SNAP CODE: **030314**

                                                                           030315

                                                                           030316

                                                                           030317

                                                                           040613

SOURCE ACTIVITY TITLE: PROCESSES WITH CONTRACT
                                                              Glass Production

NOSE CODE: **104.11.05**

                                                                        104.11.06

                                                                        104.11.07

                                                                        104.11.08

                                                                        105.11.03

NFR CODE: **1 A 2 f**

                                                                           2 A 7

1   ACTIVITIES INCLUDED

The activities described under chapter 040613 regard the process emissions during the production of different types of glass (flat glass, container glass, glass wool and other glass {including special glass}). The activities concerned with the combustion and the resulting emissions are described in the chapters 030314, 030315, 030316 and 030317. The emissions treated in this chapter are carbon dioxide emissions from the carbonisation process and emissions of micropollutants, heavy metals and dust, partly resulting from the combustion of fossil fuels, partly from the basic materials. For micropollutants, heavy metals and dust separate emission factors for combustion and process emissions are not available. The factors given are to be used as default values for the whole process.

2   CONTRIBUTION TO TOTAL EMISSION

The contribution of emissions released from the production of glass to total emissions to air in countries of the CORINAIR90 inventory is given as follows:

Table 1: **Contribution to total emissions to air of the CORINAIR90 inventory (28 countries)**

Source-activity	SNAP-code	Contribution to total emissions [%]						
		SO_2	NO_x	NMVOC	CH_4	CO	N_2O	NH_3
Flat Glass	030314	0.1	0.3	0	-	0	-	-
Container Glass	030315	0.1	0.2	0	-	0	-	-
Glass Wool	030316	0	0	-	-	-	-	-
Other Glass	030317	0	0.1	-	-	0	-	-

0 = emissions are reported, but the exact value is below the rounding limit (0.1 per cent)
- = no emissions are reported

Table 2: **Contribution to total emissions to air (OSPAR-HELCOM-UNECE Emission Inventory)**

Source-activity	Contribution to total emissions [%]							
	Arsenic	Cadmium	Chromium	Copper	Mercury	Nickel	Lead	Zinc
Glass industry	1.3	1.3	0.9	0.1	0.1	0.1	0.9	0.2

Table 3: **Contribution from the carbonisation process**

Source-activity	Contribution of carbon dioxide to total emissions [%]
Glass industry	

The emission of fluorides and dust are also important.

3   GENERAL

In the production of glass 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 similar.

The production of flat glass, container glass, glass fibres and commodity glass is dominated by large multinational companies, whereas domestic glass production (manufacture of table and decorative ware) take 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. /11, 12/

3.1   Description of Activities

The manufacturing process of glass consists of the following steps /5, 11, 12/:

- *Selection and controlling of raw materials.*

- *Preparation of raw materials:* preparation consists essentially of a weighing and mixing operation.

- *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 into glasswool mats is carried out (production of glasswool).

- *Curing:* the binder-coated fibreglass mat is allowed to cure (production of glasswool).

- *Annealing:* internal stresses are removed by heat treatment.

- *Finishing:* finishing includes in particular quality control and cutting (production of flat and container glass); finishing includes cooling the mat, and backing, cutting, and packaging the insulation, as well as quality control (production of glasswool); finishing includes quality control, cutting, and for hand-shaped glass, further decorative treatment such as engraving or polishing (special glass).

A large variety of glass with differing chemical composition is produced, and therefore a great diversity of raw materials is used in glass manufacturing /15/. Main raw materials are silica sand, lime, dolomite and soda for the production of soda lime glass, as well as lead oxide, potash and zinc oxide for the production of special glass /11, 13/. Glass wool is a boro-silicate glass, which is manufactured from sand, limestone, dolomite, boric-oxide and other oxides. Refining agents such as antimony oxide, nitrates, sulphates, and colouring agents like metal oxides and sulphides enter also in the composition of special glass, e.g. TV glass, crystal glass, etc. /15/.

Nowadays, approximately 85 % of the glass produced in Europe is made up of soda lime, and consists principally of flat and container glass. The remaining 15 % of the European glass production include glass wool and special glass such as hand-shaped glassware, lighting, TV-screen, optical glasses. /14/

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 80 % of the quantity 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. /14/

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. The

different materials are weighed and mixed, and the mixed batch is transferred to the melting furnace. /11/

3.2   Definitions

Borosilicate glass: a silicate glass that is composed of at least five percent oxide of boron and is used especially in heat-resistant glassware.

Crown glass: alkali-lime silicate optical glass having relatively low index of refraction and low dispersion value.

Fibreglass: glass in fibrous form used in making various products (as glass wool for insulation).

Flint glass: heavy brilliant glass that contains lead oxide, has a relatively high index of refraction, and is used in lenses and prisms.

Float glass: flat glass produced by solidifying molten glass on the surface of a bath of molten tin.

Glass wool: there exist two types of glass fibre products, textile and wool, which are manufactured by similar processes. Here only glasswool is taken into account: glass fibres in a mass resembling wool and being used especially for thermal insulation and air filters.

Lead glass: glass containing a high proportion of lead oxide and having extraordinary clarity and brilliance.

Optical glass: flint or crown glass of well-defined characteristics used especially for making lenses.

3.3   Techniques

For container glass production, the melting stage can be preceded by a pre-heating of the mixed batch /11/; however, this is not commonly done: around 10 batch preheaters are currently in operation world wide /14/.

The melting process is the most important step with regard to quality and quantity of glass, which depend on the furnace design /12/. In the melting furnaces, the glass is melted at temperatures ranging from 1,500 °C to 1,600 °C (the flame temperature achieving more than 2,000 °C) and are transformed through a sequence of chemical reactions to molten glass. Although there are many furnace designs, furnaces are generally large, shallow, and well-insulated vessels that are heated 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 bed. /6/ In the glass production, both continuously and batch-wise operated melting furnaces are in use. In large glass manufacturing installations as

it is the case for 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 has to be removed from the pot furnace by hand. /12, 15/

Some characteristics of the above mentioned furnaces are summarised in the following table.

Table 4: Some characteristics of furnaces used in glass production /15, 34/

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 a higher energy efficiency and a higher flame temperature, the combustion air is preheated. Air preheaters in use are recuperative or regenerative. /11, 16, 17/ 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 /11, 14/. For the production of container glass, approximately 70 % of the furnaces are operating with oil and 30 % with natural gas. City gas or liquified gas are used in isolated cases. /7/

The furnace most commonly used within flat glass production is a cross-fired furnace with regenerative preheating working in the continuous mode; very few exception with end-fired furnaces do exist in the production of printed glass /14/. In container glass production, mostly regeneratively heated furnaces are in use /14/.

Additional electric heating is frequently employed to increase output and to cope with peak-load demands. Between 5 to 30 % of the total energy is passed in the form of electrical energy directly into the glass batch through electrodes. /7/

Table 5: Specific energy demand for the production of glass

Type of Glass	Specific Energy Demand [GJ/Mg glass]
Flat glass	7
Container glass	6
Glass wool	12
Special glass	25

However, more advanced glass furnaces do exist with lower specific energy demands (for example around 4 GJ/Mg /7/ in the production of flat glass).

Glass Wool Manufacturing Process

In the "indirect" melting process, molten glass passes to a forehearth, where it is drawn off, sheared into 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, where bubbles and particles are removed by settling, and the melt is allowed to cool to the proper viscosity for the fibre forming operation. /cf. 35/

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 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 that are then attenuated (stretched to the point of breaking) by high velocity, hot air, and/or a flame. /35/

3.3.1   Gas- and Oil-Fired Glass Melting Furnaces with Regenerative Air Preheating

The common feature of all tank furnaces is a large ceramic tank which serves as a melting container. In general, tank furnaces are operated by alternating flame-heating based on the regenerative principle. /cf 7/

Regenerative air preheaters use a lattice of brickwork to recover waste heat from the exhaust gas. The regenerators 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 from the waste gas to the combustion air. The 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. The combustion air flow and the waste gas flow are then reversed: the combustion air flows then through the hot chamber and is heated there, while the waste gas flows through the second chamber, reheating the refractory lattice. The temperature of the incoming air achieves up to 1,350 °C, and the waste gas leaves the regenerative chambers with a temperature of about 500 – 550 °C. /11, 15, 18/

Depending on the arrangement of the burners and the position of the flames, one differentiates between cross-fired and end-fired tanks. /cf 7/ Because of the higher number of burner necks and the larger regenerator chambers, the specific energy consumption is higher for cross-fired furnaces than for comparable end-fired furnaces. /15/ Small and medium-sized tanks are built as end-fired tanks, larger ones as cross-fired burner tanks. In both

arrangements, the flames flow closely over the molten glass surface and transmit heat to it, primarily by radiation. /cf 7/

Cross-fired furnaces give better control of melting chamber temperatures 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 120 m^2 more and more are laid down as end-fired furnaces, since they show a simpler arrangement, a lower price and a higher energy efficiency than comparable cross-fired furnaces. /15/

3.3.2   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 /15/. 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 recuperators are often connected to waste heat boilers for steam or hot water generation. /11, 18/ The lower flame temperatures achieved (compared with those from regenerative systems) eliminates them from 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. /14/

3.3.3   Pot Furnaces

The use of pot furnaces is confined to manually worked specialty glasses, with intermittently operation and melting temperatures under 1,460 °C. One furnace usually is 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 heat consumption (relative to glass production) of pot furnaces is comparatively high and averages 30 GJ/Mg glass produced. /cf. 10/

3.3.4   Electric Furnaces

Electric furnaces melt glass by passing an electric current through the melt. Electric furnaces are either hot-top or cold-top. The former use gas for auxiliary heating, and the latter use only the electric current. /6/ Electric heating is used either for additional heating (electric boost) or almost exclusively in small- and medium-sized furnaces for the manufacturing of special glass such as lighting glass, glass fibres, crystal glass. /11, 16, 17/ One case of soda lime glass manufacturing via electric heating is currently known, but is restricted to low furnace outputs and special composition glasses /14/. Further information on electric heating is given later in this chapter.

3.4   Emissions

3.4.1   Combustion-related Emissions

Pollutants released during the manufacture of glass are sulphur oxides (SO_x), nitrogen oxides (NO_x), volatile organic compounds (non-methane VOC and methane (CH_4)), carbon monoxide (CO), carbon dioxide (CO_2) and nitrous oxide (N_2O). Also emissions of hydrogen chloride, hydrogen fluoride, particulate matter and heavy metals are produced by the melting process. Emissions of particulate matter can also result from handling raw materials. Heavy metals will be present in the particulate matter. According to CORINAIR90 of these, the main relevant pollutants are SO_2, NO_x, and CO_2 (see also Table 1).

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, which in turn depends on chemical reactions taking place within this time. The proportion of batch gases from exclusively flame-heated furnaces represents 3 to 5 % of the total gas volume. /7/

Sulphur Oxides

The amount of SO_2 released during glass manufacturing is mainly determined by the sulphur content of the fuel, the sulphate content of the molten batch and the sulphur absorption ability of the glass produced /7, 22/.

The sulphur contained in the batch is partly bound in the glass as SO_3. Glass contains up to 0.4 wt.-% SO_3 /7/. The SO_3-content is 5 to 10 % of the SO_2-content. The amount of SO_3 depends on the excess air and the combustion temperature. /cf. 7/

The SO_2 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 SO_2 content in the off-gas during the firing interval is observed. This is most likely due to 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 sulphurous species in the air preheater /22/. The oxygen content in the upper zone of the furnace also has an impact on the SO_2 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 SO_2 content of the off-gas is observed. This is due to the fact that the sulphur absorption ability of the molten glass decreases with a decreasing oxygen content in the upper furnace zone /22/.

Since natural gas and city gas contain only trace amounts of sulphur, a lower SO_2 content in the off-gas of glass melting tanks fired with gaseous fuels is observed compared to oil fired glass melting tanks. /11/

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 being nitrogen dioxide NO_2). The

concentrations of nitrous oxide in glass furnace waste gases are in general below the detection limit. /19/

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 nitrates in the raw materials for certain glasses. /19/ In the glass melting furnace, the temperature ranges from 1,500 °C to 1,600 °C /15/, leading to flame temperatures above 2,000 °C /14/. 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, oxygen content in the 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 burner and melting furnace design, amount of excess air, mixing of fuel and combustion air, etc. /18, 20, 21/ Prompt NO_x is relatively small, and when firing natural gas, fuel NO_x is sensibly zero. /19/

The conversion of nitrogen compounds contained in the raw materials and in the refining agents contributes also to NO_x emissions due to the batch NO_x formation. The quantity of nitrogen oxides arising from the feed material (see also chapter B4614) will be affected by the concentration and composition of the nitrates in the feed. /8/ 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/Nm^3 for clear glass, 4,000 mg/Nm^3 for tint glass /33/. It must be acknowledged that such tints are only occasionally manufactured.

When using gas fired glass melting tanks, the achieved flame temperature is higher compared to oil. As a consequence, oil fired tanks emit less NO_x than gas fired tanks. Moreover, as end-fired furnaces allow a more favourable flame characteristic than cross-fired glass melting furnaces, the first show lower NO_x emissions. Recuperative furnaces induce lower NO_x emissions than regenerative furnaces, due to their lower preheating temperature. /11, 18/ Following table gives the NO_x-concentrations for some types of furnaces.

Table 6: NO_x-emissions for some types of furnaces /11, 23/

Type of Furnace / Fuel	NO_x-Emission* [mg/Nm^3]
Oil fired recuperatively heated furnace	400 – 1,400
Gas fired recuperatively heated furnace	400 – 1,600
Oil fired regeneratively heated furnace • end-fired furnace • cross-fired furnace	 1,000 – 2,400 1,600 – 3,600
Gas fired regeneratively heated furnace • end-fired furnace • cross-fired furnace	 1,400 – 3,000 1,600 – 4,000

* These values refer to an O_2-content in the waste gas of 8 vol.-%.

3.4.2   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 which are emitted to air are mainly arsenic, cadmium, chromium, lead, tin, and selenium.

If fuel oil is used in the combustion process also nickel and vanadium may be found. In south and eastern Europe fluorspar is often used in the melting process. If recycled glass originating from these countries some fluorine may be emitted.

Basic materials for glass production are silicium oxide and oxides of alkalimetals. The alcali metal oxides are produced during the process from dissociation of carbonates. The emission factors given under /38/ 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, hydrocarbonates, sulfates, or a relevant amount of recycled glass are used corrections must be made.

3.5   Controls

3.5.1 NO_x-Emission Reduction Measures

3.5.1.1 Primary Emission Reduction Measures
3.5.1.1.1   *Lowering the Amount of Excess Air*
Technical Aspects
This relatively simple measure aims at achieving near stoichiometric combustion, resulting in a lower oxygen concentration in the reaction zone, and consequently in a reduction of nitrogen oxides. Sealing of the furnace against inleaked (false) air is an additional measure to lowering the amount of excess air. NO_x emission reduction efficiencies between 30 and 70 % (depending on the initial level) are achievable /18/. Further a slight decrease in specific energy consumption is observed /14/.

However, it may be noted that a move to near stoichiometric combustion can give a significant reduction in NO_x, but may lead on the other hand to an increase of the emissions of other pollutants (e. g. CO, dust) as well as to a slight increase of energy demand. Furthermore, the quality of the product and the furnace lifetime can both be influenced by the O_2-content in the upper zone of the glass melting furnace. /11/

Side-Effects
Near stoichiometric combustion (as performed when lowering the amount of excess air) lowers the nitrogen oxides formation, but in the same time induces slightly increased emissions of measured SO_2.

3.5.1.1.2   *Reduced Air Preheating*
Preheaters have originally been used to improve the heat transfer from flame to batch, and have proved to lead to savings in energy consumption /14/.

Technical Aspects
By reducing the air preheating temperature, the flame temperature is reduced and consequently the formation of nitrogen oxides. Reduction of the preheating temperature can

be carried out by using recuperative air preheaters instead of regenerative air preheaters /11/. However, when switching from a regenerative to a recuperative preheater, the melting capacity is reduced, inducing the need of larger facilities and thus higher costs. Furthermore, recuperative air preheaters achieve lower energy efficiencies. /14/

Side-Effects
The use of recuperative air preheaters instead of regenerative ones results in a reduction of flame temperature and hence glass quality, pull rate and energy efficiency /14/.

3.5.1.1.3   *Staged Combustion*
In a classical combustion facility, the totality of fuel and air/oxygen is injected at the same place. The resulting flame is then composed of a hot and oxidising primary zone located at the flame root and a colder secondary zone located at the flame end. The primary zone generates most of the NO-emissions, which increase exponentially with the temperature, whereas the contribution of the secondary zone is rather modest. Staged combustion aims at decreasing the temperature in the primary zone. Therefore, only a part of the fuel or of the air/oxygen is injected at the burner, the rest being injected downstream of the main combustion zone.

Emission reduction rates in the range of 50 to 70 % can be achieved by combining staged combustion with other primary measures. It is estimated that about 30 to 50 % of the reduction may originate from staged combustion alone. Concentrations around 700 mg/Nm^3 may be reached in the best cases. /24/

Air/Oxygen Staging
The KORTING air staging process /25/ has been tested at three furnaces in Germany at the beginning of the 90s, but has been abandoned meanwhile. Maintenance problems have appeared on the air ejector at high temperatures, and anyway this technique does not allow as good reduction efficiencies as do state-of-the-art low-NO$_x$ burners. /24, 27/

Oxygen staging with the Oxygen Enriched Air Staging (O.E.A.S.) process /26/ is still in a state of development (three test furnaces are running in the USA) and it is therefore impossible to conclude about efficiency and applicability. /24/ Due to the high costs of oxygen, this technique will most probably not be generally applied /14/.

Fuel Staging
A lack of fuel in the primary zone decreases the flame temperature. The fuel-rich secondary zone becomes reducing, generating hydrocarbon radicals reducing NO into molecular nitrogen. About 8 to 10 % of the fuel is injected into the combustion air in the port neck, resulting in sub-stoichiometric conditions in the main flame, and therefore leading to reduced NO$_x$ formation. The remaining fuel is injected within the furnace and ensures complete burnout. NO$_x$ concentrations below 800 mg/m^3 have been reported with initial values between 1,800 and 2,200 mg/m^3. /11/

Fuel staging has proven to be rather attractive: it has been implemented at 12 German glass melting tanks for nitrogen oxides abatement /11/; however, this measure is expected to be phased out with the installation of new low-NO$_x$ burners /14/.

Side-Effects
No side-effects have been observed.

3.5.1.1.4   Flue Gas Recirculation
Technical Aspects
This technology is in principle similar to staged combustion: NO_x-emissions are reduced by lowering the flame temperature. Secondary air is mixed with a part of the flue gas, and this oxygen lacking air is injected as combustive agent in the furnace.

Three tests of flue gas recirculation have been performed in the glass production sector /14/. NO_x emission abatement rates between 16 and 44 % could be achieved, but this technology proved to be difficult to be implemented, and has meanwhile been abandoned. /24/

Side-Effects
No side-effects have been observed, but it must be acknowledged that the experience is very limited.

3.5.1.1.5   Reburning / 3R Process
The reburning process and the 3R process are similar technologies, based on the same principle. In the literature, both processes are either considered as primary NO_x-emission reduction measures or as secondary NO_x-removal options. In the framework of this report, the reburning / 3R process will be presented as a primary measure, since it can be compared to the fuel-staging process.

Technical Aspects
In both the reburning and 3R processes, NO or its precursors (HCN, NH_y) formed in the combustion zone undergo reduction by injection of natural gas or fuel as the waste gases enter the regenerators from the melting chamber. In the 3R process, hydrocarbon fuel is injected into the waste gas downstream of the glass melting furnace tank. /28/ The added fuel does not burn, but pyrolyses to form radicals converting the nitrogen oxides in the waste gas into nitrogen and water. A major advantage of this process is the possibility of using all kinds of hydrocarbon fuels (natural gas, fuel oil...) /14, 19/. Air is added downstream of the denitrification zone to ensure burnout of residual "fuel" fragments.

Reburning is at an experimental stage, whereas the 3R process has been installed at one German float glass production site, achieving nitrogen oxides concentrations below 500 mg/m^3 /27/. According to /29, 30/, 3R has been successfully operated on float furnaces in Finland and California, and demonstrated on furnaces in the TV glass production (in Korea /14/), container, and shaped glass. In all cases, a nitrogen oxides abatement up to 85 % could be achieved. One further furnace has been equipped with 3R at a float glass production site in the UK. This technology is now applied by two float glass companies in the USA /14/.

Side-Effects
As this process is based on hydrocarbon fuel injection, an increased energy consumption is to be expected. Nevertheless, this technology ensures burnout of residual fuel fragments; subsequently, achievable levels of CO may be lower than with conventional combustion.

Moreover, if supplementary heat recovery is available, the additional CO_2 originating from the increased use of fuel can be compensated by the reduction that would have arisen from fossil fuel boilers or from the power station. /19/

3.5.1.1.6   *Low-NO$_x$ Glass Melting Furnaces*
Technical Aspects
In recent years, new melting furnaces have been developed achieving low NO_x emissions: the FlexMelter® and the LoNOx® melter /28, 31/.

The LoNOx® melter is a combined electrical/fossil fuel fired melting tank with recuperative air preheating, including a batch preheating step. For this melting furnace, energy efficiency has been increased to compensate for the lower thermal efficiency of the air preheater compared with the regenerator and so the heat consumption of this modified recuperatively fired furnace can be compared to conventional regeneratively fired furnaces: waste gas from the melting furnace is first fed to the recuperative air preheater and afterwards used to preheat the cullet. Air temperatures of about 750 °C are reached /22/. This melting furnace allows to achieve NO_x concentrations below 500 mg/m^3 in the waste gas. /21, 27, 28, 31/ This type of low NO_x melter is exclusively used in the container glass manufacturing at about 70 – 80 % cullets undergoing preheating /14/.

The FlexMelter® has originally been developed for discontinuous production, but is operated nowadays both in the continuous and discontinuous mode. Typical applications are glass fibres for insulation, automobile lighting, and other special glass such as crystal glass. The relatively low flame temperatures from recuperative air preheaters precludes their use for typical flat glass and most container glass production /14/.

Currently, three low-NO_x melting furnaces with a total capacity of approximately 800 Mg/d glass are operated in Germany. /14/

Side-Effects
No side-effects have been observed.

3.5.1.1.7   *Oxy-Fuel Firing*
Technical Aspects
By this very effective, but also very expensive technology, preheated combustion air is replaced by high purity oxygen and there is thus no need for regenerators. Even though the resulting nitrogen oxide concentration in the flue gas is higher with oxy-fuel firing, mass emissions of NO_x are lower. Therefore, the actual mass flow has to be considered. Oxy-fuel firing can be applied to pot furnaces and day tanks /33/. The conversion from air to 100 % oxygen may result in a 50 - 60 % reduction of energy consumption /33/. As regards the achievable NO_x reduction rate, /9/ quotes a 80 to 95 %-reduction for oxy-fuel firing over 100%-air firing (50 % in the worst case of existing furnaces with poor sealing conditions /33/).

About one hundred furnaces are run world-wide on the oxy-fuel mode, representing approximately 4 % of the whole glass production. Since the beginning of the 90s, oxy-fuel combustion has gained importance mainly in the USA, where it represents nowadays about

10 % of the number of glass melting furnaces. The reason why oxycombustion is so popular in the USA is mainly due to economical reasons: sometimes nitrogen can be used for non-melting applications in the factory or associated products and then the overall cost of the oxygen is reduced. Furthermore, when applying this technology, an increase in capacity can be observed as well as an improvement of the product quality /33/. In Germany, two container glass melting furnaces are operated in the oxy-fuel mode, and several others are planned, among which two special glass production sites /11, 27, 14/. The application fields of oxy-combustion are basically the glass fibre, TV glass, container and special glass industries /8/.

Besides the environmental aspect, since regenerators and recuperators can be omitted, low investment is a further advantage increasing the interest of glass producers in oxy-fuel firing. Moreover, the change from a recuperatively heated furnace to oxy-fuel firing is very easy /14/. For an energy balance, production of oxygen has to be considered, and energy savings can be achieved in the case of an effective heat recovery. It should however be mentioned that the related operating costs are higher compared to 100% air firing, due to the high price of oxygen and that this technology is not yet applicable to every field of glass production /24, 28/. Furthermore, oxy-fuel firing is not effective when nitrate containing batches are melted, since only thermal NO_x is being reduced by oxy-combustion /29/. Another problem which had been reported several times is the corrosion of the furnace superstructure and crown due to higher concentration of volatiles in the furnace. /14/

Side-Effects
Besides NO_x, other pollutants can be abated via oxy-fuel firing: volatile components allowing substantial savings in batch materials and particulates in special glass (e. g. borosilicates). Energy savings can be expected when no consideration of the oxygen production is made. However, since electricity is required for the production of oxygen, the total energy consumption is the same as with conventional fired furnaces. /10, 14, 24/ Furthermore, it must be mentioned that a transfer of pollution occurs upstream towards electricity production, therefore not solving the pollution problem.

3.5.1.1.8 *Electric Melting*
Technical Aspects
Molten glass is an electricity conductor and thus can be heated via electrodes immersed in the bath of glass. These electrodes are generally made up of molybdenum or platinum, and are located either at the top, at the bottom or at the walls of the furnace tank. In electrically heated furnaces, no direct emissions are released. Furthermore, compared to conventional regeneratively fired furnaces, electric melting furnaces show several advantages such as good temperature control and preheating of the batch inherent to the system, but the following drawbacks should be mentioned:

- the pollution is transferred upstream, towards electricity production;
- the lifetime of an electric melting furnace is reduced compared to a conventionally fired one;
- the furnace size is limited;
- an incompatibility between glass and electrodes occur for some glass compositions;
- high operating costs related to energy costs may be expected. /15/

Electric melting is currently limited to production of special glass, especially crystal glass, and to glass fibre production /13, 24/. Very small units have been constructed in the float industry for specially formulated glasses only /14/.

Side-Effects
Via electric melting, pollution is transferred upstream towards electricity production.

3.5.1.2 Secondary Emission Reduction Measures

Even though high NO_x emission reduction can be achieved by primary measures, especially via combustion modifications and the reburning/3R process, secondary measures can be used in some cases to meet more stringent standards. Proven NO_x-abatement measures in the glass industry are the selective non-catalytic (SNCR) and catalytic (SCR) reduction processes.

3.5.1.2.1 Selective Non Catalytic Reduction (SNCR)
Technical Aspects
Ammonia is injected at an over-stoichiometric ratio into the waste gas stream of the glass melting furnace within a temperature window ranging from 850 to 1,100 °C. This temperature window is the most important parameter with regard to satisfactory NO_x conversion, in parallel with avoiding an increased ammonia slip. In regenerative glass melting furnaces, the above given temperature window can generally not be met. Therefore, this secondary measure is rather suitable for recuperatively heated furnaces, although SNCR technology can be found also in regeneratively fired glass melting furnaces. /18, 27/

The NO_2 conversion and the NH_3 slip are function of the amount of NH_3 injected: an appropriate NH_3 distribution in the waste gas is required to obtain a satisfactory conversion rate and ammonia slip. /11/

The SNCR process is characterised by relatively high costs with regard to a rather low NO_x-removal efficiency, typically around 50 % /14, 19/, which is not sufficient as regards European regulations.
Today in Germany, 6 glass melting plants are equipped with SNCR technology, and three further installations are planned /27/. Two further installations are located in the USA, and one in Switzerland /24/. Operational parameters of the six German plants are given in Table 7.

Table 7:   Operational parameters of 6 SNCR installations in the European glass production sector /27/

Plant	1	2	3	4	5	6
Furnace	Recuperative	recuperative	recuperative	regenerative	recuperative	regenerative
Technical / Experimental	Technical	technical	technical	technical	technical	technical
Fuel	Natural gas	natural gas	heavy oil	natural gas / heavy oil	natural gas	natural gas
Glass	Special	special	container	water	special	soda lime
Waste gas flow rate	10,000 m^3/h	10,000 m^3/h	25,000 m^3/h	25,000 m^3/h	10,000 m^3/h	20,000 m^3/h
Ammonia feeding	Downstream Recuperator	downstream recuperator	between two recuperators	downstream first regenerator	downstream recuperator	middle of regenerator
Dissolved / gaseous NH$_3$	Gaseous	gaseous	gaseous	solution	gaseous	gaseous
Start of operation	1989	1992	1992	1989 / 1990	1994	1994
Efficieny	84 %	86 %	75 %	50 – 60 %	ca. 80 %	50 – 60 %
Ammonia slip	6 mg/m^3	23 mg/m^3	< 30 mg/m^3	< 30 mg/m^3	< 30 mg/m^3	< 30 mg/m^3
NO$_x$ content in the cleaned gas*	180 mg/m^3	470 mg/m^3	<500 mg/m^3	<800 mg/m^3	350 mg/m^3	650 mg/m^3

* These values refer to an O$_2$-content in the waste gas of 8 vol.-%.

Side-Effects

Neither emissions to water, nor solid waste occur. But an increase in energy consumption and an ammonia slippage can be observed. The use of ammonia on-site is a potential safety hazard.

3.5.1.2.2   Selective Catalytic Reduction (SCR)
Technical Aspects

Here, the reduction of nitrogen oxides is based on the injection of gaseous or aqueous ammonia in a near stoichiometric ratio into the waste gas of the glass melting furnace in the presence of a catalyst and within a temperature window between 300 and 400 °C. A NO$_x$-abatement up to 90 % can be achieved. Some years ago, in glass production, catalyst lifetime was reduced by the presence of sodium sulphate in the waste gas which blocks and poisons the catalyst, but nowadays a catalyst can already achieve up to 4 years lifetime, and therefore, SCR has reached the status of a proven technology. /27/ However, the SCR applied in the glass manufacturing industry is always operated with an electrostatic precipitator, in order to achieve concentrations of soda dust below 10 mg/m^3, which may be a poison to the catalyst. For the same reason of catalyst poisoning, natural gas is preferred over oil as a fuel. /14/

Six SCR installations at glass melting plants are implemented in Germany, mainly in the field of special glass production (e. g. TV screen glass) /14/. In Hombourg (France), a SCR facility has been started in 1997 in the float glass production /19, 32/. Table 8 gives an overview of the operational parameters of SCR at six German glass production plants.

Table 8: Operational parameters of 6 SCR installations in the German glass production sector /5, 27, 33/

Plant	1	2	3	4	5	6
Furnace	Regenerative	regenerative	regenerative	regenerative	regenerative	regenerative
Fuel	Natural gas	natural gas	natural gas	natural gas	natural gas	natural gas
Type of Glass	Container	special	special	container	special	special
Waste gas flow rate	50,000 m^3/h	50,000 m^3/h	40,000 m^3/h	60,000 m^3/h	40,000 m^3/h	40,000 m^3/h
Dissolved / gaseous NH_3	Solution	solution	gaseous	solution	solution	gaseous
Catalyst	Zeolithe	V_2O_5/TiO_2	V_2O_5/TiO_2	V_2O_5/TiO_2	V_2O_5/TiO_2	V_2O_5/TiO_2
Number of layers	1	1	1	2	2	1
Start of operation	1987	1989	1991	1994	1994	1994
Efficiency	55 %	75 %	70 %	76 %	n. a.	75 %
Ammonia slip	28 mg/m^3	< 30 mg/m^3	< 30 mg/m^3	2 mg/m^3	< 30 mg/m^3	< 30 mg/m^3
NO_x content in the cleaned gas	480 mg/m^3	1,000 mg/m^3	1,350 mg/m^3	500 mg/m^3	< 1,500 mg/m^3	< 1,000 mg/m^3

n. a. = data is not available

The installation at plant 1 was stopped in June 1997 in favour of primary measures /14/. The only SCR installed at a container glass production plant is currently running at PLM Glashütte Münder, where clean gas concentrations of 500 mg/Nm^3 are achieved (low NO_x burners are already installed) /5, 33/.

Side-Effects

SCR generates solid waste via deactivated catalyst, but it can often be reprocessed by the manufacturer or be used as combustion material. As for SNCR, the increased energy consumption and ammonia slippage have to be accounted for. The use of ammonia on-site is a potential safety hazard.

3.5.2 SO$_x$-Emission Reduction Measures

3.5.2.1 Primary Emission Reduction Measures

The most important option for the reduction of SO$_2$ emissions from glass melting furnaces is the use of fuels with a lower sulphur content. SO$_2$ emissions from gas fired glass melting tanks are lower than the emissions from oil fired furnaces, since gaseous fuels have a lower sulphur content than liquid fuels. /11/ However, the selection of fuels depends on their availability and on the furnace design in place. /7/

Furthermore, the melting furnace should be operated in such a way that the sulphur absorption ability of the melt is not decreased: it it thus necessary to obtain a certain oxygen concentration in the upper zone of the furnace. /11/

3.5.2.2 Secondary Emission Reduction Measures

Emissions of sulphur oxide from the off-gases of glass melting furnaces can be removed via sorption, e.g. by supply of appropriate sorbents (dry sorbent, or calcium and sodium based sorbents). Besides sulphurous compounds, hydrogen chloride, hydrogen fluoride, and gaseous heavy metals are also removed by this process. Removal efficiency for the different compounds is mainly determined by the amount of sorbent used and by the temperature at which the reaction takes place. A higher temperature leads to higher removal rates for SO$_2$ and hydrogen chloride. The removal of hydrogen fluoride is slightly lower at higher temperatures. /22/

3.5.3 Emission Reduction Measures for Other Pollutants

Measures for decreasing air emissions from the combustion process will 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.

4 SIMPLER METHODOLOGY

An estimation of the emissions can be calculated by using production statistics and generalised default emission factors as presented in /38/. The values given for the carbonisation process are very much dependant on the local situation and can only be used if no information is available.

5 DETAILED METHODOLOGY

A detailed calculation should be based on individual plant information about the amounts of substances added. Also the amount of recycled glass used should be available. However these data are often confidential. Also fuel information and information about local abatement methods should be available.

6   RELEVANT ACTIVITY STATISTICS

Glass production statistics are available from several national and international sources.

7   POINT SOURCE CRITERIA

The production of glass is usually connected to medium size stacks that may be regarded as point sources.

8   EMISSION FACTORS, QUALITY CODES AND REFERENCES

Table 9:   Emission factors to air in [g/Mg glass] for heavy metals and micropollutants for glass production in general

Substance	Default value	Range
Arsenic	0.10	0.1 - 0.25
Cadmium	0.15	0.05 - 0.25
Chromium	2.5	0.5 - 5
Copper	0.5	0.4 - 1.1
Lead (1)	10	2 - 24
Mercury	0.05	0.04 - 0.07
Nickel	2	1.2 - 2.6
Selenium	20	2.5 - 24
Zinc	10	5 - 24
Dichloromethane	5	0 - 11
Fluorine	30	5 - 70
Dust	400	3 - 800

The emission of lead is mainly determined by the amount of recycled glass used. /37/

Table 10: Theoretical process emission factors for carbon dioxide from the carbonisation process in [kg/Mg product] in relation to the alcaline content of the product

Glass type	sodium oxide (wt %)	potassium oxide (wt %)	Magnesium oxide (wt %)	calcium oxide (wt %)	barium oxide (wt %)	Carbon dioxide
Container glass	12-14	0.3-0.5	0.5-3	10-12	-	171-229
Flat glass	13.6	0.3	4.1	8.6	-	210
Continuous filament fibres						
E-fibres	< 2	< 2	20-24	20-24	-	157-203
AR-fibres	13-15	13-15	4-6	4-6	-	92-172
R/S-fibres	< 1	< 1	9-16	9-16	-	71-182
D-fibres	< 4	< 4	0	0	-	0-28
C-fibres	15-20	15-20	10-30	10-30		149-470
ECR-fibres	< 1	< 1	22-27	22-27	-	173-302
A-fibres	12-15	12-15	10-15	10-15		135-270
Special glass						
CRT panel	6.6-9.4	6.6-8.4	0-1.2	0-3.2	0	78-144
CRT tube	5.8-6.7	7.8-8.1	0.6-2.2	0.9-3.8	0	91-139
Glass tube, earth alk	12.5	2.5	2	4	0	154
Glass tube, borosilicate	3.5-6.5	0.5-1.5	0.01-0.5	0.01-1	0	27-66
Borosilicateglass	3.5-6.5	0.5-1.5	0.01-0.5	0.01-1	0	27-66
Opaque lighting glass	13.6	1.8	0	9.4	0	178
Lamb bulb	3-4	1.5-2.5	0.5	0.5	0	38-49
Glass ceramic	0.5-10	0	0-1	0.5-7	0	7.5-137
Quartz	0	0	0	0	0	0
Boron crown optical	0-5	12-18	0	0-0.3	0	56-122
Fluorine crown optical	0	0	0	0	20	57
Waterglass sodium sil.	22.5-24	0	0.008	0/008	0	160-171
Waterglass potassium silicate	0	27-32	0.008	0.008	0	126-150
Glass wool	12-18	12-18	8-15	8-15	0	119-292
Stone wool	0.5-5	0.5-5	30-45	30-45	0	238-527

The emission factors in Table 10 only give the theoretical amount of carbon dioxide emitted. Especially for container glass the amount of recycled glass may be up to 85 %.

8.1 Production of Flat Glass

For the situation in the Netherlands, the following can be proposed:

Emission factors for flat glass are given in kg/Mg glass.

handling/shipping:

dust: 0.15 kg/Mg

melting oven:

SO_2	3.0 kg/Mg
CO_2	140 kg/Mg
F_g	0.055 kg/Mg
Cl_g	0.06 kg/Mg
dust	0.37 kg/Mg

fuel:

SO_2	3.0 (fuel oil) kg/Mg
CO_2	530 kg/Mg
NO_x	5.5 kg/Mg
CO	0.09 kg/Mg

Heavy metals are incorporated in the dust emissions. The available information about compositions is scarce. The only consistent information is based on the work of Jockel and Hartje /10/, also incorporated in the PARCOM-ATMOS Manual. This information, based on the situation in Germany, is given in Table 11.

Table 11: Emission factors for glass production in [g/Mg glass] generalised for the situation in Germany.

Substance	Emission factor [g/Mg glass]	Range [g/Mg glass]
Arsenic	0.12	0.1-0.24
Cadmium	0.15	0.06-0.24
Chromium	2.4	0.5-5
Copper	0.6	0.4-1.1
Lead	12	2-24
Mercury	0.05	0.036-0.072
Nickel	1.9	1.2-2.6
Selenium	18	2.4-24
Zinc	11	4.8-24

Table 12: Emission factors for flat glass production[6)]

	Type of fuel			NAPFU E code	Emission factors						
					SO_2[3)] [g/GJ]	NO_x[4)] [g/GJ]	NMVOC[5)] [g/GJ]	CH_4 [g/GJ]	CO [g/GJ]	CO_2 [kg/GJ]	N_2O [g/GJ]
s	Coal	hc	steam	102	650[1)]	300[1)]	15[1)]	15[1)]	100[1)]	93[1)]	4[1)]
s	Coal	bc	brown coal/lignite	105	500[1)]	300[1)]	15[1)]	15[1)]	100[1)]	113[1)]	3.5[1)]
s	Coal	bc	briquettes	106	220[1)]	300[1)]	15[1)]	15[1)]	100[1)]	98[1)]	3.5[1)]
s	Biomass		wood	111	25[1)]	130[1)]	48[1)]	32[1)]	160[1)]	105[1)]	4[1)]
l	Oil		residual	203	930-1,470 1,400[2)]	98-1,800[1)] 180[2)]	3-4[1)] 3[2)]	3-4[1)] 3[2)]	10-320[1)] 15[2)]	72-78[1)] 78[2)]	2-14[1)] 14[2)]
l	Oil		gas	204	85-1,410[1)] 600[2)]	100-450[1)] 180[2)]	1.5-4[1)] 1.5[2)]	1.5-4[1)] 1.5[2)]	10-12[1)] 12[2)]	73-74[1)] 74[2)]	2-12[1)] 12[2)]
g	Gas		natural	301	0.5-8[1)]	60-570[1)] 100[2)]	2.5-10[1)] 2.5[2)]	2-3[1)] 2.5[2)]	10-120[1)] 13[2)]	53-56[1)] 53[2)]	1-3[1)] 3[2)]
g	Gas		coke oven	304	12[1)]	400-450[1)]	2.5[1)]	2.5[1)]	10[1)]	44-49[1)]	1.5[1)]

[1)]   CORINAIR90 data, area sources

[2)]   CORINAIR90 data, point sources

[3)] SO_x:
1,500	g/Mg product	Melting furnace /1/
2,246	g/Mg product	General /2/
1,675	g/Mg product	General, with venturi scrubber /2/
1,182	g/Mg product	General, with low energy scrubber /2/
2,800	g/Mg beaded glass	Ground cutlet beading furnace /1/

[4)] NO_x:
8.6-10	kg/Mg product	General /3/
2,920	g/Mg product	General /2/
4,000	g/Mg product	Melting furnace /1/
4,250	g/Mg product	Ground cutlet beading furnace
800	g/Mg product	General, (FRG, GDR, 1990) /4/

[5)]   VOC:
50	g/Mg product	Melting furnace /1/
150	g/Mg beaded glass	Ground cutlet beading furnace /1/

[6)]   It is assumed, that emission factors cited within the table are related to combustion sources in flat glass production. Footnotes may also include emission factors for other process emissions.

8.2   Production of Container Glass

For the situation in the Netherlands, the following can be proposed:

Emission factors for container glass are as follows:

handling/shipping:

dust: 0.03 - 0.15 kg/Mg glass

melting oven:

SO_2 1.2 kg/Mg glass

CO_2 150 kg/Mg glass

F_g 0.014 kg/Mg glass

Cl_g 0.05 kg/Mg glass

dust   0.30 kg/Mg glass

fuel:

SO_2 3.0 (fuel oil) kg/Mg glass

CO_2 265 kg/Mg glass

NO_x 3.8 kg/Mg glass

The dust is the main source of heavy metals. The emissions are largely determined by the composition of the basic materials and the product. Jockel and Hartje /10/ produced some generalised emission factors for the situation in Germany. These factors, also used in the PARCOM-ATMOS Manual are given in Table 13 in g/Mg glass:

Table 13: Emission factors for glass production in [g/Mg glass] generalised for the situation in Germany

Substance	Emission Factor [g/Mg glass]	Range [g/Mg glass]
Arsenic	0.12	0.1-0.24
Cadmium	0.15	0.06-0.24
Chromium	2.4	0.4-1.1
Copper	0.6	0.4-1.1
Lead	12	2-24
Mercury	0.05	0.036-0.072
Nickel	1.9	1.2-2.6
Selenium	18	2.4-24
Zinc	11	4.8-24

The following Table 14 contains fuel related emission factors for container glass production based on CORINAIR90 data in [g/GJ]. Technique related emission factors, mostly given in other units (e.g. g/Mg product) are listed in footnotes. In the case of using production statistics the specific energy consumption (e.g. GJ/Mg product) has to be taken into account, which is process and country specific. Within CORINAIR90 a range for the specific energy consumption of 6 - 100 GJ/Mg product has been reported.

Table 14: Emission factors for container glass production[7]

	Type of fuel		NAPFUE code	Emission factors						
				SO_2[2] [g/GJ]	NO_x[3] [g/GJ]	NMVOC[4] [g/GJ]	CH_4[4] [g/GJ]	CO[5] [g/GJ]	CO_2[6] [kg/GJ]	N_2O [g/GJ]
1	oil	residual	203	143-1,470[1]	100-570[1]	3[1]	3-8[1]	12-20[1]	73-78[1]	2-10[1]
1	oil	gas	204	55-1,410[1]	100-570[1]	1.5[1]	1.5-8[1]	12-20[1]	73-74[1]	2[1]
g	gas	natural	301	0.3[1]	80-570[1]	2.5-4[1]	2.5-4[1]	13-176[1]	53-57[1]	1[1]
g	gas	Liquified petroleum gas	303	0.04[1]	100[1]	2.1[1]	0.9[1]	13[1]	65[1]	1[1]

[1]   CORINAIR90 data, area sources

[2] SO_x: 2,246   g/Mg product   General /2/
                       1,700   g/Mg product   Melting furnace /1/

[3] NO_x: 4.3-5   kg/Mg product   General /3/ (spec. fuel consumption 7.5 GJ/Mg glass)
                       2,920   kg/Mg product   General /1/
                       3,100   kg/Mg product   Melting furnace /1/

[4]   VOC: 100   g/Mg product   Melting furnace /1/

[5]   CO: 100   g/Mg product   Melting furnace /1/

[6] CO_2:   423   g/Mg product   General /2/

[7]   It is assumed, that emission factors cited within the table are related to combustion sources in container glass production. Footnotes may also include emission factors for other process emissions.

8.3   Production of Glass wool

For the situation in the Netherlands, the following can be proposed:

Emission factors for several compounds in kg/Mg glass wool are:

handling/shipping:

dust: 0.03 - 0.15 kg/Mg glass

melting oven:

SO_2 0.5 kg/Mg glass
CO_2 450 kg/Mg glass
F_g 0.006 kg/Mg glass
Cl_g 0.01 kg/Mg glass
dust   0.04 (after dust collector) kg/Mg glass

spinning/wool manufacturing:

formaldehyde	0.9 kg/Mg glass
phenol(s)	0.3 kg/Mg glass
ammonia	4.5 kg/Mg glass
VOS	0.6 kg/Mg glass

fuel:

SO_2	5.0 (fuel oil) kg/Mg glass
CO_2	670 kg/Mg glass
NO_x	2.8 kg/Mg glass

Emissions of heavy metals may be contained in the dust. No specific information for glass wool production is available. For a first estimation the factors referred to above for flat glass and container glass may be used.

The following Table 15 contains fuel related emission factors for the production of glass wool based on CORINAIR90 data in [g/GJ]. Technique related emission factors, mostly given in other units (e.g. g/Mg product, g/Mg material), are listed in footnotes. In the case of using production statistics the specific energy consumption (e.g. GJ/Mg product) has to be taken into account, which is process and country specific. Within CORINAIR90 a range for the specific energy consumption of 4.3 - 100 GJ/Mg product has been reported.

Table 15: Emission factors for the production of glass wool[7]

	Type of fuel	NAPFUE code	SO_2[2] [g/GJ]	NO_x[3] [g/GJ]	NMVOC[4][5] [g/GJ]	CH_4[5] [g/GJ]	CO[6] [g/GJ]	CO_2 [kg/GJ]	N_2O [g/GJ]
					Emission factors				
l	oil Residual	203	840-1470[1]	150-450[1]		8[1]	20[1]	76-77[1]	2[1]
l	oil Gas	204	55-1410[1]	50-100[1]		81)	20[1]	73-74[1]	2[1]
g	gas Natural	301	8[1]	60-150[1]	10[1]	2-3[1]	20-30[1]	53-55[1]	1-3[1]

[1]   CORINAIR90 data, area sources (preliminary data)

[2]	SO_x:	2,246	g/Mg product	General /2/
		5,000	g/Mg material processed	Regenerative furnace and recuperative furnace /3/
		20	g/Mg material processed	Electric furnace
		300	g/Mg material processed	Unit smelter furnace
[3]	NO_x:	5,400-6,000	g/Mg product	General /3/
		2,500	g/Mg material processed	Regenerative furnace /3/
		850	g/Mg material processed	Recuperative furnace /3/
		135	g/Mg material processed	Electric furnace /3/
		245	g/Mg material processed	Forming, rotary spin /3/
		550	g/Mg material processed	Alting oven: rotary spin /3/
		150	g/Mg material processed	Cooling /3/
		150	g/Mg material processed	Unit smelter furnace /3/
		1,000	g/Mg material processed	Cursing: flame attenuation /3/

4)   NMVOC: 5,000   g/Mg product   /1/
5)   VOC: 100   g/Mg material processed   Regenerative furnace, recuperative furnace and electric furnace /3/
                          3,500   g/Mg material processed   Forming: rotary spin /3/
                          1,500   g/Mg material processed   Cursing oven: rotary spin /3/
                            150   g/Mg material processed   Forming: flame attenuation /3/
                          3,500   g/Mg material processed   Cursing: Flame attenuation /3/
6)   CO: 0-500   g/Mg glass   For electric melting /1/
                        100-600   g/Mg glass   For other furnaces /3/
                            125   g/Mg material processed   Regenerative furnace /3/ and recuperative furnace /3/
                             25   g/Mg material processed   Electric furnace /3/
                            850   g/Mg material processed   Cursing oven: rotary spin /3/
                            125   g/Mg material processed   Unit melter furnace /3/
                          1,750   g/Mg material processed   Cursing: flame attenuation /3/

7)   It is assumed, that emission factors cited within the table are related to combustion sources in glasswool production. Footnotes may also include emission factors for other process emissions.

8.4   Production of Other Glass

For the production of special glass the emission factors for general glass production as given flat glass and container glass can be used. For emissions of heavy metals some specific information is available. Emission factors are derived from the PARCOM-ATMOS Emission Factors Manual and the literature mentioned there:

- For the production of lead crystal glass an emission factor of 60 g lead/Mg product is mentioned, using bag filters as abatement method. Without abatement the emission factor is estimated to be 1% of the lead content of the glass. cf. /36/
- For coloured glass an emission factor of 0.11-0.15 g cadmium/g glass is mentioned.
- For the situation in Germany some specific information is given by Jockel and Hartje /10/. This information is given in Table 16.

Table 16:   Emission factors for heavy metals from special glass production in Germany in [g/Mg product]

Substance	Emission Factor [g/Mg product]	Range [g/Mg product]
Arsenic (lead crystal glass)	140	22-310
Arsenic (crystal glass)	96	-
Cadmium	0.15	0.06-0.24
Chromium	2.4	0.5-5
Copper	0.6	0.4-1.1
Lead (lead crystal glass)	2700	2200-3200
Lead (crystal glass)	480	-
Mercury	0.05	0.036-0.072
Nickel	1.9	1.2-2.6
Selenium	18	2.4-24
Zinc	11	4.8-24

The following Table 17 contains fuel related emission factors for the production of other glass based on CORINAIR90 data in [g/GJ]. Technique related emission factors, mostly given in other units (e.g. g/Mg product, g/Mg material processed), are listed in footnotes. In the case of using production statistics the specific energy consumption (e.g. GJ/Mg product) has to be taken into account, which is process and country specific. Within CORINAIR90 a range for the specific energy consumption of 25 - 6.000 GJ/Mg product has been reported.

Table 17:   Emission factors for the production of other glass[6]

Type of fuel		NAPFUE code	SO$_2$[2] [g/GJ]	NO$_x$[3] [g/GJ]	NMVOC[4] [g/GJ]	CH$_4$[4] [g/GJ]	CO[5] [g/GJ]	CO$_2$ [kg/GJ]	N$_2$O [g/GJ]
s Coal hc	steam	102	787[1]	150[1]	15[1]	15[1]	10[1]	94[1]	14[1]
s Biomass	wood	111		200[1]	50[1]	30[1]		92[1]	14[1]
l Oil	residual	203	960-1,470[1]	132-370[1]	3-19[1]	0.1-3[1]	15-19[1]	76[1]	14[1]
l Oil	gas	204	138-1,410[1]	80-100[1]	2[1]	1[1]	12[1]	73[1]	14[1]
l Kerosene		206	69[1]	80[1]	2[1]	1[1]	12[1]	71[1]	14[1]
l Gasoline	motor	208	45[1]	80[1]	2[1]	11)	12[1]	71[1]	14[1]
g Gas	natural	301	8-260[1]	32-622[1]	10-26[1]	0.4-3[1]	8.5-95[1]	53-56[1]	1-3.7[1]
g Gas	liquified petroleum gas	303	2[1]	20-40[1]	1-4[1]	1-4[1]	13[1]	60-65[1]	3[1]

[1]   CORINAIR90 data, area sources

[2]   SO$_x$:   2,246   g/Mg product   General /1/
                     1,500   g/Mg material processed   Textile fiber, regenerative furnace and recuperative furnace /2/
                     2,800   g/Mg product   Pressed and blown glass, melting furnace /2/
                     2,800   g/Mg beaded glass   Ground cullet beading furnace /2/

[3]   NO$_x$:   3,500-6,000   g/Mg product   General /3/
                    10,000   g/Mg material processed   Textile fiber; regenerative furnace, recuperative furnace and unit smelter furnace /2/
                     1,300   g/Mg material processed   Textile fiber; curing oven /2/
                     4,250   g/Mg product   Pressed and blown glass, melting furnace /2/
                     4,250   g/Mg beaded glass   Ground cullet beading furnace /2/

[4]   VOC: 100   g/Mg material processed   Textile fiber: regenerative furnace and recuperative furnace /2/
                       0   g/Mg material processed   Textile fiber: unit smelter furnace /2/
                     150   g/mg product   Pressed and blown glass, melting furnace /2/
                     150   g/Mg beaded glass   Ground cullet beading furnace /2/

[5]   CO: 100   g/Mg product   Pressed and blown glass, average /3/
                     100   g/Mg product   Pressed and blown glass, melting furnace /2/

[6]   It is assumed, that emission factors cited within the table are related to combustion sources in other glass production. Footnotes may also include emission factors for other process emissions.

9   SPECIES PROFILES

An analysis of dust emissions from a melting oven in the Netherlands is available. The major constituents from this analysis are given in g/Mg glass:

Substance	Concentration [g/Mg glass]
Aluminium	1.3
Chromium	0.15
Cobalt	0.05
Copper	0.15
Iron	2.4
Lead	0.30
Manganese	0.05
Nickel	1.0
Titanium	0.08
Vanadium	1.90
Zinc	0.25

These components are present as sulphates.

10   UNCERTAINTY ESTIMATES

If the simplified approach is used the results may differ very much from the real situation. A classification C-D is appropriate in this case. If more detail about the individual plant are available the factors should be corrected e in classifications in the B to C range.

11   WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

The default calculation could be very much improved if information about the basic materials used is available.

12   SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

Not relevant if treated as point source. Otherwise national emissions should be disaggregated on the basis of plant capacity, employment or population statistics.

Production of special glass is usually done in small plants. They may be treated as an area source by disaggregating national emission estimates on the basis of plant capacity, employment or population statistics.

13   TEMPORAL DISAGGREGATION CRITERIA

The production of flat glass, container glass, and glass wool can be considered as a continuous process. The production of special glass is usually a discontinuous process but no information is available on temporal profile.

14   ADDITIONAL COMMENTS

No additional comments.

15   SUPPLEMENTARY DOCUMENTS

- Emission inventory in The Netherlands, 1992. Emission to air and water
- Personal information and experience during emission inventories 1975 - 1995
- Emission factors to be used for the building industry, TNO report 89/091
- Environmental Protection Agency, Compilation of Air Pollutant Emission Factors AP-42
- PARCOM-ATMOS Emission Factors Manual
- SPIN document "Productie van glas ,glasvezel, en glaswol", 1992 (in Dutch)
- LEENDERTSE, A.: Dutch notes on BAT for the Glass and Mineral Wool Industry. prepared for the Ministry of Housing, Spatial Planning and the Environment. Directorate for Air and Energy Draft version October 1998
- WESSELS BOER CONSULTANCY: Personal communication, 1998

16   VERIFICATION PROCESSES

Verification should be applied by comparing calculated emissions with measured emissions at an individual plant.

17   REFERENCES

EPA (ed.): AIRS Facility subsystem, EPA-Doc 450/4-90-003, Research Triangle Park, March 1990.

Loos B.: Produktie van Glas, Glas vezel en Glaswol; RIVM-report 736301115; RIZA-report 92.003/15, 1992.

Bouscaren M. R.: CORINAIR Inventory, Default Emission Factors Handbook,; second Edition, comission of the European Communities, Paris, 1992.

BUNDESUMWELTMINISTERIUM (ed.). Erster Bericht der Regierung der Bundesrepublik Deutschland nach dem Rahmenübereinkommen der Vereinten Nationen über Klimaänderungen, 1994.

Schmalhorst E.; Ernas T.: First Practical Experiences with an SCR DeNO$_x$ Facility in a Container Glassworks, in: Glastechnische Berichte Glass Sci. Technol., 68 (1995) 5.

EPA (ed.): AP42 CD-Rom, 1994.

VDI (ed.): Emissionsminderung Glashütten / Emission Control Glass Manufacture; VDI 2578; Düsseldorf, 1988.

Her Majesty´s Inspectorate of Pollution (ed.): Glass Manufacture and Production Glass Frit and Enamel Frit; Environmental Protection Act 1990; Process Guidance Note IPR 3/5; London, 1992.

Barklage-Hilgefoot H.J.; Sieger W.: Primary measures for the NO$_x$-Reduction on Glass Melting Furnaces, in: Glasstechnik Bericht 62 (1989) 5.

Jockel W.; Hartje J. (1991) Datenerhebung über die Emissionen Umwelt-gefährdenden Schwermetalle. Forschungsbericht 91-1-4 02 588; TüV Rheinland e.V. Köln.

Rentz O; Schleef H.-J.; Dorn R; Sasse H.; Karl U.: Emission Control at Stationary Sources in the Federal Republic of Germany, Sulphur Oxide and Nitrogen Oxide Emission Control, UFOPLAN-Ref. No. 104 02 360, Karlsruhe, August 1996.

Eichhammer W.; Bradke H.; Flanagan J.; Laue H. J.; Bahm W.: 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.

UN/ECE (ed.): Task Force on Heavy Metal Emissions, State-of-the-Art Report–Second Edition, Prague, 1995.

Abraham D.; Quirk R.; de Reydellet A.; Scalet B. M.; Tackels G.: Personal Communication, July 1997.

VDI Kommission Reinhaltung der Luft (ed.): Emissionsminderung Glashütten, VDI Richtlinie 2578, 7. Vorentwurf, in: VDI/DIN-Handbuch Reinhaltung der Luft, Volume 1, Düsseldorf, April 1997.

Nölle G.: Technik der Glasherstellung, Deutscher Verlag für Grundstoffindustrie, Leipzig, 1978.

Teller A.J.; Hsieh J.Y.: Glass Manufacturing, in: Buonicore A.J.; Davis T.W. (eds.): Air Pollution Engineering Manual, New York, 1992.

Kircher U.: NO$_x$-Emissionen und Stand der Minerungstechnik, in: HVG-Fortbildingskurs 1993, Minderung der Staub- und Schadgas-Emissionen bei Glasschmelzöfen, Fachhochschule Nürnberg, 1993.

Quirk R.: Review of Controls of NO$_x$: Glass Opportunities – The Challenge of the Environment, in: Glass Technology, Volume 38, No. 4, August 1997.

Flamme M.: Feuerungstechnische NO$_x$-Minderungsverfahren, <u>in:</u> HVG-Fortbildungskurs 1993, Minderung der Staub- und Schadgas-Emissionen bei Glasschmelzöfen, Fachhochschule Nürnberg, 1993.

Flamme M.; Haep J.: Möglichkeiten zur Minderung der NO$_x$-Bildung im Bereich der Glasindustrie, <u>in:</u> Gaswärme International, 43 (1994) 9.

Gitzhofer K.-H.: Emissionen und Stand der Abgasreinigung, in: HVG-Fortbildungskurs 1993, Minderung der Staub- und Schadgas-Emissionen bei Glasschmelzöfen, Fachhochschule Nürnberg, 18./19. November 1993.

Kircher U.: NO$_x$-Minderung von Glasschmelzöfen, <u>in:</u> GASWÄRME International, 42 (1993) 1/3, p. 14 - 21.

Delacroix F., Delhopital G., Lalart D., Mocek L., Tackels G.: Réduction des Emissions d'Oxydes d'Azote dans l'Industrie du Verre, Comité de Suivi du Verre, Arrêté du 14 Mai 1993, July 1996.

Barklage-Hilgefort, H., Sieger W.: Primary Measures for the NO$_x$ Reduction on Glass Melting Furnaces, <u>in:</u> Glastechnische Berichte, 62 (1989), 5, p. 151 – 157.

Joshi M.L., Wishnick D.B., Madrazo R. F., Benz W.H., Panahi S.K., Slavejkov A.G., Abbasi H.A., Grosman R.E., Donaldson L.W.: Cost-Effective NO$_x$ Reduction Using Oxygen-Enriched Air Staging on Regenerative Glass Furnaces, 55th Conference on Glass Problems, November 1994.

Kircher U.: Present Status of NO$_x$ Reduction by Primary and Secondary Measures in the German Glass Industry, <u>in:</u> Proceedings: XVII International Congress on Glass, Beijing, 1995.

Shulver I.: New Developments in NO$_x$ Control – Pilkington '3R' Process, <u>in:</u> Glastechnische Berichte, 67 (1994) 11.

Quirk R.: Pilkington 3R Process in Glass Industry: An Update, <u>in:</u> Combustion et Procédés Industriels – Comment Réduire les Emissions d'Oxydes d'Azote, Rencontres et Journées Techniques de l'Ademe, Angers, September 1996.

Koppang R.; Evaluation du Reburning sur un Four de Verre Creux de 350 Mg/j, <u>in:</u> Combustion et Procédés Industriels – Comment Réduire les Emissions d'Oxydes d'Azote, Rencontres et Journées Techniques de l'Ademe, Angers, September 1996.

Pabst R.: Noncatalytic Removal of Nitrogen in a Recuperative Container Glass Furnace, <u>in:</u> Glastechnische Berichte, 57 (1994) 3.

Genuist G.: SCR: L'expérience d'EUROGLAS dans le domaine du verre plat, <u>in:</u> Combustion et Procédés Industriels – Comment Réduire les Emissions d'Oxydes d'Azote, Rencontres et Journées Techniques de l'Ademe, Angers, September 1996.

UN/ECE TASK FORCE ON THE ASSESSMENT OF ABATEMENT OPTIONS/TECHNIQUES FOR NITROGEN OXIDES FROM STATIONARY SOURCES: Draft Background Document, French-German Institute of Environmental Research, Karlsruhe, April 1998.

Landesgewerbeanstalt Bayern: Beurteilung von Anlagen zur Herstellung von Glas nach der 12. BImSchV, Nürnberg, 1994.

EPA (ed.): AP42 CD-Rom, 1995.

UK Energy Efficiency Office. Energy efficient environmental control in the glass industry. Good practice Guide no 127 (1994).

Overzicht Productie, Energieverbruik en Rookgasemissies Nederlandse Glasindustrie anno 1990; Beerkens, Dr Ir R.G.C.; Technische Physische Dienst TNO-TUD (report number TPD-GL-RPT-91-007), January 1991 (in Dutch).

LEENDERTSE, A.: Personal communication about the carbonization process, 1998.

18   BIBLIOGRAPHY

For a detailed bibliography the primary literature mentioned in AP 42 or the PARCOM-ATMOS Manual may be used.

19   RELEASE VERSION, DATE AND SOURCE

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