area, where it is cut into a large sheet of 'jumbo size' (6×3.21 meters) or 'cut-size' which are specific to customer orders, before being stacked for transportation. The other main forming process used to produce flat glass, is called "Rolled glass process". It is used almost exclusively for solar panel glass, patterned flat glass and wired glass. It consists in pouring molten glass between water-cooled metal rollers, to produce a ribbon with pre-defined thicknesses and patterned surfaces.

The advantage of rolled glass is that it has high transmittance, making it is suitable for PV and solar thermal applications. It is also possible to introduce a surface structure on the surface of the glass, depending on the intended application, e.g. a burred surface structure is often used to enhance adhesive strength between EVA and glass in PV applications. Structured glass is used in both PV and thermo- solar applications.

The process to produce patterned glass is a single pass process in which glass flows to the rollers at a temperature of about 1,050°C. The bottom roller is engraved with the negative of the pattern; the top roller is smooth. Thickness is controlled by adjustment of the gap between the rollers.

Wired glass, mainly used for safety glasses, is made in a double pass process, by using two independently driven pairs of water cooled forming rollers each fed with a separate flow of molten glass from a common melting furnace. Both molten glass ribbons have half the thickness of the end product and the wire mesh is “sandwiched” between them. Then the final ribbon of wired glass is passed through a second pair of rollers. Also these processes are concluded with annealing in order to release the stresses from the material. There are other flat glass forming processes, but they are either covered in the special glass processes or the production volumes are so low to make them irrelevant for this work.

2.3.2 Hollow glass

Hollow glass for containers is mainly produced with two forming processes, called “Press and blow” (used for jars and tapered narrow neck containers) and “Blow and blow” (used for narrow neck containers) methods. For some large-neck containers (e.g. some domestic glass products) also the simple “Press” process in a single mould can be used, but it is less spread than the other two methods.

The first part is common to both methods: after the refining section, a stream of molten glass, at its plastic temperature (1,050–1,200°C) is cut to form a solid cylinder of glass, called a gob. The gob falls by gravity and it is guided into a blank mould. The two halves of the mould are clamped shut and sealed from above.

In the press and blow method, the gob in the mould is pressed by a plunger to form a blank shape (parison). Then the parison is transferred to blow mould, that has the shape of the final container and it is blown to its final shape.

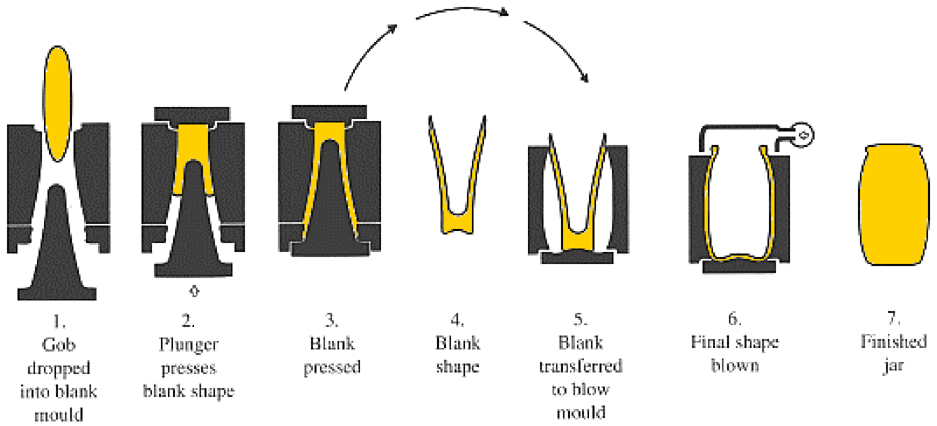

Figure 5: Hollow glass manufacturing - Press and blow method.

In the blow and blow method, the first stage is to blow the blank shape in the first mould with an air compressor. Then the parison is transferred to the second mould and it is blown to its final shape.

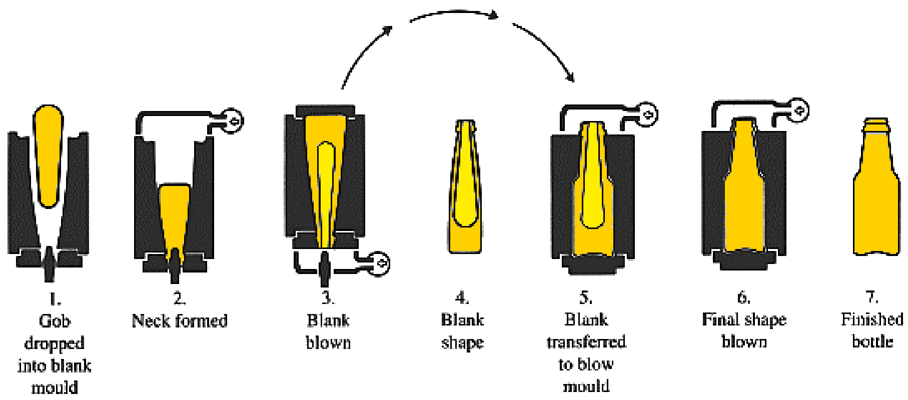

Figure 6: Hollow glass manufacturing - Blow and blow method.

After the forming section, the containers are sent to the annealing furnace, where the stresses are removed. Before (hot end) and/or after (cold end) annealing, surface treatments can be applied in order to improve the performances of the product. The coatings are generally applied to the outside surface of the containers. After that, there is a final inspection for quality control and the containers are packed onto pallets for storage and shipping.

2.3.3 Glass fibres

Glass fibres forming starts in the last section of the melting furnace, the forehearth, beneath which is located a series of four to seven bushings (blocks pierced with hundreds of holes) of platinum alloy that, in the forming phase, are used to extrude the molten glass into fibres.

Forming is achieved by drawing the molten glass flowing from the holes of the bushing at high speed. This forms between fifty and several hundred filaments with diameters from 5 to 13 microns.

In the final stage, a chemical coating or size, is applied. Size is typically added at 0.5 to 2.0 percent by weight and may include lubricants (protecting filaments from abrading and breaking), binders and/or coupling agents.

At the end, sized filaments are collected together into a bundle, forming a glass strand composed of 51 to 1,624 filaments. The strand is wound onto a drum into a forming package that is then dried in an oven, palletized and shipped or further processed into chopped fibre, roving or yarn.

A special kind of glass fibres is glass wool, that is produced using the Crown process, due to the fact that, from the forehearth, the glass flows from the bushing to a rotating dish called crown, which has several hundred fine holes round its periphery.

The molten glass is thrown out through the holes by centrifugal force and forms filaments, which are further extended into fine fibres by a high velocity blast of hot gas. After being sprayed with a suitable bonding agent, the fibres are drawn by suction onto a horizontally moving conveyor positioned below the rotating dish. The mat of tangled fibres is carried through an oven to activate the bonding agent, then it is cut to size. Glass wool is used for heat and sound insulation in buildings, transport vehicles and domestic appliances.

2.3.4 Special glass processes

Special glass processes cover a wide range of processes used for giving glass its final shape. The common point is that the production volume of this kinds of plants is very low when compared to the previous ones, so they won't be considered in detail in this work. Some of the processes for special glass production can be:

- Ribbon process (used for lightbulbs);
- Spinning process (used for some domestic glass products and other borosilicate glass);
- Pressing process (for lamp units);
- Extrusion processes (items with sharp-edged cross sections where dimensional tolerances are very small);
- Drawing process (e.g. for display glass);
- Casting process (optical glass blocks and other products).

2.3.5 Finishing and packaging

Secondary glass processing is performed after forming in order to release stress from the glass products or to give them some specific properties. The main secondary processes are:

- *Annealing*: since glass develops considerable stresses during cooling, to avoid break-downs during cutting it undergoes heat-treatment in a long furnace known as a Lehr. Temperatures are closely controlled both along and across the Lehr and the stresses are released ensuring perfect properties and solidity. Glass is then treated with coatings or lamination to enhance durability and strength;

- *Toughening*: toughening or tempering is used to further increase the resistance of glass to compression. Toughening process consists in re-heating the glass to a temperature slightly higher to the one at which deformation can occur and rapidly cooling it with an air jet. This allows to create a compressive tension between the inner layer of the glass and the outer layers, that improves the strength of the glass. In order to break such toughened or tempered glass, the compression has to be neutralised and additional tension applied. This process can be applied only on flat glass or smoothly curved one, with the condition that the thickness is uniform and not too low and the shape of the product allows to cool it uniformly. For glass containers, toughening is performed by putting the heated bottle/jar into a molten potassium salt, allowing potassium to replace sodium ions on the surface and, being larger, create a very thin layer of compression;
- *Coating and decorating*: glass can be coated with different materials and techniques in order to decorate it (e.g. enamelling) or to give it particular properties (e.g. lucidity, strength). There are several techniques and materials based on the desired final product.

Other different processes might be applied to special glasses, including cutting (flat glass) and curing (mineral wool). Glass product are then usually packed and made ready for shipping or storage.

2.4 Quality assurance

Quality assurance is carried through all the processing of glass. It usually starts at raw material reception, with the control of the quality and quantity of received materials. Then, in the furnace, some tests (density test, homogeneity test, bubble and seed count, stone count, spectrophotometric check of colour) are run in order to guarantee uniform properties of the molten bath. At the end port of the melting furnace, manual Quality Control starts, with dimensional and visual verification, repeated also at the cold end, weighing of the material, etc… After manual inspection, at the cold end, automatic inspection machines pass the products, in order to further verify their properties and the respect of standards and requirements. Some random samples can be taken and further mechanically tested in laboratories (e.g. for container glass: thermal shock, internal pressure, impact test, vertical load, annealing level, hot end coating level and cold end coating level). A random final visual inspection, after packaging, is carried on some sample products. An important aspect of the Quality Control is to verify that all the instruments are periodically calibrated and all the processes that a product underwent are properly traced.

3 Energy intensity of key processes

Glass industry is a very energy intensive sector. The most intensive process is the melting furnace, that can account up to 80% of the total energy consumption of the plant. The most used carriers in Glass industry are Electricity, Natural gas and Fuel oil. The energy carriers are used as shown in the Figure below.

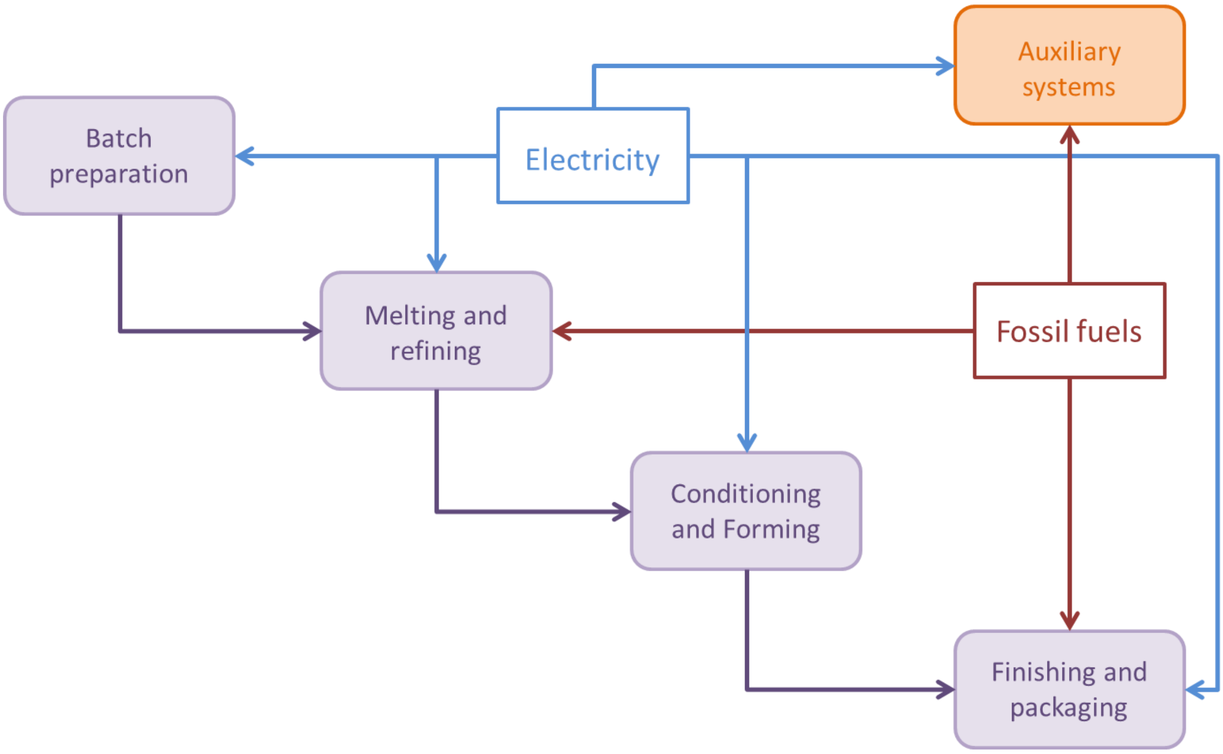

Figure 7: Energy carriers in the glass industry.

As shown, Electricity is used in all the phases of glass production, while thermal energy, in the form of combustion of fossil fuels, is mainly used in the Melting furnace and in the Annealing Lehr (finishing and packaging). Another use of fossil fuels is in the production of steam. According to BREF reference document for Glass Manufacturing, the average energy consumption can be summarized as follows:

Sector	Furnace type/capacity	GJ/tonne melted glass (1)	GJ/tonne finished product (2)
Container glass			
Bottles and jars	<100 t/d	5.5 – 7	<7.7
	>100 t/d	3.3 – 4.6	
	Electric furnaces	2.9 – 3.6	
Flacconage	<100 t/d	7 – 9	<16
	>100 t/d	4.8 – 6	
Flat glass			
	All capacities	5 – 7	<8
Continuous filament glass fibre			
	All capacities	7 – 14	<20
Domestic glass			
	Conventional furnaces		<24 for capacities <100 t/d (3) <18 for capacities >100 t/d
	<100 t/d (3)	6.7 – 9.5	
	>100 t/d	5 – 6	
	Electric furnaces (4)	3.4 – 4.3	
Special glass			
All products	Electric furnaces (4)	3.9 – 4.5	<20
Soda-lime glass	Conventional furnaces	5 – 10	
Borosilicate glass		10 – 15	
Mineral wool			
Glass wool	All capacities	2.7 – 5.5	<14
Stone wool	All capacities	4.2 – 10	<12
High Temperature Insulation Wool			
	All capacities	6.5 – 16.5	<20
Frits			
	Oxy-fired furnaces	≤9	
	Air/fuel and enriched air/fuel fired furnaces	≤13	

(1) Data refer to the furnace energy consumption.
(2) Data refer to the overall energy consumption of the installation.
(3) Values do not include installations equipped with pot furnaces or day tanks which energy consumption for the melting process may be in the range of 10 – 30 GJ/tonne melted glass.
(4) Data reported refer to energy at the point of use and are not corrected to primary energy.

Figure 8: Glass industry energy consumption by product.

By further splitting energy consumption by phases and type of furnace, the following table can be obtained:

Table 1: Energy consumption per phase.

Phase	Flat glass	Container Glass	Other Glass types*	Energy carrier
Batch preparation	3%	7%	6%	Electricity
Melting and refining	62%	78%	48%	Electricity/Fossil fuel
Conditioning and forming	14%	5%	29%	Electricity
Finishing and	21%	9%	16%	Electricity/Fossil fuel

packaging				

** This includes special glass, domestic glass, fiberglass of various types (average among specialty glass, wool fibers and textile fibers values).*

The share between electricity and fossil fuel for the phases of Melting and Finishing are dependent on both the required product and the type of furnace(s) and processes.

A simplified split can be the following:

Table 2: Energy carrier share per phase.

	Flat glass		**Container Glass**		**Other Glass types***	
Phase	Electricity	Fossil fuel	Electricity	Fossil fuel	Electricity	Fossil fuel
Batch preparation	100%	0%	100%	0%	100%	0%
Melting and refining	2%	98%	15%	85%	20%	80%
Conditioning and forming	100%	0%	100%	0%	20%	80%
Finishing and packaging	21%	79%	13%	87%	9%	91%

** This includes special glass, domestic glass, fiberglass of various types (average among specialty glass, wool fibers and textile fibers values).*

It has to be considered that, for more detailed analyses, the processes shall be further split by product.. The use of fossil fuels in forming section is partially done for fiberglass (around 74% of energy consumption of this phase is in the boiler) and specialty glass (around 92% of energy consumption of this phase is thermal).