
Category		Title
NFR	2.A.3	Glass production
SNAP	040613	Glass (decarbonizing)
ISIC	2610	Manufacture of glass and glass products
Version	Guidebook 2106	

Coordinator

Jeroen Kuenen

Contributing authors (including to earlier versions of this chapter)

Pieter van der Most, Otto Rentz, Sandrine Nunge, Carlo Trozzi, Tinus Pulles and Wilfred Appelman

Contents

1	Overview	3
2	Description of sources.....	3
2.1	Process description	3
2.2	Techniques.....	5
2.3	Emissions.....	9
2.4	Controls	11
3	Methods	12
3.1	Choice of method	12
3.2	Tier 1 default approach.....	13
3.3	Tier 2 technology-specific approach.....	14
3.4	Tier 3 Emission modelling and use of facility data	21
4	Data quality	23
4.1	Completeness.....	23
4.2	Avoiding double counting with other sectors	23
4.3	Verification.....	23
4.4	Developing a consistent time series and recalculation	24
4.5	Uncertainty assessment	24
4.6	Inventory quality assurance/quality control (QA/QC).....	24
4.7	Gridding.....	24
4.8	Reporting and documentation	24
5	Glossary.....	25
6	References	25
7	Point of enquiry	27

1 Overview

The present chapter concerns the process emissions released during the production of particular types of glass (flat glass, container glass, glass wool and other glass (including special glass)).

It is good practice, however, to report emissions from combustion activities within the glass industry under the combustion chapter 1.A.2.

The main emission from the production of glass is carbon dioxide (CO₂), originating mainly from the carbonisation process. However, since CO₂ is a greenhouse gas it is not considered in this Guidebook. Further guidance on the CO₂ emissions from glass production can be found in the IPCC Guidelines (IPCC, 2006). Other emitted pollutants include micro pollutants, heavy metals, black carbon (BC¹) and dust. Emission factors are given for process and combustion emissions together, since it is not straightforward to separate the two. However, large variations may apply depending on the glass composition, fuel type and furnace type and care should be taken in applying these factors.

2 Description of sources

This section provides a detailed overview of the processes and techniques in the glass industry, emitted pollutants and the controls applied to reduce those emissions. For a more detailed overview, please refer to the published Best Available Technique Reference (BREF) document on glass production (European Commission, 2001) or the draft revised BREF document (European Commission, 2008).

2.1 Process description

In the production of glass, different products can be distinguished, for instance flat glass, container glass, special glass, glass wool, continuous filament fibres, water glass and tableware. The smelting process for the different product groups is often similar.

The production of flat glass, container glass and glass fibres is dominated by large multinational companies, whereas domestic glass production (manufacture of table and decorative ware) in most cases takes place in small- and medium-sized enterprises. Unlike technical glass production, domestic glass production is characterised by a great diversity of products and processes, including hand forming of glass (Eichhammer *et al.*, 1994).

The manufacturing process of glass consists of the following steps (Schmalhorst and Ernas, 1995; Eichhammer *et al.*, 1994):

- Selection and controlling of raw materials.
- Preparation of raw materials, consisting essentially of a weighing and mixing operation. Sometimes water is added to avoid dust emissions; sometimes segregation and sorting are applied to remove pollutant components from the batch or recycled glass.
- Melting: the raw materials undergo fusion at high temperature in a furnace.
- Forming: the molten glass is given a shape and allowed to solidify (production of flat and container glass); the formation of fibres as continuous filaments or into glass wool mats is carried out (production of glass wool) by special fiberisation processes.

¹ For the purposes of this guidance, BC emission factors are assumed to equal those for elemental carbon (EC). For further information please refer to Chapter 1.A.1 Energy Industries.

- Curing for wool: the binder-coated fibreglass mat is allowed to cure (production of glass wool).
- Annealing: internal thermally induced stresses in the glass articles are removed by heat treatment.
- Finishing or post-processing. Examples of finishing include:
 - quality control and cutting (production of flat glass), application of coatings (hot and cold end) of container glasses plus inspection on glass faults (inclusions, dimension and shape checks);
 - cooling the glass wool mat, and backing, cutting, and packaging the insulation, as well as quality control (production of glass wool);
 - quality control, cutting, and for hand-shaped glass, further decorative treatment such as engraving or polishing (special glass);

Post processes may include tempering of glass or coatings application on glass surfaces to change optical or thermal insulation properties of flat glass products, to add functionality to the glass products or to increase scratch resistance of the glass surfaces.

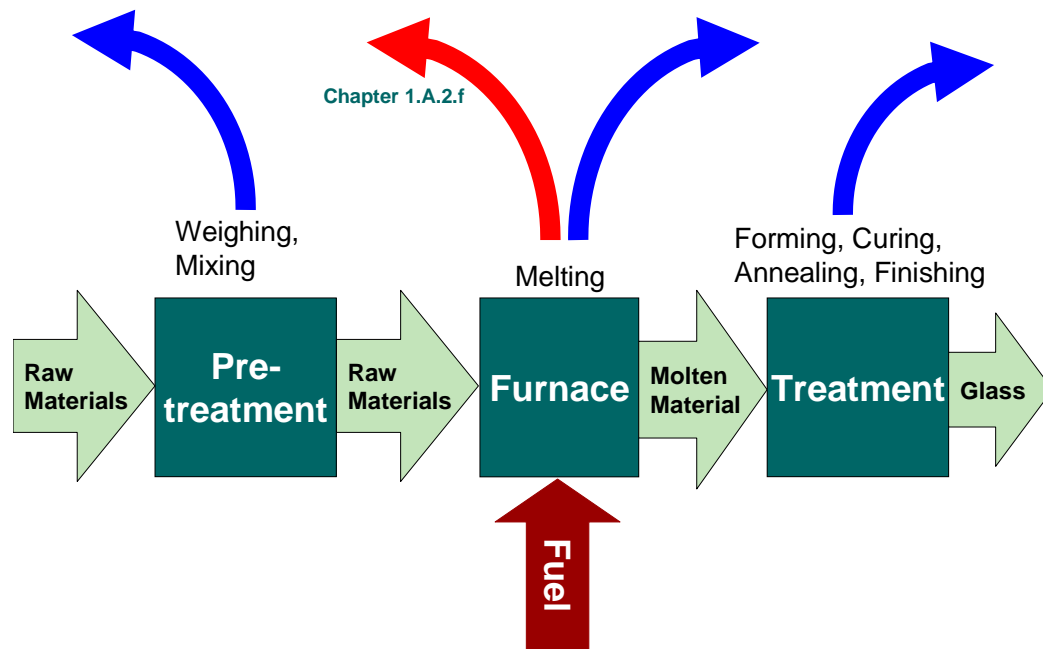
A large variety of glasses with differing chemical compositions are produced, and therefore a great diversity of raw materials is used in glass manufacturing (VDI Kommission Reinhaltung der Luft, 1997). The main raw materials are silica sand, lime or limestone, dolomite, recycled waste glass and soda for the production of soda lime silica glass, as well as lead oxide, potash and zinc oxide for the production of special glasses (UNECE, 1995). Glass wool is a boro-silicate based glass, which is manufactured from sand, limestone, dolomite, boric-oxide or sodium borates and other oxides. Refining agents such as antimony oxide, nitrates, sulphates, salts and colouring agents like metal oxides (e.g. selenium, cobalt, nickel, chromium, iron oxides) and sulphides enter also in the composition of special glass, e.g. television glass, crystal glass, etc. (VDI Kommission Reinhaltung der Luft, 1997).

At present, approximately 85 % of the glass produced in Europe is made up of soda lime silica based compositions and consists principally of flat and container glass. The remaining 15 % of the European glass production include glass wool, glass fibres and special glass such as hand-shaped glassware, lighting glass (tubes, bulbs), television screens, LCD flat glasses and optical glasses. (Abraham *et al.*, 1997)

Recycled glass is also largely used in the manufacturing of glass and represents typically between 20 and 25 % of the quantity of melted flat glass and up to 90 % of melted container glass. Throughout the industry, virtually all internally generated cullet is reused. The poor quality and contamination of external cullet virtually eliminates its use for flat, commodity and domestic glassware but much external cullet (with treatment) can be used in the container glass industry and glass wool (insulation wool) (Abraham *et al.*, 1997).

Currently, the majority of raw material is delivered to the glass production site in a prepared form; only broken glass pieces from recycling undergo processing steps such as sieving and sorting out of impurities and non-glass materials. The different materials are weighed and intensively mixed, and the mixed batch is transferred to the melting furnace.

Figure 2.1 Process scheme for 2.A.3 Glass production, applicable for the production of glass.



2.2 Techniques

For container glass production, the melting stage can be preceded by a pre-heating of the mixed batch.

The melting process is the most important step in order to achieve the required quality and quantity of glass. The melting process can take place in different furnace types with different design (Eichhammer et al., 1994). In the melting furnaces, the glass is melted at temperatures ranging from 1 300 °C to 1 650 °C (the flame temperature achieving more than 2 000 °C) and transformed through a sequence of chemical reactions into molten glass. Although there are many different furnace designs, furnaces are generally large, shallow, and well-insulated vessels (melting tanks) that are heated in most cases by fossil fuel combustion from above. In operation, raw materials are introduced continuously on top of a bed of molten glass, where they slowly mix and dissolve. Mixing is effected by natural convection, gases rising from chemical reactions, and, in some operations, by air injection into the bottom of the tank (US EPA, 1995). In the glass production, both continuously (> 95 % of the glass production) and batch-wise (< 5%) operated melting furnaces are in use. In large glass manufacturing installations, flat and container glass production, and where the forming processes are fully automated, refractory lined tank furnaces are operated in the continuous mode. For the production of smaller quantities of glass, especially for hand-shaped glassware, the batch operating mode is preferred since molten glass gobs have to be sampled from the pot furnace by handicraft operation (Eichhammer et al., 1994; VDI Kommission Reinhaltung der Luft, 1997).

Some characteristics of the above mentioned furnaces are summarised in the Table 2.1.

Table 2.1 Some characteristics of furnaces used in glass production (VDI Kommission Reinhaltung der Luft, 1997; Landesgewerbeanstalt Bayern, 1994).

Type of furnace	Type of firing	Energy source	Operating mode	Capacity [Mg/d]
Single or multi-pot	Flame or electrically heated	Gas, oil, electricity	Batch	0.1–35
Day tank	Flame or electrically heated	Gas, oil, electricity	Batch	0.1–3
Tank furnace	Flame or electrically heated	Gas, oil, electricity	Continuous	2–900

In order to achieve higher energy efficiency and a higher flame temperature, the combustion air is preheated. Air preheaters in use are recuperative or regenerative (Nölle, 1997; Teller and Hsieh, 1992). Glass melting furnaces use natural gas and/or oil as a fuel, since the use of hard coal or lignite would result into an import of molten ash in the glass phase, and would subsequently lead to a lower product quality and would block the refractory lattice of the regenerators or the recuperators (Abraham et al., 1997). For the production of container glass in Europe, both oil and natural gas are used for the furnace. City gas or liquefied gas (like propane) is used in a few isolated cases (VDI, 1998).

The furnace most commonly used within flat glass production is a cross-fired furnace with regenerative preheating working in the continuous mode; very few exceptions with end-fired furnaces do exist in the production of printed glass (Abraham *et al.*, 1997). In container glass production, mostly regeneratively heated furnaces with burner ports at one end (end-port fired regenerative furnaces) are in use (Abraham et al., 1997).

Additional electric heating (by electrodes submerged/immersed into the melt) is frequently employed to increase output and to cope with peak-load demands and to heat the deeper glass melt layers in the melting tank in case of coloured glass types. Between 0 and 30 % of the total required melting energy is passed in the form of electrical energy directly into the glass batch through electrodes (VDI, 1998). Some furnaces are completely electrically heated and use the cold-top all electric furnace types.

Table 2.2 Specific energy demand for the production of glass (source: European Commission, 2008).

Type of glass	Specific energy demand [GJ/Mg glass]
Flat glass	5.5–8
Container glass	5–15.8
Glass wool	9–20
Special glass *	12–15

* Since this is a very diverse sector, a general number on energy consumption is hard to give and the value may deviate significantly from the energy demand given in this table.

However, more advanced glass furnaces do exist with lower specific energy demands (for example around 4 GJ/Mg (VDI, 1998) in the production of container glass).

2.2.1 Glass wool manufacturing process

In the 'indirect' melting process for wool manufacturing, molten glass passes to a fore hearth, where it is drawn off, sheared into small globs and formed into marbles by roll-forming. The marbles are then stress-relieved in annealing ovens, cooled, and conveyed to storage or to further processing in other plants. In the 'direct' glass fibre process, molten glass passes from the furnace into a refining unit and fore hearths, where the melt is allowed to cool to the proper viscosity for the fibre forming operation (US EPA, 1995).

During the formation of fibres into a wool fibreglass mat (the process is known as 'forming' in the industry), glass fibres are made from molten glass and a chemical binder is simultaneously sprayed on the fibres as they are created. Although the binder composition varies with product type, typically the binder consists of a solution of phenol-formaldehyde resin, water, urea, lignin, silane and ammonia. Colouring agents may also be added to the binder. Two methods of creating fibres are used by the industry. In the rotary spin process, centrifugal force causes molten glass to flow through small holes in the surrounding wall of a rapidly rotating cylinder to create fibres that are broken into pieces by an air stream. This is the newer of the two processes and dominates the industry today. In the flame attenuation process, molten glass flows by gravity from a furnace through numerous small orifices to create threads which are then attenuated (stretched to the point of breaking) by high velocity, hot air and/or a flame (US EPA, 1995).

2.2.2 Gas- and oil-fired glass melting furnaces with regenerative air preheating

The common feature of all tank furnaces is a large ceramic (high-duty refractory materials) tank which serves as a melting container. Most tank furnaces are operated by alternating flame-heating based on the regenerative principle (VDI, 1998), and some furnaces apply oxygen firing without preheating or use combustion air preheated by continuous operating metallic flue gas — air heat exchangers: recuperators.

Regenerative air preheaters use a lattice of brickwork to recover waste heat from the exhaust gas. The regenerator systems are made up of two chambers, each of them consisting of a refractory lattice; the chamber walls and the mentioned lattice represent the heat storing material, which transfers the heat indirectly from the waste gas to the combustion air. At one stage of the cycling procedure, hot waste gas is lead from the furnace to one of these chambers, whereby the lattice is warmed up. The combustion air enters the furnace via the other chamber preheated in a previous stage. In the next stage, combustion air flow and the waste gas flow are then reversed: the combustion air flows then through the preheated chamber and is heated there, while the waste gas flows through the second chamber (cooled by the air in the previous stage), reheating the refractory lattice. The temperature of the incoming air achieves up to 1 150–1 350 °C, and the waste gas leaves the regenerative chambers with a temperature of about 450–600 °C (VDI Kommission Reinhaltung der Luft, 1997; Kircher, 1993).

The arrangement of the burners and the position of the flames differentiate cross-fired from end-fired tanks (VDI, 1998). Because of the higher number of burner necks (burner / exhaust gas ports with heat losses) and smaller residence times of the flames in the combustion chamber, the specific energy consumption is generally higher for cross-fired furnaces than for comparable end-fired furnaces (VDI Kommission Reinhaltung der Luft, 1997). Medium-sized tanks are built as end-fired tanks, larger ones as cross-fired burner tanks. Small tank furnaces apply recuperators for combustion air preheating. More and more furnaces use oxygen instead of preheated air for combustion to save (in some case) energy, to reduce nitrogen oxide (NO_x) emissions or to improve glass quality. In all arrangements, the flames flow closely over the molten glass surface and transmit heat to it, primarily by radiation (VDI, 1998).

Cross-fired furnaces give better control of melting chamber temperature profiles and oxidation state and therefore predominate in the larger throughput and 'quality glass' furnaces. Cross-fired furnaces are used exclusively in float glass furnaces and in the larger container furnaces, whereas for melting surfaces up

to 140 m² furnaces are laid down as end-fired furnaces, since they show a simpler arrangement, a lower price and higher energy efficiency than comparable cross-fired furnaces (VDI Kommission Reinhaltung der Luft, 1997). Furnaces for smaller pull (typically below 150–200 tons molten glass per day) often use recuperators for air preheating or apply oxygen gas.

2.2.3 Gas- and oil-fired glass melting furnaces with recuperative air preheating

Another configuration of the tank furnace is the recuperatively heated glass melting tank. Recuperative air preheaters use most commonly a steel heat exchanger, recovering heat from the exhaust gas by exchange with the combustion air; the preheating temperature can reach up to 800 °C (VDI Kommission Reinhaltung der Luft, 1997), but are generally around 600–750 °C. Here, the hot waste gas and the cold combustion air flow through two parallel but separated ducts, and the heat exchange is performed via the separation wall. Unlike regenerative heating furnaces, the combustion is not interrupted and the waste gas is continuously recuperated via the heat exchanger. In order to achieve an optimal energy use, the flue gas flows from recuperators are sometimes connected to waste heat boilers for steam or hot water generation (Kircher, 1993). The lower flame temperatures achieved (compared with those from regenerative systems) limits their use in the higher quality glasses (e. g. float glass) or high specific pull (many container glasses). Recuperatively heated furnaces are generally of cross-fired configuration and generally less energy efficient than regenerative furnaces (Abraham *et al.*, 1997).

2.2.4 Pot furnaces

The use of pot furnaces is confined to manually worked specialty glasses, with intermittent operation and melting temperatures under 1 460 °C. One furnace is usually comprised of several pots permitting simultaneous melting of several types of glass. Flame-heated regeneratively and recuperatively operated furnaces, as well as electrically heated furnaces, are put to use here. City gas, natural gas, liquefied gases and light oil as well as electricity are used as heat energy. The specific energy consumption (relative to glass production) of pot furnaces is comparatively high and averages 30 GJ/Mg glass produced (Jockel and Hartje, 1991).

2.2.5 Electric furnaces

Electric furnaces melt glass by passing an electric AC-current through the melt. Electric furnaces are either hot-top or cold-top. The former use gas for auxiliary heating while the latter use only the electric current (US EPA, 1995). Electric heating is used either for additional heating (electric boost) or almost exclusively without fossil fuel combustion in small- and medium-sized furnaces for the manufacturing of special glass such as lighting glass, glass fibres and crystal glass (Nölle, 1997; Teller and Hsieh, 1992).

2.3 Emissions

2.3.1 Combustion-related emissions (covered in chapter 1.A.2)

Pollutants released during the manufacture of glass are sulphur oxides (SO_x), nitrogen oxides (NO_x), in very rare cases carbon monoxide (CO), carbon dioxide (CO₂) or nitrous oxide (N₂O). Also emissions of heavy metals are produced by the melting process. Emissions of particulate matter can also result from handling raw materials. Heavy metals can sometimes be present in the particulate matter. The main relevant pollutants are SO₂, NO_x, and CO₂.

The waste gases released from melting furnaces consist mainly of combustion gases generated by fuels and of gases arising from the melting of the batch or vapour released from the melt, which in turn depends on chemical reactions taking place in the furnace. The proportion of batch gases from exclusively flame-heated furnaces represents 3–5 % of the total gas volume (VDI, 1998).

2.3.1.1 Sulphur oxides

The amount of SO₂ released during glass manufacturing is mainly determined by the sulphur content of the fuel, the sulphur content in the batch and the sulphur absorption ability of the glass produced (VDI, 1998; Gitzhofer, 1993).

The sulphur added to the batch is partly bound in the glass as SO₃ or sulphide in the reduced molten glasses. Glass contains up to 0.4 wt.% SO₃ (VDI, 1998). The SO₃ content in the flue gases is 5–10 % of the SO₂ content. The amount of SO₃ depends on the excess air.

The SO₂ content in the off-gas is also determined by the operating conditions of the glass melting tank. With tank furnaces operated by alternating flame heating, based on the regenerative principle, an increase of the SO₂ content in the off-gas during the firing interval is observed. This is most likely due to enhanced sulphate decomposition at temporarily reduced combustion conditions, a decrease in the sulphur absorption ability of the molten glass with an increasing temperature in the upper zone of the furnace, and evaporation of already condensed sulphur species in the air preheater (Gitzhofer, 1993). The oxygen content in the combustion space of the furnace also has an impact on the SO₂ content of the off-gas: if the amount of excess air is decreased, in order to minimise fuel input and to suppress NO_x formation, an increase in the SO₂ content of the off-gas may be observed. This is due to the fact that the sulphur absorption ability of the molten glass falls with decreasing oxygen content in the upper furnace zone (Gitzhofer, 1993) and due to sulphate decomposition in the gas atmospheres containing reduced species such as hydrocarbons and CO.

Since natural gas and city gas contain only trace amounts of sulphur, a much lower SO₂ content in the off-gas of glass melting tanks fired with gaseous fuels is observed compared to oil fired glass melting tanks.

2.3.1.2 Nitrogen oxides

The relevant NO_x emission process step within the production of glass is the melting stage. NO_x emissions released by glass furnaces are nitric oxides (NO to about 90 % due to the near stoichiometric operation of the furnaces, the remainder of the NO_x in the flue gases being nitrogen dioxide (NO₂)). The concentrations of nitrous oxide in glass furnace waste gases are in general below the detection limit (Quirk, 1997).

Four main NO_x formation mechanisms exist. Three of them are combustion related and include thermal, fuel and prompt NO_x formation. The fourth mechanism (the 'batch' NO_x formation) results from the use of

nitrites in the raw materials for certain glasses. (Quirk, 1997) In the glass melting furnace, the glass melting temperature ranges from typically 1 350 °C to 1 600 °C (VDI Kommission Reinhaltung der Luft, 1997), leading to flame temperatures above 2 000 °C (Abraham et al., 1997). This explains the presence of high NO_x concentrations, almost exclusively due to thermal NO_x formation (according to the Zeldovich mechanism). Several parameters influence the mechanism of thermal NO_x formation: flame temperature, type of fuel (gas firing gives higher maximum flame temperatures than oil firing), oxygen content in the flame reaction zone, and retention time of the combustion gas in high temperature zones of the flame. These parameters are in direct relation with operating parameters as for example type of burner, burner positions, burner settings and melting furnace design, amount of excess air, mixing of fuel and combustion air, air velocity, etc. (Kircher, 1993; Flamme, 1993; Flamme and Haep, 1994). Prompt NO_x formation is relatively small and when firing natural gas, fuel NO_x is sensibly zero (Quirk, 1997).

The release of nitrogen compounds during heating of the nitrate containing raw materials and in the refining agents also contributes to NO_x emissions. The quantity of nitrogen oxides arising from the feed material will be affected by the concentration and composition of the nitrates in the feed (Her Majesty's Inspectorate of Pollution, 1992). For example, certain tinted glasses in the flat glass sector require the use of nitrates, which produce additional NO_x emissions almost as great as uncontrolled emissions from a clear flat glass operation: typical emissions might be 2 500 mg/Nm³ for clear glass and 4 000 mg/Nm³ for tint glass (UNECE, 1998). It must be acknowledged that such tints may be only occasionally manufactured. In the special glass industry, melting of much oxidized glasses or using fining agents such as antimony oxide or cerium oxide, requires addition of nitrates to the batch. This increases the NO_x emissions for these furnaces.

When using gas-fired glass melting tanks, the flame temperature achieved is higher compared to oil. As a consequence, oil-fired tanks emit less NO_x than gas fired tanks. Moreover, as end-fired furnaces have different flame characteristic from cross-fired glass melting furnaces, the former often show lower NO_x emissions. Recuperative furnaces induce lower NO_x emissions (if expressed in mg/Nm³, not in kg/ton) than regenerative furnaces, due to their lower preheating temperature (Kircher, 1993), but because of the increased energy consumption of recuperative furnaces (they are less energy efficient) the specific NO_x emissions (per ton molten glass) may be almost the same as for regenerative furnaces.

2.3.2 Process-related emissions

The most important source of atmospheric emissions is the hot furnace. The heavy metals from the raw materials or the fuel partly vaporize in the hot furnace. The heavy metals, depending on type of glass and raw materials, which are emitted to air, may be arsenic (in very few cases), lead and selenium.

If fuel oil or petroleum coke is used in the combustion process nickel and vanadium may also be found. In some areas of the world, fluorspar is often used as a flux in the melting process. If recycled glass originating from these countries is used in the batch some extra fluorine (HF) may be emitted.

Basic materials for glass production are silica and oxides of alkali metals or earth-alkali metals. The alkali metal oxides are produced during the process from dissociation of carbonates. The CO₂ emission factors given under Leendertse (1998) are calculated from the amount of carbonates added in general in the production process of the different types of glass, assuming that all metal oxides have their origin in carbonates and that no recycled glass is added. If, however, oxides, hydro carbonates, sulphates, or relevant amounts of recycled glass are used, adaptations to these factors must be made.

2.3.3 Heat demand

The actual energy requirements experienced in the various sectors vary widely from about 3.5 to over 40 GJ/tonne. This figure depends very heavily on the furnace design, type of glass product, pull rate, amount of glass recycling, scale and method of operation. However, the majority of glass is produced in large furnaces and the energy requirement for melting is generally below 8 GJ/tonne. More information about the energy use of the glass production process can be found in the draft revised BREF document for the glass industry (European Commission, 2008). Most energy in glass factories is used for the melting process, although with glass fibre or glass wool production, forming and curing/drying processes also require significant amounts of energy.

2.4 Controls

Emission reduction measures in the glass industry include primary and secondary reduction measures, mostly aiming at reducing emissions of NO_x and SO_x. These include:

- lowering the amount of excess air;
- reduced air preheating;
- staged combustion;
- flue gas recirculation;
- reburning / 3R process;
- low NO_x glass melting furnaces;
- oxy-fuel firing;
- electric melting;
- Selective Non-Catalytic Reduction (SNCR);
- Selective Catalytic Reduction (SCR).

An extended description of the control technologies that may be applied in the glass industry can be found in the BREF document for the Glass Industry (European Commission, 2001) or the draft revised BREF document (European Commission, 2008).

Measures for decreasing emissions to air from the combustion process may also result in a reduction of the heavy metal and dust emissions. Dust emissions from handling raw materials can be reduced using fabric filters or using different improved handling techniques. The emissions of carbon dioxide from the carbonisation process can be reduced by adding more recycled glass or using non-carbonate basic materials and by fossil fuel energy saving measures.

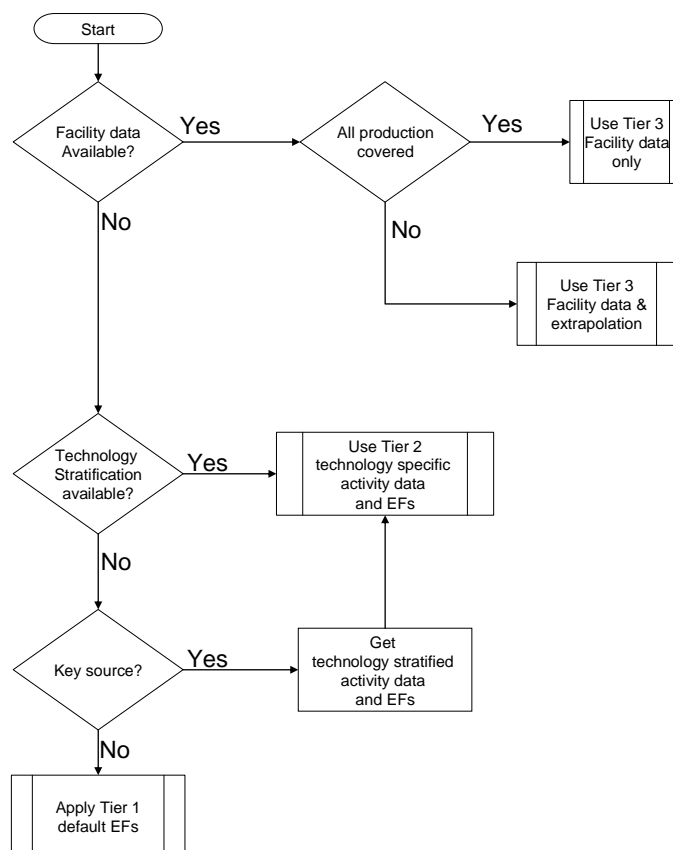
3 Methods

3.1 Choice of method

Figure 3.1 presents the procedure to select the methods for estimating process emissions from the glass industry. The basic procedure is as follows:

- If detailed information is available: use it.
- If the source category is a key category, a Tier 2 or better method must be applied and detailed input data must be collected. The decision tree directs the user in such cases to the Tier 2 method, since it is expected that it is more easy to obtain the necessary input data for this approach than to collect facility level data needed for a Tier 3 estimate
- The alternative Tier 3 method (detailed process modelling) is not explicitly included in this decision tree. However, detailed modelling will always be done at facility level and results of such modelling could be seen as 'facility data' in the decision tree.

Figure 3.1 Decision tree for source category 2.A.3 Glass production.



3.2 Tier 1 default approach

3.2.1 Algorithm

The Tier 1 approach for process emissions from glass production uses the general equation:

$$E_{\text{pollutant}} = AR_{\text{production}} \times EF_{\text{pollutant}} \quad (1)$$

Where:

$E_{\text{pollutant}}$	=	the emission of the specified pollutant
$AR_{\text{production}}$	=	the activity rate for the glass production
$EF_{\text{pollutant}}$	=	the emission factor for this pollutant

This equation is applied at the national level, using annual national total glass production. Information on the production of glass, suitable for estimating emissions using the simpler estimation methodology (Tier 1 and 2), is widely available from United Nations statistical yearbooks or national statistics.

The Tier 1 emission factors assume an averaged or typical technology and abatement implementation in the country and integrate all the sub-processes in glass production between inputting the raw material and the final shipment off the facilities.

In cases where specific abatement options are to be taken into account a Tier 1 method is not applicable and a Tier 2 or Tier 3 approach must be used.

3.2.2 Default emission factors

For the purposes of this guidance, BC emission factors are assumed to equal those for elemental carbon (EC). For further information please refer to Chapter 1.A.1 Energy Industries.

Table 3.1 contains the reported default emission factors for glass production (including emissions from both melting and non-melting activities). The emission factors are the result of an assessment of the emission factors from flat and container glass, since these two sectors together represent 80 % of the European glass industry (European Commission, 2008). An average distribution of two-thirds container glass and one-third flat glass has been used.

Care should be taken not to report the same emissions under both chapter 1.A.2.g.i and the present source category. Emission factors for the main air pollutants, such as NO_x and SO_x are assumed to originate mainly from combustion and are therefore addressed in chapter 1.A.2.g.i. All other emissions from the glass production process are treated in the present chapter using the Tier 1 approach, to avoid the possible risk of double counting between this chapter and the combustion chapter 1.A.2.g.i.

In reality, however, there will be SO_x emitted from the process. For glass production in general, the SO_x emission typically ranges from 0.4 – 2 kg/ton glass (Beerkens, 2008).

Emissions of fluorine and chlorine also originate from the production of glass. However, since these are not in the reporting requirements, they are not considered in the Guidebook.

The emission of lead often depends on the amount of recycled external glass used and of the cullet quality (Beerkens, 2008).

For the purposes of this guidance, BC emission factors are assumed to equal those for elemental carbon (EC). For further information please refer to Chapter 1.A.1 Energy Industries.

Table 3.1 Tier 1 emission factors for source category 2.A.3 Glass production

Tier 1 default emission factors					
	Code	Name			
NFR source category	2.A.3	Glass production			
Fuel	NA				
Not applicable	HCH, PCBs				
Not estimated	NO _x , NMVOC, SO _x , NH ₃ , CO, PCDD/F, Benzo(a)pyrene, Benzo(a)fluoranthene, Benzo(k)fluoranthene, Indeno(1,2,3-cd)pyrene, HCB				
Pollutant	Value	Unit	95 % confidence interval		Reference
			Lower	Upper	
TSP	300	g/Mg glass	100	600	Average between flat and container glass
PM ₁₀	270	g/Mg glass	90	540	Visschedijk et al (2004) applied on TSP
PM _{2.5}	240	g/Mg glass	80	480	Visschedijk et al (2004) applied on TSP
BC	0.062	% of PM _{2.5}	0.031	0.12	US EPA (2011, file no.: 91143)
Pb	1.7	g/Mg glass	0.1	15	Average between flat and container glass
Cd	0.13	g/Mg glass	0.01	0.28	Average between flat and container glass
Hg	0.003	g/Mg glass	0.0003	0.039	Average between flat and container glass
As	0.19	g/Mg glass	0.01	1.1	Average between flat and container glass
Cr	0.23	g/Mg glass	0.01	2.3	Average between flat and container glass
Cu	0.007	g/Mg glass	0.001	0.011	Average between flat and container glass
Ni	0.49	g/Mg glass	0.02	1	Average between flat and container glass
Se	0.8	g/Mg glass	0.02	8.9	Average between flat and container glass
Zn	0.37	g/Mg glass	0.13	0.56	Average between flat and container glass

Note: the emission of lead is mainly determined by the amount of recycled glass used (Beerkens, 2008).

3.2.3 Activity data

Information on the production of glass, suitable for estimating emissions using the (simpler) Tier 1 methodology, is widely available from United Nations statistical yearbooks or national statistics.

Further guidance is provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, volume 3 on Industrial Processes and Product Use (IPPU), chapter 2.4.1.3 'Choice of activity data'.

3.3 Tier 2 technology-specific approach

3.3.1 Algorithm

The Tier 2 approach is similar to the Tier 1 approach. To apply the Tier 2 approach, both the activity data and the emission factors need to be stratified according to the different types of glass production (here referred to as "technologies") that may occur in the country.

The Tier 2 approach is as follows:

Stratify the glass production in the country to model the different product and process types occurring in the national glass industry into the inventory by:

- defining the production using each of the separate glass types (together called 'technologies' in the formulae below) separately;

- applying technology-specific emission factors for each process type:

$$E_{\text{pollutant}} = \sum_{\text{technologies}} AR_{\text{production,technology}} \times EF_{\text{technology,pollutant}} \quad (2)$$

where:

$AR_{\text{production,technology}}$	=	the production rate within the source category, using this specific technology
$EF_{\text{technology,pollutant}}$	=	the emission factor for this technology and this pollutant

A country where only one technology is implemented will result in a penetration factor of 100 % and the algorithm in equation (3) reduces to:

$$E_{\text{pollutant}} = AR_{\text{production}} \times EF_{\text{technology,pollutant}} \quad (3)$$

where:

$E_{\text{pollutant}}$	=	the emission of the specified pollutant
$AR_{\text{production}}$	=	the activity rate for the glass production
$EF_{\text{pollutant}}$	=	the emission factor for this pollutant

The emission factors in this approach will still include all sub-processes within the industry from inputting raw materials until the produced glass is shipped to the customers.

3.3.2 Technology-specific emission factors

This sub-section presents the technology-specific emission factors needed to apply a Tier 2 approach for estimating process emissions from glass production. A BREF document for this industry is available at <http://eippcb.jrc.es/pages/FActivities.htm> – see Section 4.3.1

Emission factors in the BREF documents are mostly given in ranges. The range is interpreted as the 95 % confidence interval, while the geometric mean of this range is chosen as the value for the emission factor in the tables below.

For the purposes of this guidance, BC emission factors are assumed to equal those for elemental carbon (EC). For further information please refer to Chapter 1.A.1 Energy Industries.

3.3.2.1 Production of flat glass

Table 3.2 provides emission factors for flat glass production. Emission factors for heavy metals are based on averages of measurements from European glass facilities (Rivet, 2008). Also SO_x is emitted from the process, but SO_x emissions from the glass industry are reported under chapter 1.A.2.g.i to avoid the risk of double counting of emissions as much as possible. The emission factors for total solid particulates (TSP) are taken from the draft revised BREF document for the glass industry (European Commission, 2008). The PM₁₀ and PM_{2.5} emissions are calculated from the TSP emission factor using Coordinated European Particulate Matter Emission Inventory Program (CEPMEIP) fractions (Visschedijk et al., 2004).

Table 3.2 Tier 2 emission factors for source category 2.A.3 Glass production, flat glass

Tier 2 default emission factors					
	Code	Name			
NFR source category	2.A.3	Glass production			
Fuel	NA				
SNAP (if applicable)	030314 Flat glass				
Technologies/Practices	Flat glass production				
Region or regional conditions					
Abatement technologies	Abated furnaces (primary/secondary methods)				
Not applicable	HCH, PCBs				
Not estimated	NO _x , NMVOC, SO _x , NH ₃ , CO, PCDD/F, Benzo(a)pyrene, Benzo(a)fluoranthene, Benzo(k)fluoranthene, Indeno(1,2,3-cd)pyrene, HCB				
Pollutant	Value	Unit	95 % confidence interval		Reference
			Lower	Upper	
TSP	130	g/Mg glass	20	800	European Commission (2008)
PM ₁₀	120	g/Mg glass	18	720	Visschedijk et al (2004) applied on TSP
PM _{2.5}	100	g/Mg glass	16	640	Visschedijk et al (2004) applied on TSP
BC	0.062	% of PM _{2.5}	0.031	0.12	US EPA (2011, file no.: 91143)
Pb	0.4	g/Mg glass	0.23	0.68	Rivet (2008)
Cd	0.068	g/Mg glass	0.01	0.25	Rivet (2008)
Hg	0.003	g/Mg glass	0.001	0.039	Rivet (2008)
As	0.08	g/Mg glass	0.01	0.18	Rivet (2008)
Cr	0.08	g/Mg glass	0.01	0.13	Rivet (2008)
Cu	0.007	g/Mg glass	0.001	0.011	Rivet (2008)
Ni	0.74	g/Mg glass	0.54	0.97	Rivet (2008)
Se	0.15	g/Mg glass	0.02	0.4	Rivet (2008)
Zn	0.37	g/Mg glass	0.13	0.56	Rivet (2008)

Please be aware that hydrochloric acid (HCl) and hydrogen fluoride (HF) are also emitted from a glass production facility but these are not considered in the present Guidebook. In case of oil-firing, vanadium may be emitted and nickel emissions will also be higher.

Again, emissions of NO_x and SO_x originate from combustion activities and it is good practice to report these emissions in chapter 1.A.2.g.i. Please find the relevant combustion emission factors in that chapter.

3.3.2.2 Production of Container Glass

For the production of container glass, default emission factors are provided in Table 3.3. Emission factors are mainly taken from the revised BREF document for the glass industry (European Commission, 2008), while the PM₁₀ and PM_{2.5} fractions are calculated using the CEPMEIP particulates study (Visschedijk et al., 2004).

Table 3.3 Tier 2 emission factors for source category 2.A.3 Glass production, container glass

Tier 2 default emission factors					
	Code	Name			
NFR source category	2.A.3	Glass production			
Fuel	NA				
SNAP (if applicable)	030315 Container glass				
Technologies/Practices	Container glass production				
Region or regional conditions					
Abatement technologies	Primary measures; without secondary abatement				
Not applicable	HCH, PCBs				
Not estimated	NO _x , NMVOC, SO _x , NH ₃ , CO, Hg, Cu, Zn, PCDD/F, Benzo(a)pyrene, Benzo(a)fluoranthene, Benzo(k)fluoranthene, Indeno(1,2,3-cd)pyrene, HCB				
Pollutant	Value	Unit	95 % confidence interval		Reference
			Lower	Upper	
TSP	280	g/Mg glass	100	580	European Commission (2008)
PM ₁₀	250	g/Mg glass	90	520	Visschedijk et al (2004) applied on TSP
PM _{2.5}	220	g/Mg glass	80	460	Visschedijk et al (2004) applied on TSP
BC	0.062	% of PM _{2.5}	0.031	0.12	US EPA (2011, file no.: 91143)
Pb	2.9	g/Mg glass	0.1	15	European Commission (2008)
Cd	0.12	g/Mg glass	0.07	0.28	European Commission (2008)
As	0.29	g/Mg glass	0.01	1.1	European Commission (2008)
Cr	0.37	g/Mg glass	0.02	2.3	European Commission (2008)
Ni	0.24	g/Mg glass	0.02	1	European Commission (2008)
Se	1.5	g/Mg glass	0.075	8.9	European Commission (2008)

As for the flat glass section, it must be stressed that also HCl and HF are emitted, but since these are not necessary for the national inventory they are omitted here. It is good practice to report emissions of SO_x and NO_x in source category 1.A.2.g.i.

3.3.2.3 Production of glass fibres

Appropriate emission factors for use with the production of glass fibres are provided in Table 3.4 below. Only emission factors for particulates are available; emission factors for individual heavy metals are not available. The emission factor for TSP is taken from the revised BREF document for the glass industry (European Commission, 2008). Emission factors for PM₁₀ and PM_{2.5} are estimated using the CEPMEIP particle size distribution (Visschedijk et al., 2004).

Particulate emissions of glass fibre ovens can show a high variation, depending on the exact definition of particulate matter, because the vapours from the glass fibre ovens can condensate to dust particles over a large temperature range. The emission factors given in the table below should therefore be used with care.

The BREF document does, however, provide information on emissions of metal groups. The emission factors for these groups may be useful for verification.

Table 3.4 Tier 2 emission factors for source category 2.A.3 Glass production, glass fibres

Tier 2 default emission factors					
	Code	Name			
NFR source category	2.A.3	Glass production			
Fuel	NA				
SNAP (if applicable)	030317 Other glass				
Technologies/Practices	Continuous filament glass fibres				
Region or regional conditions					
Abatement technologies	Primary measures; without secondary abatement				
Not applicable	HCH, PCBs				
Not estimated	NO _x , NMVOC, SO _x , NH ₃ , CO, Hg, Cu, Zn, PCDD/F, Benzo(a)pyrene, Benzo(a)fluoranthene, Benzo(k)fluoranthene, Indeno(1,2,3-cd)pyrene, HCB				
Pollutant	Value	Unit	95 % confidence interval		Reference
			Lower	Upper	
TSP	100	g/Mg glass	30	350	European Commission (2008)
PM ₁₀	90	g/Mg glass	27	315	Visschedijk et al (2004) applied on TSP
PM _{2.5}	70	g/Mg glass	21	280	Visschedijk et al (2004) applied on TSP
BC	2	% of PM _{2.5}	1	4	US EPA (2011, file no.: 91142)

3.3.2.4 Production of glass wool

Appropriate emission factors for use with the production of glass wool are provided in Table 3.5 below. These are taken from the revised BREF document for glass production (European Commission, 2008). It is good practice to take care not to double count these emissions with the emissions reported under source category 1.A.2.g.i (Combustion in Manufacturing Industries).

Glass wool products usually contain a proportion of phenol-resin-based binder. The binder solution is applied to the fibres in the forming area and is cross-linked and dried in the curing oven. The forming area waste gas will contain particulate matter, phenol, formaldehyde and ammonia. The particulate matter consists of both organic and inorganic material, often with a very small particle size. Lower levels of VOC and amines may also be detected if they are included in the binder system. Due to the nature of the process, the gas stream has a high volume and high moisture content. The releases from the oven will consist of volatile binder materials, binder breakdown products, water vapour and combustion products from the oven burners. After exiting the oven, the product is cooled by passing a large quantity of air through it. This gas is likely to contain glass wool fibre and low levels of organic material. Product finishing involves cutting, handling and packaging, which can give rise to dust emissions (European Commission, 2001).

An important factor that has a major impact on emissions from forming, curing and cooling is the result of binder applied to the product, as higher binder content products will generally result in higher emission levels. Binder-derived emissions depend essentially on the mass of binder solids applied over a given time and therefore high binder content and, to a lesser extent, high density products may give rise to higher emissions (European Commission, 2001).

The emissions of melting and the after melting treatment are combined in Table 3.5.

Table 3.5 Tier 2 emission factors for source category 2.A.3 Glass production, glass wool

Tier 2 default emission factors					
	Code	Name			
NFR source category	2.A.3	Glass production			
Fuel	NA				
SNAP (if applicable)	030316 Glass wool (except binding)				
Technologies/Practices	Glass wool production				
Region or regional conditions					
Abatement technologies					
Not applicable	HCH, PCBs				
Not estimated	NO _x , NMVOC, SO _x , NH ₃ , CO, Hg, Cu, Zn, PCDD/F, Benzo(a)pyrene, Benzo(a)fluoranthene, Benzo(k)fluoranthene, Indeno(1,2,3-cd)pyrene, HCB				
Pollutant	Value	Unit	95 % confidence interval		Reference
			Lower	Upper	
NMVOC	500	g/Mg glass	100	2 800	European Commission (2008)
NH ₃	1 400	g/Mg glass	300	6 500	European Commission (2008)
TSP	670	g/Mg glass	80	5 600	European Commission (2008)
PM ₁₀	590	g/Mg glass	70	5 000	Visschedijk et al (2004) applied on TSP
PM _{2.5}	520	g/Mg glass	60	4 500	Visschedijk et al (2004) applied on TSP
BC	2	% of PM _{2.5}	1	4	US EPA (2011, file no.: 91142)

3.3.2.5 Other glass production

The present sub-section concerns other glass production. This section gives Tier 2 emission factor tables for glass types that were not discussed above. This section includes emission factor tables for lead crystal glass and water glass. Table 3.6 only contains emission factors for particulates and Pb from lead crystal glass. The emission factors are based on information from the revised BREF document for the glass industry (European Commission, 2008); additional information has been obtained from industrial experts (Beerkens, 2008).

Table 3.6 Tier 2 emission factors for source category 2.A.3 Glass production, other glass, lead crystal glass

Tier 2 default emission factors					
	Code	Name			
NFR source category	2.A.3	Glass production			
Fuel	NA				
SNAP (if applicable)	030317 Other glass				
Technologies/Practices	Lead crystal glass				
Region or regional conditions					
Abatement technologies	Filters in operation				
Not applicable	HCH, PCBs				
Not estimated	NO _x , NMVOC, SO _x , NH ₃ , CO, Hg, Cu, Zn, PCDD/F, Benzo(a)pyrene, Benzo(a)fluoranthene, Benzo(k)fluoranthene, Indeno(1,2,3-cd)pyrene, HCB				
Pollutant	Value	Unit	95 % confidence interval		Reference
			Lower	Upper	
TSP	10	g/Mg glass	5	30	Beekens (2008)
PM ₁₀	9	g/Mg glass	5	27	Visschedijk et al (2004) applied on TSP
PM _{2.5}	8	g/Mg glass	4	24	Visschedijk et al (2004) applied on TSP
BC	0.062	% of PM _{2.5}	0.031	0.12	US EPA (2011, file no.: 91143)
Pb	10	g/Mg glass	5	30	Beekens (2008)

For lead crystal glass, emission factors can vary widely depending on the type of filters that are in operation. Nearly all plants in the EU have filters in operation that reduce the PM emissions to values

below 20–30 g/ton glass, sometimes even below 10 g/ton. Most of this PM consists of Pb. However, if no filter is in operation, emissions of particulates as well as Pb can rise to over 1 kg/ton (Beerkens, 2008).

Table 3.7 Tier 2 emission factors for source category 2.A.3 Glass production, other glass, water glass

Tier 2 default emission factors					
	Code	Name			
NFR source category	2.A.3	Glass production			
Fuel	NA				
SNAP (if applicable)	030317 Other glass				
Technologies/Practices	Water glass				
Region or regional conditions					
Abatement technologies					
Not applicable	HCH, PCBs				
Not estimated	NO _x , NMVOC, SO _x , NH ₃ , CO, Hg, Cu, Zn, PCDD/F, Benzo(a)pyrene, Benzo(a)fluoranthene, Benzo(k)fluoranthene, Indeno(1,2,3-cd)pyrene, HCB				
Pollutant	Value	Unit	95 % confidence interval		Reference
			Lower	Upper	
TSP	200	g/Mg glass	70	600	European Commission (2008)
PM ₁₀	180	g/Mg glass	60	540	Visschedijk et al (2004) applied on TSP
PM _{2.5}	160	g/Mg glass	50	480	Visschedijk et al (2004) applied on TSP
BC	0.062	% of PM _{2.5}	0.031	0.12	US EPA (2011, file no.: 91143)

3.3.3 Abatement

A number of add-on technologies exist that aim to reduce the emissions of specific pollutants. The resulting emission can be calculated by replacing the technology-specific emission factor with an abated emission factor as given in the formula:

$$EF_{\text{technologyabated}} = (1 - \eta_{\text{abatement}}) \times EF_{\text{technologyunabated}} \quad (4)$$

Where:

$EF_{\text{technology, abated}}$ = the emission factor after implementation of the abatement

$\eta_{\text{abatement}}$ = the abatement efficiency

$EF_{\text{technology, unabated}}$ = the emission factor before implementation of the abatement

The present sub-section presents default abatement efficiencies for a number of abatement options, applicable in this sector. The abatement efficiencies should be applied with care, since they provide an average efficiency over the sector, not taking into account the various glass types.

3.3.3.1 Flat glass, blown or drawn glass and container glass

This sub-section provides abatement efficiencies for flat glass, blown or drawn glass and container glass. Efficiencies are only provided for particulates and are related to an old, uncontrolled plant.

Table 3.8 Abatement efficiencies ($\eta_{\text{abatement}}$) for source category 2.A.3, Glass production.

Tier 2 Abatement efficiencies					
	Code	Name			
NFR Source Category	2.A.3	Other mineral products			
Fuel	NA	not applicable			
SNAP (if applicable)	030314 030315	Flat glass Container glass			
Technologies/Practices	Flat glass, blown or drawn glass, container glass				
Abatement technology	Pollutant	Efficiency	95% confidence interval		Reference
		Default Value	Lower	Upper	
Gas or fuel oil-fired, limited emission control	particle > 10 μm	75%	25%	92%	Visschedijk et al. (2004)
	10 μm > particle > 2.5 μm	75%	25%	92%	Visschedijk et al. (2004)
	2.5 μm > particle	75%	25%	92%	Visschedijk et al. (2004)
Electrically heated, ESP, scrubber or fabric filter	particle > 10 μm	99%	96%	100%	Visschedijk et al. (2004)
	10 μm > particle > 2.5 μm	99%	96%	100%	Visschedijk et al. (2004)
	2.5 μm > particle	99%	96%	100%	Visschedijk et al. (2004)

3.3.3.2 Glass fibres

This sub-section provides abatement efficiencies for glass fibres. Efficiencies are only provided for particulates and related to an old, uncontrolled plant.

Table 3.9 Abatement efficiencies ($\eta_{\text{abatement}}$) for source category 2.A.3, Glass production.

Tier 2 Abatement efficiencies					
	Code	Name			
NFR Source Category	2.A.3	Other mineral products			
Fuel	NA	not applicable			
SNAP (if applicable)	030317	Other glass			
Technologies/Practices	Glass fibres				
Abatement technology	Pollutant	Efficiency	95% confidence interval		Reference
		Default Value	Lower	Upper	
Gas or fuel oil-fired, limited emission control	particle > 10 μm	50%	0%	83%	Visschedijk et al. (2004)
	10 μm > particle > 2.5 μm	50%	0%	83%	Visschedijk et al. (2004)
	2.5 μm > particle	50%	0%	83%	Visschedijk et al. (2004)
Electrically heated, ESP, scrubber or fabric filter	particle > 10 μm	75%	25%	92%	Visschedijk et al. (2004)
	10 μm > particle > 2.5 μm	75%	25%	92%	Visschedijk et al. (2004)
	2.5 μm > particle	75%	25%	92%	Visschedijk et al. (2004)

3.3.4 Activity data

Information on the production of glass, suitable for estimating emissions using Tier 1 or Tier 2 is widely available from United Nations statistical yearbooks or national statistics.

Further guidance is provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, volume 3 on Industrial Processes and Product Use (IPPU), chapter 2.4.1.3, 'Choice of activity data'.

3.4 Tier 3 Emission modelling and use of facility data

3.4.1 Algorithm

There are two different methods to apply emission estimation methods that go beyond the technology specific approach described above:

- detailed modelling of the glass production process;
- facility-level emission reports.

3.4.1.1 Detailed process modelling

A Tier 3 emission estimate, using process details will make separate estimates for the consecutive steps in the glass production process.

3.4.1.2 Facility-level data

Where facility-level emissions data are of sufficient quality (see Chapter 6 on Inventory Management in Part A of the Guidebook) are available, it is good practice to use these data. There are two possibilities:

- facility reports cover all glass production in the country;
- facility level emission reports are not available for all glass plants in the country.

If facility-level data cover all glass production in the country, it is good practice to compare the implied emission factors (reported emissions divided by the national glass production) with the default emission factor values or technology-specific emission factors. If the implied emission factors are outside the 95 % confidence intervals for the values given in the Tier 1 and Tier 2 emission factor tables, it is good practice to explain the reasons for this in the inventory report

If the total annual glass production in the country is not included in the total of the facility reports, it is good practice to estimate the missing part of the national total emissions from the source category, using extrapolation by applying:

$$E_{Total,pollutant} = \sum_{Facilities} E_{Facility,pollutant} + \left(National\ Production - \sum_{Facilities} Production_{Facility} \right) \times EF \quad (5)$$

Where:

$E_{total,pollutant}$	=	the total emission of a pollutant for all facilities within the source category
$E_{facility,pollutant}$	=	the emission of the pollutant as reported by a facility
$Production_{total}$	=	the production rate in the source category
$Production_{facility}$	=	the production rate in a facility
$EF_{pollutant}$	=	the emission factor for the pollutant

Depending on the specific national circumstances and the coverage of the facility-level reports as compared to the total national glass production, it is good practice to choose the emission factor (EF) in this equation from the following possibilities, in decreasing order of preference:

- technology-specific emission factors, based on knowledge of the types of technologies implemented at the facilities where facility level emission reports are not available;
- the implied emission factor derived from the available emission reports:

$$EF = \frac{\sum_{Facilities} E_{Facility,pollutant}}{\sum_{Facilities} Production_{Facility}} \quad (6)$$

- the default Tier 1 emission factor. This option should only be chosen if the facility-level emission reports cover more than 90 % of the total national production

3.4.2 Tier 3: emission modelling and use of facility data

Many glass production facilities are major industrial facilities and emission data for individual plants might be available through a pollutant release and transfer registry (E-PRTR) or another emission reporting scheme. When the quality of such data is assured by a well developed quality assurance/quality control (QA/QC) system and the emission reports have been verified by an independent auditing scheme, it is good practice to use such data. If extrapolation is needed to cover all the glass production in the country either the implied emission factors for the facilities that did report, or the emission factors as provided above could be used.

This Guidebook does not present emission models for the glass industry. However, such a model could be developed and used in the national inventories. Should this happen, it is good practice to compare the model results to the Tier 1 and Tier 2 emission factors to assess the credibility of the model. If the model provides implied emission factors outside the 95 % confidence intervals in the tables above, it is good practice to include an explanation for this in the documentation with the inventory and preferably reflected in the Informative Inventory Report.

3.4.3 Activity data

Since PRTRs generally do not report activity data, such data in relation to the reported facility level emissions are sometimes difficult to find. A possible source of facility-level activity might be the registries of emission trading systems.

In many countries national statistics offices collect production data at the facility level but these are in many cases confidential. However, in several countries national statistics offices are part of the national emission inventory systems and the extrapolation, if needed, could be performed at the statistics office, ensuring that confidentiality of production data is maintained.

4 Data quality

4.1 Completeness

In cases where attempts are made to split the emissions from glass manufacturing into combustion emissions and non-emission combustions, care must be taken to include all emissions.

It is good practice to check whether the NO_x and SO_x emissions that are not reported under the present source category are included in the emissions reported under source category 1.A.2.g.i.

4.2 Avoiding double counting with other sectors

Care should be taken not to double count emissions reported in combustion and process emissions. Emissions of NO_x and SO_x are assumed to originate mostly from combustion; therefore it is good practice to report these in source category 1.A.2.g.i.

4.3 Verification

4.3.1 Best Available Technique emission factors

The revised BREF document for the glass industry (European Commission, 2008) for the glass industry provides achievable emission levels (AELs) associated with the use of Best Available Techniques (BAT),

for different types of glass produced. Please refer to this document for additional information and emission concentrations when using BAT.

4.4 Developing a consistent time series and recalculation

No specific issues for Tier 1 and 2.

For Tier 3 using facility level data, it might occur that a different selection of facility-level data is included in different years. This can lead to time series inconsistencies. Moreover, PRTR data are generally available for specific years only. Splicing such recent reported data under E-PRTR/ EPER with historical data could be used to get consistent time series. Splicing could be used for both the activity data and the country-specific emission factors.

Unexpected discontinuities in time series can occur when specific glass production facilities come into operation or are closed in specific years. If this happens, it is good practice to clearly document such explanations in the inventory archives.

4.5 Uncertainty assessment

No specific issues.

4.5.1 Emission factor uncertainties

No specific issues.

4.5.2 Activity data uncertainties

No specific issues.

4.6 Inventory quality assurance/quality control (QA/QC)

Emissions from the production of glass as discussed in this chapter only include the emissions of pollutants that are mainly due to causes other than the combustion of fuels. Emissions of pollutants that are expected to be mainly due to fuel combustion are to be reported under source category 1.A.2.g.iii in the industrial combustion sector. It is good practice to check whether the production data, used in this chapter, are consistent with the associated fuel use as reported in the industrial combustion sector (chapter 1.A.2). The specific energy use of the glass production process varies significantly with the furnace design, scale and method of operation. The actual energy requirements vary between 3.5 and 40 GJ/Mg glass produced. However, the majority of glass is produced in large furnaces and the energy requirement for melting is generally below 8 GJ/Mg.

4.7 Gridding

No specific issues.

4.8 Reporting and documentation

Care should be taken not to double count emissions and to report them both under this source category and in combustion in manufacturing industries (chapter 1.A.2).

5 Glossary

AR _{production, technology}	the production rate within the source category, using a specific technology
AR _{production, technology}	the production rate within the source category, using a specific technology
AR _{production}	the activity rate for glass production
E _{facility, pollutant}	the emission of the pollutant as reported by a facility
E _{pollutant}	the emission of the specified pollutant
E _{total, pollutant}	the total emission of a pollutant for all facilities within the source category
EF _{country, pollutant}	a country-specific emission factor
EF _{pollutant}	the emission factor for the pollutant
EF _{technology, abated}	the emission factor after implementation of the abatement
EF _{technology, pollutant}	the emission factor for this technology and this pollutant
EF _{technology, unabated}	the emission factor before implementation of the abatement
Penetration _{technology}	the fraction of production using a specific technology
Production _{facility}	the production rate in a facility
Production _{total}	the production rate in the source category
$\eta_{\text{abatement}}$	the abatement efficiency

6 References

Abraham, D., Quirk, R., de Reydellet, A., Scalet, B.M. and Tackels, G., 1997. *Personal communication*. July 1997.

Beerkens, R.G.C., 2008. *Personal communication*.

Eichhammer, W., Bradke, H., Flanagan, J., Laue, H.J. and Bahm, W., 1994. *Energy efficient techniques in domestic glass production*. Report to European Commission Directorate-General for Energy – DG XVII, Contract No. XVII/7001/90-8, June 1994.

European Commission, 2001. *Integrated Pollution Prevention and Control (IPPC), Reference Document on Best Available Technologies (BREF) in the Glass Manufacturing Industry*. European Commission, December 2001.

European Commission, 2008. *Integrated Pollution Prevention and Control (IPPC), Revised reference Document on Best Available Technologies (BREF) in the Glass Manufacturing Industry*, draft. European Commission, February 2008.

Flamme, M., 1993. 'Feuerungstechnische NO_x-minderungsverfahren'. In: *HVG-Forbildungskurs 1993, Minderung der Staub- und Schadgas-emissionen bei Glasschmelzöfen*, Fachhochschule Nürnberg.

- Flamme, M. and Haep, J., 1994. 'Möglichkeiten zur Minderung der NO_x-bildung im Bereich der Glasindustrie'. In: *Gaswärme International*, 43,9.
- Gitzhofer, K.-H., 1993. 'Emissionen und Stand der Abgasreinigung'. In: *HVG-Fortbildungskurs 1993, Minderung der Staub- und Schadgas-Emissionen bei Glasschmelzöfen*.
- Her Majesty's Inspectorate of Pollution, 1992. *Glass Manufacture and Production Glass Frit and Enamel Frit, Environmental Protection Act 1990, Process Guidance Note IPR 3/5*. London, 1992.
- IPCC, 2006. *IPCC Guidelines for National Greenhouse Gas Inventories*. Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). IGES, Japan.
- Jockel, W. and Hartje, J., 1991. *Datenerhebung über die Emissionen Umwelt-gefährdender Schwermetalle*. Forschungsbericht 91-1-4 02 588, TÜV Rheinland e.V., Köln.
- Kircher, U., 1993. 'NO_x-Emissionen und Stand der Minderungstechnik'. In: *HVG-Fortbildungskurs 1993, Minderung der Staub- und Schadgas-Emissionen bei Glasschmelzöfen*. Fachhochschule Nürnberg.
- Landesgewerbeamt Bayern, 1994. *Beurteilung von Anlagen zur Herstellung von Glas nach der 12. BImSchV*, Nürnberg.
- Leendertse, A., 1998. *Personal communication about the carbonization process*.
- Nölle, G., 1978. *Technik der Glasherstellung*. Deutscher Verlag für Grundstoffindustrie, Leipzig.
- Quirk, R., 1997. 'Review of controls of NO_x: Glass opportunities – The challenge of the environment'. In: *Glass Technology*, Volume 38, No. 4, August 1997.
- Rivet, F., 2008. *Personal communication*.
- Schmalhorst, E. and Ernas, T., 1995. 'First practical experiences with an SCR DeNO_x facility in a container glassworks'. In: *Glastechnische Berichte Glass Sci. Technol.*, 68, 5.
- Teller, A.J. and Hsieh, J.Y., 1992. 'Glass manufacturing'. In: Buonicore, A.J. and Davis, T.W. (eds.), *Air pollution engineering manual*. New York.
- UNECE, 1995. *State-of-the-art report – second edition*. Task Force on Heavy Metal Emissions, Prague.
- UNECE, 1998. *Task Force on Assessment of Abatement Options / Techniques for Nitrogen Oxides from Stationary Sources, Draft Background Document*. French-German Institute of Environmental Research, Karlsruhe, April 1998.
- US EPA, 1995. *Compilation of Air Pollutant Emission Factors (AP-42) CD-ROM*. United States Environment Protection Agency.
- US EPA, 2011. SPECIATE database version 4.3, U.S. Environmental Protection Agency's (EPA). Available at: <http://cfpub.epa.gov/si/speciate/>. (accessed 5 June 2013).
- VDI, 1998. *Emissionsminderung Glasshütten / Emission control glass manufacture*. VDI 2578, Düsseldorf.
- VDI Kommission Reinhaltung der Luft, 1997. 'Emissionsminderung Glashütten, VDI Richtlinie 2578, 7. Vorentwurf'. In: *VDI/DIN-Handbuch Reinhaltung der Luft, Volume 1*. Düsseldorf, April 1997.
- Visschedijk, A.J.H., Pacyna, J., Pulles, T., Zandveld, P. and Denier van der Gon, H., 2004. 'Coordinated European Particulate Matter Emission Inventory Program (CEPMEIP)'. In: Dilara, P. et al. (eds.),

Proceedings of the PM emission inventories scientific workshop, Lago Maggiore, Italy, 18 October 2004.
EUR 21302 EN, JRC, pp 163–174.

7 Point of enquiry

Enquiries concerning this chapter should be directed to the relevant leader(s) of the Task Force on Emission Inventories and Projection's expert panel on combustion and industry. Please refer to the TFEIP website (www.tfeip-secretariat.org) for the contact details of the current expert panel leaders.