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Integrated Pollution Prevention and Control (IPPC)

Reference Document on
Best Available Techniques in the Glass Manufacturing
Industry

October 2000

Executive Summary

EXECUTIVE SUMMARY

1) Introduction

This reference document on best available techniques in the glass industry reflects an information exchange carried out according to Article 16 (2) of Council Directive 96/61/EC. The document has to be seen in the light of the preface that describes the objective of the document and its use.

This document covers the industrial activities specified in Sections 3.3 and 3.4 of Annex 1 of Directive 96/61/EC, namely:

- 3.3 Installations for the manufacture of glass including glass fibre with a melting capacity exceeding 20 tonnes per day.
- 3.4 Installations for melting mineral substances including the production of mineral fibres with a melting capacity exceeding 20 tonnes per day.

For the purposes of this document the industrial activities falling within these descriptions in the Directive are referred to as the glass industry, which is considered to be comprised of eight sectors. These sectors are based on the products manufactured, but inevitably there is some overlap between them. The eight sectors are: container glass; flat glass; continuous filament glass fibre; domestic glass; special glass (including water glass); mineral wool (with two sub-sectors, glass wool and stone wool.); ceramic fibre; and frits.

The document is made up of seven chapters and a number of annexes containing supplementary information. The seven chapters and four annexes are:

- 1. General Information
- 2. Applied Processes and Techniques
- 3. Present Consumption and Emission Levels
- 4. Techniques to Consider in the Determination of BAT
- 5. BAT Conclusions
- 6. Emerging Techniques
- 7. Conclusions and Recommendations
- 8. Annex 1 Example installation emission data
- 9. Annex 2 Example sulphur balances
- 10. Annex 3 Monitoring
- 11. Annex 4 Member State Legislation

The objective of the executive summary is to summarise the main findings of the document. Due to the nature of the main document it is impossible to present all of its complexities and subtleties in such a short summary. Therefore, references are made to the main text and it should be stressed that only the main document in its entirety should be used as a reference in the determination of BAT for any particular installation. To base such decisions on the executive summary alone could lead to the information being taken out of context and to a misinterpretation of the complexities of the issues.

2) The Glass Industry

Chapter 1 provides general background information on the glass industry. Its main purpose is to provide a basic understanding of the industry as a whole to help decision makers view the information provided later in the document in context with the wider influences affecting the industry.

The glass industry within the European Union (EU) is extremely diverse, both in the products made and the manufacturing techniques employed. Products range from intricate hand-made lead crystal goblets to huge volumes of float glass produced for the construction and automotive

industries. Manufacturing techniques vary from small electrically heated furnaces in the ceramic fibre sector to cross-fired regenerative furnaces in the flat glass sector, producing up to 700 tonnes per day. The wider glass industry also includes many smaller installations that fall below the 20 tonnes per day threshold in Annex 1 to the Directive.

The glass industry is essentially a commodity industry, although many ways of adding value to high volume products have been developed to ensure the industry remains competitive. Over 80 % of the industry output is sold to other industries, and the glass industry as a whole is very dependent on the building industry, and the food and beverage industry. However, some of the smaller volume sectors produce high value technical or consumer products.

The total production of the glass industry within the EU in 1996 was estimated at 29 million tonnes (excluding ceramic fibres and frits), an indicative breakdown by sector is given in the table below.

Sector	% of Total EU Production (1996)
Container Glass	60
Flat Glass	22
Continuous Filament Glass Fibre	1.8
Domestic Glass	3.6
Special Glass	5.8
Mineral Wool	6.8

Approximate sector based breakdown of glass industry production (excluding ceramic fibre and frit sectors)

Chapter 1 provides information for each sector under the following headings: sector overview, products and markets, commercial and financial considerations, and main environmental issues. Due to the diversity of the industry the information given is very different for each sector. As an illustrative example the information given for the container glass sector is summarised in the paragraph below. Comparable information is provided for all sectors where available.

Container glass production is the largest sector of the EU glass industry, representing around 60 % of the total glass production. The sector covers the production of glass packaging i.e. bottles and jars although some machine made tableware may also be produced in this sector. In 1997 the sector produced over 17.3 million tonnes of glass products from the 295 furnaces operating in the EU. There are approximately 70 companies with 140 installations. Container glass is produced in all Member States with the exception of Luxembourg. The beverage sector accounts for approximately 75 % of the total tonnage of glass packaging containers. The main competition is from alternative packaging materials steel, aluminium, cardboard composites and plastics. A significant development within the sector has been the increased use of recycled glass. The average rate of utilisation of post consumer waste within the EU container glass sector is approximately 50 % of total raw material input, with some installations utilising up to 90 % waste glass.

3) Applied Processes

Chapter 2 describes the processes and manufacturing techniques commonly encountered in the glass industry. Most processes can be divided into five basic stages: materials handling; melting; forming; downstream processing and packaging.

The diversity of the glass industry results in the use of a wide range of raw materials. The techniques used for materials handling are common to many industries and are described in Section 2.1 of the BREF. The main issue is the control of dust from the handling of fine materials. The main raw materials for melting are glass forming materials (e.g. silica sand, cullet), intermediate/modifying materials (e.g. soda ash, limestone, feldspar) and colouring/decolouring agents (e.g. iron chromite, iron oxide).

Melting, the combination of the individual raw materials at high temperature to form a molten glass, is the central phase in the production of glass. The melting process is a complex combination of chemical reactions and physical processes, and melting can be divided into several stages: heating; primary melting; fining and homogenisation; and conditioning.

The main melting techniques are summarised below. Different techniques are used within the stone wool and frits sectors, and these techniques are described in detail in the main document. Glass making is a very energy intensive activity and the choice of energy source, heating technique and heat recovery method are central to the design of the furnace. The same choices are also some of the most important factors affecting the environmental performance and energy efficiency of the melting operation. The three main energy sources for glass making are natural gas, fuel oil and electricity.

Regenerative furnaces utilise regenerative heat recovery systems. Burners are usually positioned in or below combustion air/waste gas ports. The heat in the waste gases is used to preheat air prior to combustion, by passing the waste gases through a chamber containing refractory material, which absorbs the heat. The furnace only fires on one side at a time. After about twenty minutes, the firing is reversed and the combustion air is passed through the chamber previously heated by the waste gases. Preheat temperatures up to 1400 °C may be attained leading to very high thermal efficiencies. In the cross-fired regenerative furnace, combustion ports and burners are positioned along the sides of the furnace, and the regenerator chambers are located either side of the furnace. In the end-fired regenerative furnace the principles of operation are the same, however, the two regenerative chambers are situated at one end of the furnace.

Recuperative furnaces utilise heat exchangers (termed recuperators) for heat recovery, with continuous preheat of combustion air by the waste gases. Air preheat temperatures are limited to around 800 °C for metallic recuperators. The specific melting capacity (per unit of melter area) of recuperative furnaces is around 30 % lower than for a regenerative furnace. The burners are located along each side of the furnace, transverse to the flow of glass, and fire continuously from both sides. This type of furnace is primarily used where high flexibility of operation is required with minimum initial capital outlay, particularly where the scale of operation is too small to make the use of regenerators economically viable. It is more appropriate to small capacity installations although higher capacity furnaces (up to 400 tonnes per day) are not uncommon.

Oxy-fuel firing involves the replacement of the combustion air with oxygen (>90 % purity). The elimination of the majority of the nitrogen from the combustion atmosphere reduces the volume of the waste gases by about two thirds. Therefore, furnace energy savings are possible because it is not necessary to heat the atmospheric nitrogen to the temperature of the flames. The formation of thermal NO_x is also greatly reduced. In general, oxy-fuel furnaces have the same basic design as unit melters, with multiple lateral burners and a single waste gas exhaust port. However, furnaces designed for oxygen combustion do not utilise heat recovery systems to pre-heat the oxygen supply to the burners.

Electric furnaces consist of a refractory lined box supported by a steel frame, with electrodes inserted either from the side, the top or more usually the bottom of the furnace. Energy for melting is provided by resistive heating as the current passes through the molten glass. The technique is commonly applied in small furnaces particularly for special glass. There is an upper size limit to the economic viability of electric furnaces, which depends on the cost of electricity compared with fossil fuels. The replacement of fossil fuels in the furnace eliminates the formation of combustion products.

Combined fossil fuel and electric melting can take two forms: predominantly fossil fuel firing with electric boost; or predominantly electrical heating with a fossil fuel support. Electric boosting is a method of adding extra heat to a glass furnace by passing an electric current

through electrodes in the bottom of the tank. A less common technique is the use of gas or oil as a support fuel for a principally electrically heated furnace.

Discontinuous batch melters are used where smaller amounts of glass are required, particularly if the glass formulation changes regularly. In these instances pot furnaces or day tanks are used to melt specific batches of raw material. Many glass processes of this type would not fall under the control of IPPC because they are likely to be less than 20 tonnes per day melting capacity. Basically a pot furnace consists of a lower section to preheat the combustion air and an upper section which holds the pots and serves as the melting chamber. Day tanks are further developed from pot furnaces to have larger capacities, in the region of 10 tonnes per day. Structurally they more closely resemble the quadrangle of a conventional furnace, but are still refilled with batch each day.

Special melter designs have been produced to improve efficiency and environmental performance. The best known of this type of furnace are the LoNO_x melter and the Flex Melter.

Aspects of the main process and techniques used within the industry are outlined for each sector in the paragraphs below.

Container glass is a diverse sector and almost all of the melting techniques described above are found. The forming process is carried out in two stages, the initial forming of the blank either by pressing with a plunger, or by blowing with compressed air, and the final moulding operation by blowing to obtain the finished hollow shape. These two processes are thus respectively termed "press and blow" and "blow and blow". Container production is almost exclusively by IS (Individual Section) machines.

Flat glass is produced almost exclusively with cross-fired regenerative furnaces. The basic principle of the float process is to pour the molten glass onto a bath of molten tin, and to form a ribbon with the upper and lower surfaces becoming parallel under the influence of gravity and surface tension. From the exit of the float bath the glass ribbon is passed through the annealing lehr, gradually cooling the glass to reduce residual stresses. On-line coatings can be applied to improve the performance of the product (e.g. low emissivity glazing).

Continuous filament glass fibre is produced using recuperative or oxy-fuel fired furnaces. The glass flows from the furnace to the forehearth where it passes through bushings at the base. The glass is drawn through the bushing tips to form continuous filaments. The filaments are drawn together and pass over a roller or belt, which applies an aqueous coating to each filament. The coated filaments are gathered together into bundles (strands) for further processing.

Domestic glass is a diverse sector involving a wide range of products and processes. Ranging from intricate handmade lead crystal, to high volume, mechanised methods used for mass produced tableware. Almost all of the melting techniques, described above are used in the sector, from pot furnaces to large regenerative furnaces. The forming processes are automatic processing, hand made or semi-automatic processing, and following production the basic items can be subjected to cold finishing operations (e.g. lead crystal is often cut and polished).

Special glass is also a very diverse sector, covering a wide range of products that can differ considerably in composition, method of manufacture and use. The most common techniques are recuperative furnaces, oxy-gas furnaces, regenerative furnaces, electric melters and day tanks. The wide product range means that many forming techniques are used within the sector. Some of the most important are: press and blow production; rolling; pressing, ribbon process; tube extrusion; the drawing process; and dissolution (water glass).

Glass wool furnaces are usually either electric melters, gas fired recuperative furnaces, or oxy-fuel furnaces. Molten glass flows along a forehearth and through single orifice bushings into rotary centrifugal spinners. Fiberising is by centrifugal action with attenuation by hot flame gases. An aqueous phenolic resin solution is sprayed onto the fibres. The resin coated fibre is drawn

under suction onto a moving conveyor and then passes through an oven to dry and cure the product.

Stone wool is usually produced with the coke fired hot blast cupola. The molten material gathers in the bottom of the furnace and flows out along a short trough onto the spinning machine. Air is used to attenuate the fibres and to direct them onto the collection belts. An aqueous phenolic resin solution is sprayed onto the fibres by a series of spray nozzles. The remainder of the process is essentially as for glass wool.

Ceramic fibre is produced exclusively using electric furnaces. The melt is fiberised either by high speed wheels or a high pressure air jet, and the fibres are drawn on to a collection belt. The product can be baled at this point or processed into blanket to be baled as product or needle felted. Further downstream processing may also be carried out.

Frit production utilises both continuous furnaces and batch furnaces. It is common for small batches to be produced for a wide range of formulations. Frit furnaces are generally natural gas or oil fired, and many frit plants use oxy-fuel firing. Continuous furnaces can be cross-fired or end-fired with a single burner. Discontinuous batch furnaces are box shaped or cylindrical refractory lined vessels, mounted to allow a degree of rotation. The melt can be quenched directly in a water bath, or can be cooled between water cooled rollers to produce a flake product.

4) Consumption and Emission Levels

Chapter 3 provides information on the ranges of consumption and emission levels that are encountered within the glass industry across the scope of processes and techniques described in Chapter 2. The inputs and outputs are discussed for the industry as a whole, and then a more specific consideration is made for each sector. The key emission characteristics, emission sources and energy issues are identified in this chapter. The information is intended to allow the emission and consumption figures for any particular installation being considered for a permit, to be viewed in context against other processes in the same sector or in the glass industry as a whole.

The core process inputs can be divided into four main categories: raw materials (those materials which form part of the product), energy (fuels and electricity), water, and ancillary materials (processing aids, cleaning materials, water treatment chemicals, etc). Glass industry raw materials are largely solid inorganic compounds, either naturally occurring minerals or man-made products. They vary from very coarse materials to finely divided powders. Liquids and gases are also widely used, both as ancillary materials and as fuels.

In the main document Table 3.1 lists the most common raw materials used for the production of glass. The raw materials used in product forming and other downstream activities (e.g. coatings and binders) are more specific to each sector and are discussed in later sections. The glass industry as a whole is not a major consumer of water, the main uses being cooling, cleaning and batch humidification. Glass making is an energy intensive process and therefore fuels can form a significant input to the processes. The main energy sources within the glass industry are fuel oil, natural gas and electricity. Energy and fuel issues are discussed in Section 3.2.3 and in the sector specific sections.

The core process outputs can be divided into five main categories: product, emissions to air, liquid waste streams, solid process residues, and energy.

All of the sectors within the glass industry involve the use of powdered, granular or dusty raw materials. The storage and handling of these materials represents a significant potential for dust emissions.

The major environmental challenges for the glass industry are emissions to air and energy consumption. Glass making is a high temperature, energy intensive activity, resulting in the

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emission of products of combustion and the high temperature oxidation of atmospheric nitrogen; i.e. sulphur dioxide, carbon dioxide, and oxides of nitrogen. Furnace emissions also contain dust and lower levels of metals. It is estimated that in 1997 the glass industry emissions to air consisted of: 9000 tonnes of dust; 103500 tonnes of NO_x; 91500 tonnes of SO_x; and 22 million tonnes of CO₂ (including electrical generation). This amounted to around of 0.7 % of total EU emissions of these substances. Total energy consumption by the glass industry was approximately 265 PJ. The main emissions arising from melting activities within the glass industry are summarised in the table below.

Emission	Source / Comments
Particulate matter	Condensation of volatile batch components. Carry over of fine material in the batch. Product of combustion of some fossil fuels.
Oxides of Nitrogen	Thermal NO _x due to high melter temperatures. Decomposition of nitrogen compounds in the batch materials. Oxidation of nitrogen contained in fuels.
Oxides of Sulphur	Sulphur in fuel. Decomposition of sulphur compounds in the batch materials. Oxidation of hydrogen sulphide in hot blast cupola operations.
Chlorides/HCl	Present as an impurity in some raw materials, particularly man made sodium carbonate. NaCl used as a raw material in some special glasses.
Fluorides/HF	Present as a minor impurity in some raw materials. Added as a raw material in the production of enamel frit to provide certain properties in the finished product. Added as a raw material in the continuous filament glass fibre industry, and in some glass batches to improve melting, or to produce certain properties in the glass e.g. opalescence. Where fluorides are added to the batch, typically as fluorspar, uncontrolled releases can be very high.
Heavy Metals (e.g. V, Ni, Cr, Se, Pb, Co, Sb, As, Cd)	Present as minor impurities in some raw materials, post consumer cullet, and fuels. Used in fluxes and colouring agents in the frit industry (predominantly lead and cadmium). Used in some special glass formulations (e.g. lead crystal and some coloured glasses). Selenium is used as a colorant (bronze glass), or as a decolourising agent in some clear glasses.
Carbon Dioxide	Combustion product. Emitted after decomposition of carbonates in the batch materials (e.g. soda ash, limestone).
Carbon Monoxide	Product of incomplete combustion, particularly in hot blast cupolas.
Hydrogen Sulphide	Formed from raw material or fuel sulphur in hot blast cupolas due to the reducing conditions found in parts of the furnace.

Summary of emissions to atmosphere arising from melting activities

The emissions from downstream activities can vary greatly between the different sectors and are discussed in the sector specific sections. Although there are similarities in the melting techniques used in many sectors the downstream activities tend to be specific. Emissions to air can arise from: coating application and/or drying; secondary processing (e.g. cutting, polishing, etc); and from some product forming operations (e.g. mineral wool, and ceramic fibre).

In general, emissions to the water environment are relatively low and there are few major issues that are specific to the glass industry. However, there are activities undertaken in some sectors which require further consideration and are discussed in the sector specific sections, particularly domestic glass, special glass and continuous filament glass fibre.

A characteristic of most of the sectors is that the great majority of internally generated glass waste is recycled back to the furnace. The main exceptions to this are the continuous filament sector, the ceramic fibre sector and producers of very quality sensitive products in the special glass and domestic glass sectors. The mineral wool and frits sectors show a wide variation in the amount of waste recycled to the furnace ranging from nothing to 100 % for some stone wool plants.

5) Techniques for Consideration in the Determination of BAT

Many of the sectors within the glass industry utilise large continuous furnaces with lifetimes up to twelve years. These furnaces represent a large capital commitment and the continuous operation of the furnace and the periodic rebuild provide a natural cycle of investment in the process. Major changes of melting technology are most economically implemented if coincided with furnace rebuilds, and this can also be true for complex secondary abatement measures. However, many improvements to the operation of the furnace, including the installation of secondary techniques, are possible during the operating campaign.

This summary briefly outlines the main techniques for controlling each substance emitted from melting activities and from some of the downstream operations. It concentrates predominantly on emissions to air as these are generally the most significant emissions from glass processes. Chapter 4 gives detailed descriptions of each technique and explains the emission levels achieved, the applicability of the technique, financial issues and other associated considerations.

Particulate Matter

Techniques for controlling particulate emissions include secondary measures, generally electrostatic precipitators and bag filters, and primary measures.

The electrostatic precipitator (EP) consists of a series of high voltage discharge electrodes and corresponding collector electrodes. Particles are charged and subsequently separated from the gas stream under the influence of the electric field. EPs are very effective in collecting dust in the range 0.1 μm to 10 μm , and overall collection efficiency can be 95 - 99 %. Actual performance varies depending mainly on waste gas characteristics and EP design. In principle, this technique is applicable to all new and existing installations in all sectors (except stone wool cupolas due to the risk of explosion). Costs are likely to be higher for existing plants, particularly where there are space restrictions.

In most applications a modern well designed two or three stage EP could be expected to achieve 20 mg/m^3 . Where high efficiency designs are used or where favourable conditions exist lower emission levels are often possible. Costs vary greatly, depending heavily on required performance and waste gas volume. Capital costs (including acid gas scrubbing) are generally in the range 0.5 to 2.75 million euros, with operating costs 0.03 to 0.2 million euros annually.

Bag filter systems use a fabric membrane which is permeable to gas but which will retain the dust. Dust is deposited on and within the fabric, and as the surface layer builds up it becomes the dominating filter medium. The direction of gas flow can be either from the inside of the bag to the outside, or from the outside to the inside. Fabric filters are highly efficient and a collection efficiency of 95 - 99 % would be expected. Particulate emissions between 0.1 mg/m^3 and 5 mg/m^3 can be achieved and levels consistently below 10 mg/m^3 , could be expected in most applications. The ability to achieve such low levels can be important if dusts contain significant levels of metals, and low metal emissions must be achieved.

In principle, bag filters are applicable to all new and existing installations in all sectors. However, due to their potential to blind in certain circumstances, they are not the preferred choice in all applications. In most cases there are technical solutions to these difficulties, but there may be an associated cost. Capital and operating costs are broadly comparable with EPs.

Primary control techniques are based mainly on raw material changes and furnace/firing modifications. In most applications primary techniques cannot achieve emission levels comparable with bag filters and EPs.

Oxides of Nitrogen (NO_x)

The most appropriate techniques for controlling emissions of NO_x are generally: primary measures, oxy-fuel melting, chemical reduction by fuel, selective catalytic reduction and selective non-catalytic reduction.

Primary measures can be split into two main types “conventional” combustion modifications and then special furnace designs or optimised combustion design packages. Oxy-firing is also a primary technique but is dealt with separately due to its specific nature. Conventional combustion modifications are usually based on: reduced air/fuel ratio, reduced preheat temperature, staged combustion and low NO_x burners; or a combination of these techniques. Capital costs are generally quite low and operating costs are often reduced due to reduced fuel usage and improved combustion. A great deal of progress has been made in this area, but the emission reductions achievable clearly depend on the starting point. NO_x reductions of 40 - 60 % are not uncommon and emission levels of less than 650 - 1100 mg/Nm³ have been achieved in some applications.

Special furnace designs have been developed which reduce NO_x emissions, e.g. the LoNO_x melter. These designs have been very successful but there are certain process constraints that limit their applicability. The FENIX process is a combustion optimisation package based on primary measures, that is tailored for a specific furnace. Results of 510 mg/Nm³ and around 1.1 kg/tonne of melt have been reported, but the number of examples is limited at the time of writing.

Oxy-fuel firing involves the replacement of the combustion air with oxygen. The elimination of the majority of the nitrogen from the combustion atmosphere reduces the volume of the waste gases by about two thirds. Therefore, energy savings are possible because it is not necessary to heat the atmospheric nitrogen to the temperature of the flames. The formation of thermal NO_x is greatly reduced, because the only nitrogen present in the combustion atmosphere is the residual nitrogen in the oxygen/fuel, nitrogen from nitrate breakdown, and that from any parasitic air.

The principle of oxy-fuel firing is well established and in principle can be considered as applicable to the industry as a whole. However, the technique is still considered by some sectors (particularly flat glass and domestic glass), as a developing technology with potentially high financial risk. Considerable development work is being undertaken and the technique is becoming more widely accepted as the number of plants increases. The issues surrounding this technique are very complex and are discussed in detail in Chapter 4. The economic competitiveness of the technique depends largely on the scale of energy savings (and the relative costs of alternative abatement techniques) compared with the cost of oxygen. Both the technical and economic viability of the technique are heavily dependent on site specific issues.

Chemical reduction by fuel describes those techniques where fuel is added to the waste gas stream to chemically reduce NO_x to N₂ through a series of reactions. The fuel does not burn but pyrolyses to form radicals which react with the components of the waste gas. The two main techniques that have been developed for use in the glass industry are the 3R process and the Reburning process. Both of these techniques are currently restricted to regenerative furnaces. The 3R process has been fully developed for application within the industry and the Reburning process has been run at full plant scale and has shown promising results. The 3R process can achieve emission levels of less than 500 mg/Nm³ corresponding to an increase in fuel usage of 6 - 10 %. The Reburning process is hoped to achieve comparable emission levels following development. The increased energy usage for both techniques can be greatly reduced by the use of energy recovery systems, and by combining the techniques with primary measures.

Selective catalytic reduction (SCR) involves reacting NO_x with ammonia in a catalytic bed generally at around 400 °C. Most applications in the glass industry will require a 3-stage system including dust abatement and acid gas scrubbing. Systems are normally designed to achieve 75 - 95 % reductions, and in general emission levels of less than 500 mg/Nm³ are achievable. The cost of SCR depends mainly on the waste gas volume and the desired NO_x reduction. In general, capital costs (including EP and scrubbing) are in the range 1 million to 4.5 million euros with operating costs 0.075 to 0.5 million euros annually. In principle, SCR can be applied to most processes in the glass industry and to both new and existing processes. However, there are a number of issues that can limit the applicability of the technique in certain cases. For example, the technique has not been proven for heavy fuel oil fired glass furnaces, glass wool or continuous filament glass fibre.

Selective non-catalytic reduction (SNCR) operates on the same basis as SCR but the reactions take place at higher temperature (800 - 1100 °C) without the need for a catalyst. SNCR does not require dust abatement or acid gas scrubbing. Reduction efficiencies of 30 - 70 % are generally achievable, the critical factor is the availability of sufficient ammonia at the correct temperature window. Capital costs are in the range 0.2 to 1.35 million euros and operating costs from 23000 to 225000 euros per year, depending on furnace size. In principle, the technique is applicable to all glass processes including new and existing plants. The main limitation to the applicability of SNCR is whether the reagent can be introduced at a point in the waste gas system where the correct temperature can be maintained for an adequate reaction time. This is of particular relevance in existing plants and for regenerative furnaces.

Oxides of Sulphur (SO_x)

The main techniques for controlling SO_x emissions are fuel selection, batch formulation and acid gas scrubbing.

In oil fired processes the main source of SO_x is the oxidation of sulphur in the fuel. The amount of SO_x derived from the batch materials varies depending on the glass type but in general wherever oil is burned the SO_x emissions from the fuel outweigh those from the batch materials. The most obvious way to reduce SO_x emissions is to reduce the sulphur content of the fuel. Fuel oil is available in various sulphur grades (<1 %, <2 %, <3 % and >3 %), and natural gas is essentially sulphur free. The conversion to a lower sulphur content fuel does not generally result in any increased costs except the higher fuel price. The conversion to gas firing requires different burners and a range of other modifications. The prices of the various fuels vary substantially with time and between Member States, but in general lower sulphur fuels are more expensive. As explained in Chapter 5 the financial and political issues associated with fuel pricing and availability are such that fuel selection is considered to be outside the scope of this document. However, where natural gas is burned SO_x emissions will usually be lower, and where oil is burned a sulphur level of 1% or less is considered BAT. Burning higher sulphur content fuels may also represent BAT if abatement is used to achieve equivalent emission levels.

In conventional glass making, sulphates are the main source of SO_x emissions from batch materials. Sulphates are the most widely used fining agents and are also important oxidising agents. In most modern glass furnaces the levels of batch sulphates have been reduced to the minimum practicable levels, which vary depending on the glass type. The issues surrounding the reduction of batch sulphates are discussed in Section 4.4.1.1 and the issues relating to the recycling of filter/EP dust are discussed in Section 4.4.3.3.

In stone wool production important sources of SO₂ emission (in addition to coke) are the use of blast furnace slag and cement bound briquettes in the batch. The availability of low sulphur coke and slag are restricted by very limited supply within economical transport distances. Slag can generally be eliminated from most batches, with the exception of the production of limited amounts of white fibre for specific applications. The use of cement bound waste briquettes involves a balance between waste minimisation and SO_x emission reduction, which will often

depend on specific priorities and must be considered in association with the use of acid gas scrubbing. This issue is discussed extensively in chapters 4 and 5 of the main document.

The operating principles of dry and semi-dry scrubbing are the same. The reactive material (the absorbent) is introduced to, and dispersed in the waste gas stream. This material reacts with the SO_x species to form a solid, which must be removed from the waste gas stream by an electrostatic precipitator or bag filter system. The absorbents chosen to remove SO_x are also effective in removing other acidic gases. In the dry process the absorbent is a dry powder (usually Ca(OH)₂, NaHCO₃, or Na₂(CO)₃). In the semi-dry process the absorbent (usually Na₂CO₃, CaO or Ca(OH)₂) is added as a suspension or solution and water evaporation cools the gas stream. The reductions achieved with the techniques depend on a number of factors including waste gas temperature, the amount and type of absorbent added (or more precisely the molar ratio between reactant and pollutants) and the dispersion of the absorbent. Section 4.4.3.3 outlines the efficiencies obtained with various absorbents and processes.

The complete recycling of filter dust, including the sulphated waste, is often considered to be a reasonable environmental and economic option, where it is technically possible. The overall reduction of SO_x emissions is limited (by mass balance considerations) to the reduction at source obtained by substituting sulphate in the raw materials by filter dust. (Clearly this is in addition to other appropriate primary measures to reduce overall sulphur input.) Therefore, in order to reduce acid gas emissions, it may be necessary to consider an external disposal route for a portion of the collected material. The determination of what represents the best protection of the environment as a whole can often be site-specific and may involve balancing the potentially conflicting priorities of waste minimisation and SO_x emission reduction. Where this is the case a process sulphur balance will be essential in determining emission levels commensurate with BAT.

With closed loop filter dust recycling, the SO_x emission levels observed today, are generally in the range of 200 - 800 mg/Nm³ for natural gas firing and 800 - 1600 mg/ Nm³ with 1 % S fuel oil. The majority of installed SO_x scrubbing systems operate with dry lime scrubbing at a temperature of around 400 °C, which is the waste gas temperature obtained from an efficient regenerative type furnace. At these temperatures, an SO_x reduction of around 50 % can be achieved. An improved SO_x reduction rate can be reached at temperatures around 200 °C and with a humid atmosphere but this involves further considerations.

SO_x scrubbing is an extremely complex area which generated a great deal of discussion within the technical working group. It is therefore essential that the discussion and explanation presented in chapters 4 and 5 are considered in full.

Fluorides (HF) and Chlorides (HCl)

HF and HCl emissions generally arise from the volatilisation of fluorides and chlorides in the batch materials, either present as impurities, or added intentionally to provide specific product or processing characteristics to the glass. The main techniques for the reduction of these emissions are batch modification or scrubbing. Where the halides are present as impurities emissions can generally be controlled by raw material selection, although scrubbing is often used either where raw material selection is not sufficient or where scrubbing is used to control other substances. Where halides are used to impart specific characteristics there are two main approaches scrubbing or batch reformulation to achieve the same characteristics by other means. Particular successes with reformulation have been achieved in continuous filament glass fibre.

Emissions from Non-Melting Activities

Emissions from downstream processing are sector specific and are described in some detail in Section 4.5 of the main document. With the exception of the mineral wool sector emissions are generally much lower than from the melting activities. Abatement techniques are generally

based on conventional dust collection and wet scrubbing techniques with some thermal oxidation.

In mineral wool processes there is the potential for substantial emissions from the application and curing of organic resin based binder systems. The techniques for controlling these emissions are discussed in detail in Section 4.5.6 of the main document.

Emissions to Water

In general, emissions to the water environment are relatively low and there are few major issues that are specific to the glass industry. Water is used mainly for cleaning and cooling and can be readily recycled or treated using standard techniques. Specific issues of organic contamination can arise from mineral wool and continuous filament glass fibre processes. Issues of heavy metals (particularly lead) can arise from special glass, frits and domestic glass processes. The table below identifies the main potential techniques for controlling emissions to water.

Physical/Chemical Treatment

- | | |
|--------------|--------------------------------|
| • Screening | • Neutralisation |
| • Skimming | • Aeration |
| • Settlement | • Precipitation |
| • Centrifuge | • Coagulation and Flocculation |
| • Filtration | |

Biological Treatment

- Activated sludge
- Biofiltration

List of potential wastewater treatment techniques for use in the Glass Industry

Solid Waste

A characteristic of the glass industry is that most of the activities produce relatively low levels of solid waste. Most of the processes do not have significant inherent by-product streams. The main process residues are unused raw materials, waste glass that has not been converted into the product, and waste product. Other solid wastes include waste refractory and dust collected in abatement equipment or flues. Non-fibrous waste is generally readily recycled to the process and techniques are under development for recycling other wastes. The extent of waste recycling is increasing as financial incentives develop, particularly increased disposal costs. The main process residues encountered in the glass industry and the techniques used to control them are discussed in Section 4.7 of the main document.

Energy

Glass making is a very energy intensive process and the choices of energy source, heating technique and heat recovery method are central to the design of the furnace and to the economic performance of the process. The same choices are also some of the most important factors affecting the environmental performance and energy efficiency of the melting operation. In general, the energy necessary for melting glass accounts for over 75 % of the total energy requirements of glass manufacture. The cost of energy for melting is one of the largest operational costs for glass installations and there is a significant incentive for operators to reduce energy use.

The main techniques for reducing energy usage are listed below and are discussed in detail in the main document:

- Melting technique and furnace design (e.g. regenerators, recuperators, electric melting, oxy-fuel combustion, and electric boost).
- Combustion control and fuel choice (e.g. low NO_x burners, stoichiometric combustion, oil/gas firing).
- Cullet usage
- Waste heat boilers
- Cullet/batch preheating

6) Summary of BAT Conclusions

Chapter 5 presents the conclusions on the best available techniques to achieve integrated prevention and control of pollution in the glass industry. The chapter contains an introduction, a general section and then sector specific conclusions. It is intended that the “general BAT” in Chapter 5 could be used to judge the current performance of an existing installation or to judge a proposal for a new installation and thereby assist in the determination of appropriate “BAT” – based conditions for that installation. The figures presented are **not** emission limit values and should not be understood as such. The appropriate emission limit values for any specific case will need to be determined taking into account the objectives of the IPPC Directive and the local considerations.

Chapter 5 was written following a great deal of discussion and redrafting within the Technical Working Group. The context and subtleties of the conclusions are very important and it is difficult to summarise the chapter without compromising these issues and the effort and discussion that was required to get to the current position. This summary outlines the main conclusions of Chapter 5 but it is essential that the full document and particularly the full text of Chapter 5 are consulted for a full understanding.

This summary outlines some of the industry wide issues and then summarises the main general conclusions using a predominantly substance based approach. One important conclusion that came out of this work was that the glass industry is so diverse that it is often inappropriate to specify particular techniques. The general approach taken in Chapter 5 is to identify levels of performance that are indicative of the best available techniques, but at the same time acknowledging that the best way of achieving these levels of performance could differ from process to process.

General

An important characteristic of many installations in the glass industry is the periodic rebuild of the furnaces, although the extent of the rebuild can vary. There may be technical and economic advantages to co-ordinating the implementation of certain techniques until a rebuild, but this is not always the case. The rebuild cycle also means the age of a furnace is important in determining the appropriate course of action in terms of overall BAT.

The reference conditions for Chapter 5 are:

- For combustion gases: dry, temperature 0°C (273K), pressure 101.3 kPa, 8 % oxygen by volume (continuous melters), 13 % oxygen by volume (discontinuous melters). For oxy-fuel fired systems the expression of the emissions corrected to 8 % oxygen is of little value, and emissions from these systems should be discussed in terms of mass.
- For others gases (including emissions from curing and drying ovens without tail gas incineration): temperature 0°C (273 K), pressure 101.3 kPa with no correction for oxygen or water vapour concentration.

In the main document, emission levels associated with BAT are presented as ranges for both emission concentration (mg/m³) and mass emission (kg/tonne of glass melted), to allow comparison between furnace techniques and to provide an indication of the relative

environmental impact. For fossil fuel fired furnaces the relationship between mass and concentration depends predominantly on specific energy consumption for melting, but this varies considerably depending on a wide range of factors including melting technique, furnace size and glass type. For such a diverse industry it is very difficult to relate concentrations and mass emission figures directly without presenting ranges so wide as to diminish the value of numerical conclusions. Therefore, the approach taken is to give concentration figures as the basis of BAT and to use indicative conversion factors based on modern energy efficient furnaces to determine mass emission figures which “generally equate to” these concentration levels.

For the purposes of this executive summary emission levels associated with BAT are given in concentration only. The exception to this is where techniques such as oxy-firing are discussed and mass emissions are the most meaningful way of describing the performance level. For the mass per tonne of glass melted reference should be made to the discussion on conversion factors in Section 5.2 and to the sector specific sections in Chapter 5.

Particulate Matter/Dust

The conclusion regarding dust emissions was broadly comparable for all sectors and is summarised in the paragraph below. There were two minor exceptions to this conclusion. For ceramic fibre the emission level associated with BAT was considered to be less than 10 mg/Nm³ due to the nature of the particulate matter. For frit processes the general conclusion was as given below but it was acknowledged that for some installations a degree of development would be required to achieve these levels.

In general, BAT for controlling dust emissions from furnaces in the glass industry is considered to be the use of either an electrostatic precipitator or bag filter system, operating where appropriate, in conjunction with a dry or semi-dry acid gas scrubbing system. The BAT emission level associated with these techniques is 5 - 30 mg/Nm³ which generally equates to less than 0.1 kg/tonne of glass melted. Values in the lower part of the range given would generally be expected for bag filter systems. These figures are based on a typical averaging period of not less than 30 minutes and not greater than 24 hours. In some cases the application of BAT for metals emissions may result in lower emissions levels for dust.

Some opinions within the Technical Working Group differed on whether the environmental benefits of secondary abatement of dust justified the higher costs in all cases. However, the general conclusion is that on balance secondary dust abatement represents BAT for most glass furnaces, unless equivalent emissions can be achieved with primary measures. The pros and cons of primary and secondary techniques are discussed extensively in Section 4.4.1.7 and 5.2.

Oxides of Nitrogen

This substance proved to be one of the most difficult on which to reach firm BAT conclusions. In particular, it is difficult to ascribe general emission levels that apply to more than one sector. It is therefore essential that the figures given in this section are only viewed as an indicative summary of the conclusions presented in Chapter 5. To base any consideration of BAT permit conditions on the information in this summary without reference to the main document would be to take the figures completely out of context. This could lead to unnecessarily stringent or lenient benchmarks being used for comparison.

For oxides of nitrogen the selection of techniques that represents BAT will depend very much on the site-specific issues, in particular the melting technique used and the age of the furnace. Certain techniques may achieve different results in different applications and may incur differing costs depending on site specific conditions.

For container glass, flat glass, special glass (including water glass), mineral wool and frit processes it is considered that the emission level for oxides of nitrogen (expressed as NO₂)

associated with the techniques that will generally constitute BAT is 500 - 700 mg/Nm³. Although the emission level associated with BAT is generally the same, the techniques that can be used to achieve these levels, their associated costs, and the relative difficulty of applying them vary between the sectors.

There are various situations where further considerations are necessary and the emission levels indicated above may not be appropriate. For example, where nitrates are needed, where certain recycled materials are used or where a furnace is nearing the end of its campaign. These considerations are very important and are discussed in the sector specific sections of Chapter 5.

At the time of writing the continuous filament sector is going through a transition period in NO_x control, which makes it difficult to form firm conclusions regarding BAT. The most promising technique appears to be oxy-fuel melting, although some good results have been achieved with primary measures and there are no overriding technical obstacles to the use of SNCR. In general in this sector, BAT for oxides of nitrogen (expressed as NO₂) is considered likely to be oxy-fuel melting; and the emission level associated with BAT is considered to be 0.5 - 1.5 kg/tonne of glass melted. This statement is not a firm conclusion, rather a balanced judgement based on the information available at the time of writing. It is acknowledged that the technique still carries an element of financial risk, but it is expected that the technique will become more widely accepted as BAT in the medium term. Where other techniques are practicable a comparable BAT emission level for air fuel fired furnaces is considered to be 500 - 700 mg/Nm³.

Similarly it is difficult to form firm conclusions for NO_x levels in the domestic glass sector. There are certain issues specific to the sector which affect the options for NO_x control. Some of these can be illustrated by a comparison with container glass e.g. potentially higher quality constraints; lower production volumes; smaller average furnace size; cullet restrictions; higher temperatures and longer residence times. All of these factors lead to higher specific energy consumption and increase the potential for NO_x formation. In general where electrical melting (either 100 % or predominantly electrical) is economically viable, and particularly for lead crystal, crystal glass and opal glass production the technique is considered BAT. In this case, the emission level associated with BAT would generally be 0.2 – 1.0 kg/tonne of glass melted.

Where electrical melting is not economically viable a number of other techniques could be used. The domestic glass sector utilises a wide range of furnace types and the most appropriate technique will generally be installation specific. It is envisaged that given the necessary time for development and implementation of techniques, the emission level for oxides of nitrogen (expressed as NO₂) associated with BAT will be 500 - 700 mg/Nm³ (or for oxy-fuel melting 0.5 – 1.5 kg/tonne of glass melted). This is based on the use of (or combinations of) primary measures (combustion modifications), oxy-fuel firing, SNCR, SCR or 3R/Reburning (regenerative furnaces only).

Stone wool cupolas do not generally give rise to substantial NO_x emissions and emissions less than 0.5 kg/tonne of melt can be achieved without specific controls. Where tank furnaces are used the emission level associated with BAT is considered to be equivalent to glass wool production. Ceramic fibre is produced exclusively with electric furnaces and NO_x emissions are generally significantly below 0.5 kg/tonne of melt.

Oxides of Sulphur

The determination of emission levels associated with BAT for each of the sectors is a complex subject with many inter-related and in some instances conflicting considerations. These issues are explained in detail in chapters 5 and 4 with the information presented here only an indicative summary.

A major influence is the choice of fuel and its sulphur level. Therefore, the circumstances for oil and gas firing are considered separately. Furthermore, certain formulations, particularly soda-

lime glasses, require the use of sulphates in the batch, and clearly such formulations will tend to show higher unabated SO₂ emissions.

It is envisaged that in most instances BAT for dust emissions will involve the use of a dust abatement system, which will often include acid gas scrubbing, and this is taken into account in the proposed emission levels associated with BAT in Chapter 5. The sulphated waste produced can generally be recycled with the furnace raw materials to avoid the generation of a solid waste stream. However, there is a limit to the extent to which the glass can act as a sink for the sulphur and the system can rapidly reach an equilibrium where a significant amount of the sulphur recycled is re-emitted. Therefore, with full dust recycling the desulphurisation effect of the scrubber can be limited by the capacity of the glass to absorb sulphur.

In order to reduce SO₂ emissions further it may be necessary to consider an external disposal route or if practicable to reduce fuel sulphur levels.. The economically viable options for recycling the material off-site are extremely limited and the most likely disposal route is landfill, resulting in a solid waste stream. From an integrated environmental approach there is a need to consider the relative priorities of the reduction of SO₂ emissions and the potential generation of a solid waste stream. The most appropriate approach may differ from process to process and for this reason emission levels are presented for where SO₂ reduction is the priority and for where waste reduction is the priority. In practice there are many cases where the lower emission level can be achieved with full dust recycling.

The table below summarises the emission levels associated with BAT for each sector and for various situations. Again this is only an indicative summary and reference should be made to Chapter 5 to allow consideration of the complexities involved.

Sector	BAT emission levels (mgSO ₂ /Nm ³)		Comments
	gas-firing	oil-firing	
Container glass with SO ₂ reduction as priority	200 - 500	500 - 1200	
Container glass with waste minimisation as priority	< 800	< 1500	Where mass balance does not allow the figures above to be achieved.
Flat glass with SO ₂ reduction as priority	200 - 500	500 - 1200	
Flat glass with waste minimisation as priority	< 800	< 1500	Where mass balance does not allow the figures above to be achieved.
Continuous filament glass fibre	< 200	500 - 1000	If sulphates in batch, gas-firing could be up to 800. For oil-firing, upper end of range relates to dust recycling.
Domestic glass	200 - 500	500 - 1300	If low sulphate in batch, then <200 for gas-firing. Figures in upper part of ranges relate to dust recycling.
Special glass including water glass	200 - 500	500 - 1200	Figures in upper part of ranges relate to dust recycling.
Glass wool	generally <50	300 - 1000	Generally low sulphate glass.
Stone wool (coke fired) with waste minimisation and recycling as priority.	(a) < 600 (b) < 1100 (c) < 1400		(a) Stone charge (b) 45 % cement bound briquettes (c) Cement briquettes inc. filter dust
Stone wool (coke fired) with SO ₂ reduction as priority.	(a) < 200 (b) < 350 (c) < 420		(a) Stone charge (b) 45 % cement bound briquettes (c) Cement briquettes inc. filter dust
Ceramic fibre (electric melting)	< 0.5 kg/tonne melt		Electric furnaces only, concentration will be case specific.
Frits	< 200	500 - 1000	Oil firing is rare.

Indicative summary of oxides of sulphur emission levels associated with BAT (expressed as SO₂)

Other Emissions from Melting

Each of the sector-specific sections in Chapter 5 has a subsection to cover those emissions from the melting operations other than dust, NO_x, and SO_x. The most significant of these “other emissions” are generally chlorides (expressed as HCl), fluorides (expressed as HF), and metals and their compounds. Certain metals are grouped together and termed either Group 1 or Group 2. Those metals, which fall outside of these groupings are either specified individually, due to their higher toxicity, or covered only within the category of dust, because their low toxicity does not justify specific consideration. The two Groups are given in the table below.

Group 1 metals and their compounds	Group 2 metals and their compounds
Arsenic	Antimony
Cobalt	Lead
Nickel	Chromium III
Selenium	Copper
Chromium VI	Manganese
	Vanadium
	Tin

Classifications of metals and their compounds

The BAT conclusions for most sectors relating to these substances were generally equivalent. BAT for controlling these emissions is considered to be raw material selection to minimise

emissions, combined with acid gas scrubbing, where appropriate. Acid gas scrubbing may not always be necessary either to protect the abatement equipment or to achieve the figures given for SO_x. Where this is the case, acid gas scrubbing is considered to constitute BAT if the levels identified below cannot be achieved by primary measures. The emission levels associated with BAT for the pollutants specified below are considered to be:

- Chlorides (expressed as HCl) <30 mg/Nm³
- Fluorides (expressed as HF) <5 mg/Nm³
- Metals (gas + solid phase) (Group 1 + Group 2) <5 mg/Nm³
- Metals (gas + solid phase) (Group 1) <1 mg/Nm³

In the frits and special glass sectors there are some cases with potential emissions of cadmium and thallium. The emission level associated with BAT for these metals and their compounds is <0.2 mg/Nm³. For the production of continuous filament glass fibre the fluoride emission level associated with BAT is 5 - 15 mg/Nm³. The lower end of this range relates to non-fluoride added compositions and the higher end relates to added fluoride compositions.

In the stone wool sector emission levels associated with BAT are also given for carbon monoxide and hydrogen sulphide. These are <200 mg/Nm³ and < 5 mg/Nm³, respectively.

Downstream Processes

Downstream processes vary greatly depending on the specific sector and installations involved and reference should be made to the sector specific sections in Chapter 5. However, with the exception of mineral wool some indicative emission levels associated with BAT are given below. Not all substances will be encountered in all installations or sectors, and certain substances are addressed in some of the sector specific sections that are not covered here because they apply to only one sector. Notwithstanding these issues, there is some commonality in the types of techniques that could be used if secondary abatement was appropriate.

- Chlorides (expressed as HCl) <30 mg/Nm³
- Fluorides (expressed as HF) <5 mg/Nm³
- Particulates <20 mg/Nm³
- Metals (gas + solid phase) (Group 1 + Group 2) <5 mg/Nm³
- Metals (gas + solid phase) (Group 1) <1 mg/Nm³

Emissions to Water

Aqueous emissions from the activities in the glass industry are generally low and not specific to the industry. However, a number of activities can give rise to more significant aqueous emissions. The emission levels given below are generally considered to be appropriate to protecting the water environment and are indicative of the emission levels that would be achieved with those techniques generally considered to represent BAT. They do not necessarily represent levels currently achieved within the industry but are based on the expert judgement of the TWG.

- Suspended solids <30 mg/l
- Chemical oxygen demand (Note1) 100 - 130 mg/l
- Ammonia (Kjeldahl) <10 mg/l
- Sulphate <1000 mg/l
- Fluoride 15 - 25 mg/l
- Arsenic <0.3 mg/l
- Antimony <0.3 mg/l
- Barium <3.0 mg/l
- Cadmium <0.05 mg/l
- Chromium (Total) <0.5 mg/l

Executive Summary

• Copper	<0.5 mg/l
• Lead (Note 2)	<0.5 mg/l
• Nickel	<0.5 mg/l
• Tin (Note 3)	<0.5 mg/l
• Zinc	<0.5 mg/l
• Phenol	<1.0 mg/l
• Boric acid	2 - 4 mg/l
• pH	6.5 - 9
• Mineral oil	<20 mg/l

(Note 1) - For the continuous filament glass fibre sector this figure is considered to be 200 mg/l. In general, chemical oxygen demand is quite low and the actual level associated with BAT may depend on the receiving water. If the receiving water is particularly sensitive levels below this figure may be required.

(Note 2) - For domestic glass processes utilising significant amounts of lead compounds, 1.0 mg/l is currently considered to be more appropriate. There are no overriding technical obstacles to the achievement of 0.5 mg/l, and given the necessary time for the development and implementation of appropriate techniques this figure will be achievable.

(Note 3) - For container glass processes utilising aqueous scrubbers for treating downstream emissions an emission level of <3 mg/l is more appropriate.

Under certain circumstances, discharge to a sewage treatment works or to other off-site treatment may also constitute BAT. Where this approach is proposed consideration should be given to the suitability of the receiving facility.

7) Project Conclusions and Recommendations

This chapter is divided into three sections: information exchange, general conclusions and recommendations for further work. The first section outlines the timescales and mechanisms for the information exchange exercise. A great deal of information was made available from industry and Member States and was generally of high quality. The available information was refined and validated during the consultation processes. It is recommended that this document be reviewed in the next 4 to 5 years.

The main general conclusions are:

- That the information exchange was successful and a high degree of agreement was reached following the second meeting of the technical working group.
- The industry is extremely diverse and it is not generally appropriate to specify a single technique as BAT in most cases.
- A great deal has been achieved in recent years to improve the environmental performance of the industry. However, further developments/improvements are expected particularly with primary techniques but also with the application of secondary techniques that have been more commonly applied in other sectors.

The main recommendations for future work are:

- A more in depth (preferably semi-quantitative) assessment of cross media issues would be beneficial.
- A more detailed consideration of the costs of techniques would be useful in determining BAT.
- When the work is reviewed a more in-depth assessment of techniques to improve energy efficiency would be useful, taking into account more recently available information.
- When the work is reviewed the progress with primary emission control methods should be reassessed.

- When the work is reviewed a reassessment should be made of those techniques which currently have some issues unproven or contested, either for the glass industry as a whole or in certain applications. In particular, sulphur dioxide removal, oxy-fuel firing and SCR.