Environmental, Health, and Safety Guidelines for Glass Manufacturing

Introduction

The Environmental, Health, and Safety (EHS) Guidelines are technical reference documents with general and industry-specific examples of Good International Industry Practice (GIIP)[1]. When one or more members of the World Bank Group are involved in a project, these EHS Guidelines are applied as required by their respective policies and standards. These industry sector EHS guidelines are designed to be used together with the **General EHS Guidelines** document, which provides guidance to users on common EHS issues potentially applicable to all industry sectors. For complex projects, use of multiple industry-sector guidelines may be necessary. A complete list of industry-sector guidelines can be found at: www.ifc.org/ifcext/enviro.nsf/Content/EnvironmentalGuidelines

The EHS Guidelines contain the performance levels and measures that are generally considered to be achievable in new facilities by existing technology at reasonable costs. Application of the EHS Guidelines to existing facilities may involve the establishment of site-specific targets, with an appropriate timetable for achieving them.

The applicability of the EHS Guidelines should be tailored to the hazards and risks established for each project on the basis of the results of an environmental assessment in which site-specific variables, such as host country context, assimilative capacity of the environment, and other project factors, are taken into account. The applicability of specific technical recommendations should be based on the professional opinion of qualified and experienced persons.

When host country regulations differ from the levels and measures presented in the EHS Guidelines, projects are expected to achieve whichever is more stringent. If less stringent levels or measures than those provided in these EHS Guidelines are appropriate, in view of specific project circumstances, a full and detailed justification for any proposed alternatives is needed as part of the site-specific environmental assessment. This justification should demonstrate that the choice for any alternate performance levels is protective of human health and the environment.

Applicability

The EHS Guidelines for Glass Manufacturing include information relevant to glass manufacturing facilities. It does not include extraction of raw materials, which is addressed in the EHS Guidelines for Construction Materials Extraction. Annex A contains a full description of industry activities for this sector.

This document is organized according to the following sections:

Section 1.0 — Industry-Specific Impacts and Management
Section 2.0 — Performance Indicators and Monitoring
Section 3.0 — References
Annex A — General Description of Industry Activities

[1] Defined as the exercise of professional skill, diligence, prudence and foresight that would be reasonably expected from skilled and experienced professionals engaged in the same type of undertaking under the same or similar circumstances globally. The circumstances that skilled and experienced professionals may find when evaluating the range of pollution prevention and control techniques available to a project may include, but are not limited to, varying levels of environmental degradation and environmental assimilative capacity as well as varying levels of financial and technical feasibility.

1.0 Industry-Specific Impacts and Management

The following section provides a summary of EHS issues associated with glass manufacturing, which occur during the operational phase, along with recommendations for their management. Recommendations for the management of EHS issues common to most large industrial facilities during the construction and decommissioning phases are provided in the **General EHS Guidelines**.

1.1 Environment

Environmental issues in glass manufacturing primarily include the following:

- Emissions to air
- Wastewater
- Solid waste

Emissions to Air

Glass manufacturing is a high-temperature, energy-intensive activity, resulting in the emission of combustion by-products (sulfur dioxide, carbon dioxide, and nitrogen oxides) and the high-temperature oxidation of atmospheric nitrogen. Furnace emissions also contain particulate matter (PM) and may contain low levels of metals. Melting furnaces contribute between 80 and 90 percent of the total pollutant emissions to air from a glass production facility. Emissions from the forming and finishing phases are related to the various types of glass production processes. Container press and blow machines generate most emissions due to contact between molten glass (the "gob") and equipment lubricants. Manufacturing of flat glass, container glass, tableware, and artistic glass production also generates emissions related to combustion in the annealing process where the glass product is maintained at 500–550°C in a controlled cooling process in the "lehr" (annealing oven).

Producers should consider product lightweighting in containers and tableware as an effective means to reduce environmental impacts by increasing the product count that can be manufactured from a given weight of molten glass.

Particulate Matter

Particulates are a significant pollutant emitted by glass manufacturing facilities. All sub-sectors within the glass manufacturing industry involve the use of powdered, granular, or dusty raw materials. Raw materials storage and mixing are common activities for all glass industry sub-sectors. Dust emissions are an expected result of raw materials transportation, handling, storage, and mixing. Dust generated by these processes is typically coarser than the particulates emitted from the hot processes, which have sizes below 1 µm, but the small particulates readily agglomerate into larger particles. Whereas dust emitted from handling processes is mostly an occupational health and safety (OHS) issue, PM generated by the hot processes in the batch plant is a potential environmental issue.

The primary recommended prevention and control techniques to reduce dust emissions and minimize potential impacts from raw materials transportation, handling, storage, and mixing include:

- Segregate storage and batch preparation areas from other operational areas;
- Use enclosed silos to store batch materials;
- Reduce the amount of fine particles in the batch by humidification with water or with alkali solutions (for example, sodium hydroxide, [NaOH], sodium carbonate [Na_2CO_3]) or by presintering, briquetting or palletizing.
- Implementation of correct loading and unloading practices;
- Raw material batch transportation to the furnaces in enclosed conveyors;

- Execution of controls in the furnace feed area (e.g. batch moisturizing; balanced operation of the furnace to keep it at slightly positive (<10 Pa) pressure to improve combustion efficiency but limiting potential for dust emission; dust extraction through filters; enclosed closed screw feeders; and feed pocket enclosure).

The main sources of fine PM emissions to the atmosphere from the melting process include the combination of volatile components from the batch and melt with sulfur oxides to produce compounds that condense in furnace waste gases, the carry over of fine materials in the batch, and the combustion of some fossil fuels.

Prevention and control measures to reduce particulate emissions include:

- Increased cullet utilization;
- Optimization of furnace design and geometry to permit reduction in furnace temperature;
- Use of fuels with low sulfur content;
- Consideration of material charging patterns, grain size, and moisture optimization.

Effective application of the primary particulate control measures described above can result in furnace flue gas particulate emissions concentrations of less than 100 mg/Nm^3. Unabated particulate emissions increase with furnace age as deterioration of refractory requires increasing energy input, hence velocity of combustion products through the furnace.

End-of-pipe prevention and control techniques to reduce dust emission include the installation of electrostatic precipitators (ESP) or baghouse filters.[2] ESPs may have overall dust collection of 95 to 99 percent and may achieve emission concentrations of 20 mg/m^3. However, their cost[3] generally limits their utilization to relatively large glass manufacturing installations with two or more melting units where economies of scale are available. The cost of ESPs and baghouses may vary greatly and depends significantly on required performance and waste gas volume. Baghouses are used for lower waste gas volume, typically up to 20,000 - 30,000 Nm^3/h of flue gases, whereas ESPs would be more normal at higher flue gas flow rates. Bag filter (also known as 'bag house' or 'fabric filter')[4] systems are also highly efficient with a collection efficiency of 95 to 99 percent.

Nitrogen Oxides

The main emission sources of nitrogen oxides (NO_X) are the generation of thermal NO_X caused by high furnace temperatures, the decomposition of nitrogen compounds in the batch materials, and the oxidation of nitrogen contained in fuels. Conventional primary process modifications are usually based on the following techniques or a combination thereof: reduced air / fuel ratio, staged combustion, low NO_X and sealed burners, and fuel choice. An additional effective measure is to run furnaces under slightly reducing conditions.

It is important to minimize combustion air supply to furnaces, in order to enhance energy efficiency and restrict NO_x formation. It is generally recommended to maintain 0.7–1 percent O_2 in unit melters and 1– 2 percent O_2 in end-port furnaces, measured at

[2] Installation of these types of abatement units is considered the best available technique as defined by European Union legislation.

[3] Capital costs (including acid gas scrubbing) are generally in the range of €1.0 to €1.5 million for a 50-100 ton/day furnace (either baghouses or ESP), and €2.5 to €3.5 million for a 500 ton/day furnace (typically ESP). The annual operating costs range between €50,000 and €250,000 if the by product is reused in melting process though this requires consistency of color. The cost of by product disposal is very high and can double these operating costs. Capital costs for installation of end-of-pipe treatment are usually higher for existing rather than new plants, particularly where space restrictions need to be considered.

[4] Although bag filters are efficient at lower temperature, temperature control is essential. This control is needed to prevent corrosion due to acid condensation generated by low temperature and to ensure that the filter integrity is not compromised through thermal destruction caused by excessively high temperature. Additional information about the applicability and performance of PM control techniques is presented in the **General EHS Guidelines.**

the combustion chamber exit and to monitor the carbon monoxide (CO) level, which should be kept as low as possible (200–300 ppm to 1,000 ppm CO maximum).

Other primary process measures to be considered include the selection of oxy-fuel melting (full O_2 firing or partial O_2 firing), discussed in Annex A, and the selection of low NO_X furnaces[5].

End-of-pipe (secondary) pollution-control techniques for reduction of NO_X emissions in glass manufacturing include the following, which should be implemented in cases where primary measures do not achieve necessary NO_X levels:

- Chemical reduction by fuel (e.g. the 3R process);
- Use of Selective Catalytic Reduction (SCR).

The use of Selective Non-catalytic Reduction (SNCR) is not a widely adopted practice in the glass industry. Additional information about the applicability and performance of NO_x emissions controls is provided in the **General EHS Guidelines.**

Sulfur Oxides

The presence of sulfur oxides (SO_X) in waste gases from glass furnaces depends on the sulfur content in the fuel and the sulfite / sulfate / sulfide content in raw materials , particularly the addition of sodium or calcium sulfate for glass oxidation.

The recommended pollution control techniques to reduce sulfur dioxide (SO_2) emissions include the following:

- Use of fuels with low sulfur content and, in particular, natural gas;
- Reduction in the amounts of sodium or calcium sulfate in the batch materials.

Generally, when natural gas is used as fuel, SO_X levels in the exhaust gases are low. If further reduction in acid gas emission is desired, for example if a sulfur-containing fuel is used, then the following techniques can be considered:

- A dry scrubber in which calcium- or sodium-based[6] materials are injected into the flue gas stream products before filtering waste gas;
- Installation of semi-wet scrubbers (reactive scrubbers or quench reactors) characterized by the addition of some basic reactive chemicals (calcium- and sodium-based) that are dissolved into wash water (wet abatement).

If a dry absorption process is used, (such as SO_2 and / or hydrogen chloride [HCl] or hydrogen fluoride [HF] abatement with sodium bicarbonate [$NaHCO_3$] or hydrated lime [$Ca(OH)_2$]), bag filters are generally more effective than ESP, because they have a large contact surface and long solid-gas contact time.

Chlorides and Fluorides

These pollutants arise in glass-melting furnaces waste gases from raw material impurities and volumes are usually limited. The main exceptions occur in opal (opaque) and continuous fiber glass manufacturing, in which the level of fluoride / HF

5 Some new melting furnaces are designed with different options to achieve NO_X emission abatement. Low NO_X and FlexMelter furnaces are characterized by a backstream output for waste gases in a furnace area that is divided from the combustion area to create the conditions for "stage combustion." Another technique is the "cascade system," which occurs in the combustion port. A differential precombustion of a portion of the fuel occurs before the final combustion phase, allowing combustion with comburent air that has a lower O_2 percentage. This type of technology is normally more expensive than traditional combustion solutions and should be compared with costs and efficiencies of other furnaces that have a standard layout and end-of-pipe abatement systems.

6 The most commonly used sodium compound is sodium bicarbonate ($NaHCO_3$), which is used in dry condition in the NEUTREC process. $NaHCO_3$ is crushed in a mill to a size smaller than 15 μm and then is added to the waste gas stream. At a temperature higher than 107°C (usually higher than 140°C), $NaHCO_3$ decomposes to sodium carbonate (Na_2CO_3) and water. The capacity of "native" Na_2CO_3 with a large surface to react with acid compounds is high. This reactivity reduces the amount of reactive chemicals and consequently that of by-product.

before mitigation can reach 1,000 mg/Nm^3 or more, through the addition of fluorspar to the batch. Dry and semi-dry scrubbing techniques are generally used to treat HF emissions. When the glass is particularly aggressive (e.g. opal due to fluorine presence), the use of an electric furnace is considered the preferred choice.

Except when making special glasses, the sources of HCl and HF emissions are normally related to impurities present in the raw materials (e.g. sodium or calcium chloride), and, less often, to the presence of small amount of calcium fluoride (CaF_2) in the batch. Both HF and HCl emissions may be controlled using the abatement techniques described above for abatement of SO_2 emissions.

Metals

Metal emission is an important issue in some sub-sectors (e.g. lead crystal and frits production), however, this problem is present in all other glass manufacturing sectors to a lesser degree. Heavy metals may be present as minor impurities in some raw materials, in cullet, and in fuels. Lead and cadmium are used in fluxes and coloring agents in the frit industry. Particulates from lead crystal manufacture may have a lead content of 20–60 percent. Special glass manufactures may release arsenic, antimony, and selenium (the coloring agent in bronze glass or decoloring agent in some clear glasses).

High-efficiency dust abatement techniques should be used for reduction of metal-containing particulate emissions. Gaseous metal emissions (e.g. if selenium is used) are contained through the installation of dry and semidry scrubbers in combination with dust abatement techniques.

Greenhouse Gases (GHG)

Glass manufacturing is a significant emitter of greenhouse gases (GHG), especially carbon dioxide (CO_2). Production of 1 kg of glass in a gas-fired furnace generates approximately 0.6 kg CO_2, of which 0.45 kg arise from fossil fuels combustion and 0.15 kg from dissociation of carbonate raw material ($CaCO_3$ and dolomite) used in the batch. The GHG production is directly linked with the type of glass, the type of fossil fuels used, process energy efficiency, and the use of cullet. Due to the high quality requirements of certain glass products (e.g. pharmaceutical and cosmetical products, laboratory or lighting products) the opportunity of cullet usage is restricted.

In addition to recommended management strategies for GHGs in the **General EHS Guidelines**, sector specific approaches to prevent and control GHG emissions include:

- Measures to increase energy efficiency (as described below);
- Use of low carbon content fuels (e.g. natural gas, where possible, instead of fuel oil or solid fossil fuels);
- Maximizing cullet use to increase energy efficiency and to limit the use of carbonate raw materials, especially in container glass production. Opportunities to use a high proportion of cullet in batch are particularly good when manufacturing green containers. Furnace energy use is typically reduced by 0.15–0.3 percent for each percent of cullet in batch.[7]
- Use of inverter-based variable speed drives with large combustion air and cooling air fans.
- Waste heat recovery from furnace flue gases: heat may be used for batch or cullet preheat (see below), or to provide hot or steam for space heating purposes. A developing technology is to recovery heat in the form of high-pressure steam which may be expanded in a turbine for power generation.

[7] In the European Union (EU) cullet use in container glass production varies from < 20 % to >90 %, with an EU average in the region of 48 %, and amber glass 25 – 60 %.

- Techniques for improving furnace efficiency include the following:[8]
  - *Furnace size*: Furnaces rated at less than 50 tons / day output have high structural losses in relation to energy used in glass melting and are therefore inefficient;
  - *Choice of melting technique*: Regenerative furnaces are more energy efficient than recuperative furnaces due to their higher preheat of combustion air;
  - Adoption of enhanced insulation techniques and materials;
  - Measures to control combustion;
  - Maximization of cullet use;
  - Preheating of batch and cullet before entry to the furnace by waste heat recovery from furnace flue gases.

Wastewater

Industrial Process Wastewater

The most significant water use occurs during cooling and cullet cleaning. Aqueous emissions will consist of contact cooling water system purges, cleaning waters, and surface water runoff. Closed-water process systems should be used to minimize losses. Amounts of liquid effluents discharged from glass manufacture are marginal in comparison with other industrial sectors and are limited to particular processes (e.g. hot gob quenching and water-cooled shears). Discharges may be affected by glass solids, some soluble glass-making materials (e.g. sodium sulfate), some organic compounds caused by lubricant oil used in the cutting process, and treatment chemicals (e.g. dissolved salts and water treatment chemicals) for the cooling-water system.

Process Wastewater Treatment

Techniques for treating industrial process wastewater in this sector include oil water separators; flow and load equalization with pH adjustment; screening and sedimentation for suspended solids reduction using settling basins or clarifiers; multimedia filtration for reduction in non-settleable suspended solids; dewatering and disposal of residuals in landfills, or if hazardous in designated hazardous waste disposal sites. Additional engineering controls and pretreatment steps may be required to treat contact cooling water for metals, dissolved salts, organics and water treatment chemicals.

Management of industrial wastewater and examples of treatment approaches are discussed in the **General EHS Guidelines**. Through use of these technologies and good practice techniques for wastewater management, facilities should meet the Guideline Values for wastewater discharge as indicated in the relevant table of Section 2 of this industry sector document. Mechanical processing of glass should require recycling of process waters.

Other Wastewater Streams & Water Consumption

Guidance on the management of non-contaminated wastewater from utility operations, non-contaminated stormwater, and sanitary sewage is provided in the **General EHS Guidelines**. Contaminated streams should be routed to the treatment system for industrial process wastewater. Recommendations to reduce water consumption, especially where it may be a limited natural resource, are provided in the **General EHS Guidelines**.

Solid Waste

Most activities of the glass industry produce relatively low levels of waste. Solid waste is generated from glass manufacturing mainly in the shipping areas. Cleanup and maintenance in receiving areas can reduce this waste and allow material spills to be collected and added to the raw materials. Paving the

[8] EU BREF (2001).

receiving areas allows for efficient and effective collection and cleanup and also allows spilled material to be adequately identified, segregated, and recycled into the process.

Solid-process residues deriving from the melting process include dust from regenerators (or recuperators) that is removed during mechanical or thermal cleaning, and waste-refractory materials from periodic furnace maintenance, repair, and decommissioning (about 500–2,000 tons / operation, usually conducted every 5–15 years), including refractories rich in chromium and zirconium. Other waste includes dust collected in abatement equipment.

Pollution-prevention opportunities include the following:

- Maximizing the use of cullet as a feedstock;
- Recycling refractory waste as a feedstock for brick manufacturing (this technique does not affect the quality of the final product);
- Replacing refractory bricks typically every 6–12 years (appropriate recycling of these materials presents a pollution-prevention opportunity that should be defined when furnace / forehearth rebuild and repair is implemented);
- Reusing collected dust in the batch, color permitting.

1.2 Occupational Health and Safety

The most significant occupational health and safety hazards occur during the operational phase of glass manufacturing projects and primarily include the following:

- Exposure to heat
- Exposure to noise
- Exposure to respiratory hazards
- Physical hazards
- Electrical hazards

Heat

The principal exposure to heat occurs during the operation and maintenance of furnaces or other hot equipment. Prevention and control methods include the following:

- Minimizing the time required for work in high air temperature environments through the implementation of shorter duration shifts at these locations;
- To prevent excessive heat in the workplace, adequate ventilation and cooling air should be provided to displace fumes and dust away from the work stations;
- Making available and using, as needed, air- or O_2-supplied respirators;
- Shielding surfaces where worker proximity and close contact with hot equipment is expected and using personal-protective equipment (PPE), as needed, including insulating gloves and shoes.

Noise

Workers may be exposed to noise during glass manufacturing. Hearing loss (hypoacusia) is a typical occupational illness in this industry, especially for glass-container manufacturing. In the glass-container forming process, the high pressure in the cooling-mold process may create significant noise emissions. The noise level from glass-pressing machines can be as high as 100 decibels or more, potentially causing hearing impairment. Recommendations for preventing and controlling exposure to noise, including the use of hearing protection and other PPE, are discussed in the **General EHS Guidelines**.

Respiratory Hazards
(Dust, Fumes, and Toxic Compound Exposure)

Occupational health risks in glass manufacturing may be related to the presence, in the workplace, of fine airborne PM. This PM may contain silica dust, deriving from silica sands and feldspar, and sometimes toxic compounds (e.g. lead oxide, boron, arsenic, tin, nickel, cobalt). Workplaces in container and tableware facilities also typically contain oil fume and smoke arising from hot mold lubrication. Particulates deriving from the manufacturing of lead crystal can reach a lead content of 20–60 percent. Some special glass-manufacture processes may generate high levels of HCl, HF, arsenic, antimony, and selenium in the workplace.

Hot-surface treatment may use tin and titanium compounds, such as tin chloride or tin-chlorinated organic compounds, that may cause the emissions of dust rich in tin, titanium, and HCl. Methods to prevent and control exposure include the following:

- Segregating raw material storage and batch preparation areas from other operational areas;
- Implementing correct loading and unloading practices;
- Providing batch material transportation to the furnaces through covered conveyors / tubes;
- Using ventilation systems.

Physical Hazards

Potential eye injuries from broken glass and flying glass particles are a common risk factor in glass manufacturing and should be prevented by universal use of safety glasses for all workers and visitors. Severe cutting injuries can arise if flat glass breaks during handling. Injury risk should be minimized by automation of flat-glass handling and provision of cut-resisting gloves and long aprons to workers who do handle flat glass.

Electrical Hazards

Workers may be exposed to electrical hazards due to the presence of electrical equipment throughout glass manufacturing facilities. Recommendations to prevent and control exposure to electrical hazards are provided in the **General EHS Guidelines**.

1.3 Community Health and Safety

Community health and safety impacts during the construction, operation, and decommissioning of glass-manufacturing plants are common to those of most large industrial facilities and are discussed in the **General EHS Guidelines**.

2.0 Performance Indicators and Monitoring

2.1 Environment

Emissions and Effluent Guidelines

Tables 1 and 2 present emission and effluent guidelines for this sector. Guideline values for process emissions and effluents in this sector are indicative of good international industry practice as reflected in relevant standards of countries with recognized regulatory frameworks. These guidelines are achievable under normal operating conditions in appropriately designed and operated facilities through the application of pollution prevention and control techniques discussed in the preceding sections of this document. These levels should be achieved, without dilution, at least 95 percent of the time that the plant or unit is operating, to be calculated as a proportion of annual operating hours. Deviation from these levels in consideration of specific, local project conditions should be justified in the environmental assessment.

Effluent guidelines are applicable for direct discharges of treated effluents to surface waters for general use. Site-specific discharge levels may be established based on the availability and conditions in use of publicly operated sewage collection and treatment systems or, if discharged directly to surface waters, on the receiving water use classification as described in the **General EHS Guidelines**.

Emissions guidelines are applicable to process emissions. Combustion source emissions guidelines associated with steam- and power-generation activities from sources with a heat input capacity equal to or lower than 50 MWth are addressed in the **General EHS Guidelines** with larger power source emissions addressed in the **EHS Guidelines for Thermal Power**. Guidance on ambient considerations based on the total load of emissions is provided in the **General EHS Guidelines**.

Table 1. Air emission levels for glass mnfg.

Pollutants	Units	Guideline Value
Particulates Natural gas Other fuels	mg/Nm^3	 100[a] 50[a]
SO_2	mg/Nm^3	700–1,500[b]
NO_X	mg/Nm^3	1,000
HCl	mg/Nm^3	30
Fluorides	mg/Nm^3	5
Lead	mg/Nm^3	5
Cadmium	mg/Nm^3	0.2
Arsenic	mg/Nm^3	1
Other heavy metals (total)	mg/Nm^3	5[c]

[a] Where toxic metals are present, not to exceed 20 mg/Nm^3. To achieve dust emissions of 50 mg/Nm^3 installation of secondary treatments (bag filters or electrostatic precipitators) is necessary. Good operating conditions of the furnace and adoption of primary measures can achieve emission levels of 100 mg/Nm^3.
[b] 700 mg/Nm^3 for natural gas firing. 1 500 mg/Nm^3 for oil firing.
[c] 1 mg/Nm^3 for selenium.

Table 2. Effluent levels for glass mnfg.

Pollutants	Units	Guideline Value
pH	S.U.	6–9
Total suspended solids	mg/L	30
COD	mg/L	130
Oil and grease	mg/L	10
Lead	mg/L	0.1
Antimony	mg/L	0.3
Arsenic	mg/L	0.1
Fluorides	mg/L	5
Boric acid	mg/L	2
Temperature increase	°C	<3[a]

[a] At the edge of a scientifically established mixing zone which takes into account ambient water quality, receiving water use, potential receptors and assimilative capacity

Environmental Monitoring

Environmental monitoring programs for this sector should be implemented to address all activities that have been identified to have potentially significant impacts on the environment, during normal operations and upset conditions. Environmental monitoring activities should be based on direct or indirect indicators of emissions, effluents, and resource use applicable to the particular project.

Monitoring frequency should be sufficient to provide representative data for the parameter being monitored. Monitoring should be conducted by trained individuals following monitoring and record-keeping procedures and using properly calibrated and maintained equipment. Monitoring data should be analyzed and reviewed at regular intervals and compared with the operating standards so that any necessary corrective actions can be taken. Additional guidance on applicable sampling and analytical methods for emissions and effluents is provided in the **General EHS Guidelines**.

Resource Use and Emission Loads

Tables 3 and 4 provide examples of resource-consumption indicators for energy and water, in addition to emission-mass loads in this sector. Industry-benchmark values are provided for comparative purposes only, and individual projects should target continual improvement in these areas.

Table 3. Resource and energy consumption[a,d]

Inputs per unit of product	Unit	Industry benchmark
Fuels Specific fuel consumption for container glass regenerative end port furnaces with production > 200 ton/day	GJ/tonne melted	3.9[b]
Specific fuel consumption for float furnaces with production 400–500 ton/day	GJ/tonne melted	5.5
Specific fuel consumption for borosilicate glass unit melters with production 10–15 ton/day	GJ/tonne melted	9
Electricity Specific electricity use	kWh/tonne melted	110
Water Water consumption per unit of production	m^3/tonne melted	4[c]

[a] The specific energy consumption is significantly related to the furnace dimensions, glass-production capacity, loading, age, and cullet utilization. Small furnaces and furnaces operating at less than nominal capacity are generally less energy efficient, since specific heat losses are high. The energy consumption is also dependent on glass quality (melt temperature), cullet percent, and furnace age. The lower range value provided is achievable by new furnaces and through maximization of cullet use, good insulation of the furnace, and good operating conditions (i.e., not excessive operating temperatures and good combustion control.) Fuel use figures assume no electric boost heating. Electricity use figures similarly exclude direct use in melting, but do include use in combustion air fans.
[b] Specific energy consumptions for regenerative furnaces and oxy-fuel furnaces without O_2 production and for container-glass productions are lower than consumptions for recuperative furnaces and for flat glass and tableware production.
[c] Values available for glass-fiber manufacturing
[d] In soda-lime glass manufacturing, a 10 percent increase in cullet allows reductions of energy consumption up to 3 percent ranging from 22 to 30 kcal/kg (0.09–0.13 GJ/ton)

Table 4. Emission load generation			
Outputs per unit of product[a]	Unit	Industry benchmark	
		Flat-glass furnaces	Container-glass furnaces
Particulate matter	kg/tonne glass melted	0.02–0.1	0.002–0.22
	mg/Nm^3	5.0–40	1–35
NO_X	kg/tonne glass melted	1.1–2.9	<0.75
	mg/Nm^3	495–1,250	<400
SO_X	kg/tonne glass melted	0.54–4.0	0.2–3.5
	mg/Nm^3	200–1,700	100–1,650
HCl	kg/tonne glass melted	<0.01–0.08	0.01–0.07
	mg/Nm^3	4.0–30	7–30
HF	kg/tonne glass melted	<0.002–0.01	=0.02
	mg/Nm^3	<1.0–4.0	=1–6
Metals	kg/tonne glass melted	<0.001	<0.001
	mg/Nm^3	<1.0	<1.0

[a] Data provided in European Union (2005) using primary and secondary abatement techniques. The data covers both gas and oil fired furnaces.

2.2 Occupational Health and Safety

Occupational Health and Safety Guidelines

Occupational health and safety performance should be evaluated against internationally published exposure guidelines, of which examples include the Threshold Limit Value (TLV®) occupational exposure guidelines and Biological Exposure Indices (BEIs®) published by American Conference of Governmental Industrial Hygienists (ACGIH),[9] the Pocket Guide to Chemical Hazards published by the United States National Institute for Occupational Health and Safety (NIOSH),[10] Permissible Exposure Limits (PELs) published by the Occupational Safety and Health Administration of the United States (OSHA),[11] Indicative Occupational Exposure Limit Values published by European Union member states,[12] or other similar sources.

Accident and Fatality Rates

Projects should try to reduce the number of accidents among project workers (whether directly employed or subcontracted) to a rate of zero, especially accidents that could result in lost work time, different levels of disability, or even fatalities. Facility rates may be benchmarked against the performance of facilities in this sector in developed countries through consultation with published sources (e.g. US Bureau of Labor Statistics and UK Health and Safety Executive

Occupational Health and Safety Monitoring

The working environment should be monitored for occupational hazards relevant to the specific project. Monitoring should be designed and implemented by accredited professionals[13] as part of an occupational health and safety monitoring program. Facilities should also maintain a record of occupational accidents and diseases and dangerous occurrences and accidents. Additional guidance on occupational health and safety monitoring programs is provided in the **General EHS Guidelines**.

[9] Available at: http://www.acgih.org/TLV/ and http://www.acgih.org/store/

[10] Available at: http://www.cdc.gov/niosh/npg/

[11] Available at: http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9992

[12] Available at: http://europe.osha.eu.int/good_practice/risks/ds/oel/

[13] Accredited professionals may include Certified Industrial Hygienists, Registered Occupational Hygienists, or Certified Safety Professionals or their equivalent.

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Annex A: General Description of Industry Activities

The glass industry includes a variety of manufacturing facilities and products. It produces glass objects from a wide range of raw materials among which the most important ones are silica sand, glass cullet, and intermediate / modifying materials such as soda ash, limestone, dolomite, and feldspar. Raw materials availability is an important aspect in plant conceptual design and siting. The significant quantities of low-cost raw materials needed and the relatively low specific value of the manufactured products are fundamental factors in selecting a suitable plant location that reduces the transportation distances for the main raw materials and the products. This is particularly important in container glass manufacturing, which constitutes the largest glass industry sector.

More than 90 percent of the industry products are sold to other industries. Glass manufacturing is significantly dependent on the building construction sector, car manufacturing, and food and beverage industry. However, there are smaller volume sectors that produce high-value technical or consumer products. The special glass sector includes several subsectors like cathode ray and X-ray tubes, lighting glass (tubes and bulbs), glass for electronics and electro-technology, glass seals and insulators, borosilicate glass (pharmaceutical containers and cookware), ceramic glasses, optical glass, foam glass, brick and artistic glass.

Once sand, limestone, soda ash, and other raw materials are received, they are stored in separate bins. Before melting, the raw materials are transferred to a weighting and mixing system where they are mixed with cullet to ensure the necessary homogeneity. The mixture is conveyed to a batch storage bin where it is held until it is fed into the melting furnace. The melting furnace heats the raw materials to temperatures between 1,500°C and 1,650°C, which, through a sequence of chemical reactions, causes the materials to be transformed to molten glass. The glass melt is "pulled" from the furnace and is thermally conditioned in the "forehearth" to ensure the best modeling characteristics in successive working phases. After the forming process, glass is annealed in the "lehr" to remove unwanted stress from the formed glass, which is followed by an inspection and testing phase. The final packing phase prepares the finished product for storage or transportation. A typical glass manufacturing process is illustrated in Figure 1-A.

Raw Materials

Different glass sub-sectors and the individual plants use a wide range of raw materials. The main raw materials include glass-forming materials (e.g. silica sand, cullet), intermediate / modifying materials (e.g. soda ash, limestone, feldspar, and dolomite), and coloring / decoloring agents (e.g. chromites, iron oxide, cobalt oxide, selenium, and zinc selenite). For the manufacturing of special and technical glass, lead oxide, potash, zinc oxide, and other metal oxides are used. Refining agents include arsenic and antimony oxide, nitrates, and sulfates. Three to four raw materials represent more than 95 percent of the raw materials used by the glass manufacturing industry (sand, soda ash, limestone and dolomite), however, several raw materials are used in glass-forming materials, intermediate and modifying materials, and coloring agents.

Energy Consumption and Fuels

Glass manufacturing is an energy-intensive activity and it is critical to adopt energy efficiency measures, particularly in the design phase of the melters. The melting process is the most energy-intensive phase, involving between 60 and 80 percent of total energy consumption of glass manufacturing. The furnace characteristics (in particular, type and size) affect the specific energy performance. Other energy users in glass manufacturing are forehearths, the forming process, annealing, and factory heating among others. Combustion and cooling air fans are significant electricity users. Benefits in reducing energy consumption and air emissions per unit output can be obtained from actions aimed at reducing the product weight, particularly for container glass. This can be achieved through design optimization, forming process optimization and implementation of post-forming treatments.

Melting Process

The choice of energy source, heating technique, and heat recovery method are central to the design of a glass-melting furnace. These choices are some of the most important factors affecting the environmental performance and energy efficiency of the melting operation and, therefore, the energy efficiency of the overall glass production process. Glass-melting furnaces are categorized by their fuel source and method of heat application into the following four types: regenerative, recuperative, unit melter, and electric melter. The recuperative, regenerative, and unit melter furnaces can be fueled by gas, oil or pulverized solid fuels. The fuels used are an important factor in terms of GHG, particulate and SO_2 emissions. The decision on the fuels to be used should consider environmental aspects in the context of the plant site.

Regenerative Furnaces

These furnaces utilize paired regenerative heat recovery systems to preheat combustion air. Burners are usually positioned in or below combustion air / waste gas ports. The furnace fires on one side at a time. Hot furnace flue gases pass though and heat refractory material in the regenerator chamber. After an appropriate time, the firing is reversed and inlet combustion air passes through the hot regenerator chamber that was previously heated by the waste gases. Preheat temperatures are normally between 1,100°C and 1,350°C yielding the highest thermal efficiency for fossil fuel fired furnaces.

There are two types of regenerative furnaces, cross-fired and end-fired. The cross-fired regenerative furnaces have combustion ports and burners positioned along the sides of the furnace, while the regenerator chambers are located on either side of the furnace. The end-fired furnaces have the two regenerator chambers situated at one end of the furnace and they each have a single port. End-fired (or end-port) furnaces are used most often in small applications, because they have more compact dimensions and utility, and lower heat losses, energy consumption, and constructions costs. However, they are characterized by a U-shape flame from one regenerator chamber to the adjacent one, which is problematic in “covering” large glass surfaces (maximum surface size is about 110–120 m^2 and about 400–450 ton / day of pull). For large glass surfaces, cross-fired (or side-port) furnaces are preferred. Almost all of the furnaces used for flat glass manufacturing have side ports.

Recuperative Furnaces / Unit Melter Furnaces

Recuperative furnaces use metallic heat exchangers for heat recovery, with continuous preheat of combustion air by the waste gases. Material properties limit air preheat temperatures to approximately 750°C to 800°C, but there are innovative furnaces, still in the testing phase, which allow preheat to 900°C and higher. Because of the lower air preheat temperatures, the specific melting capacity (per unit of melter area) of these furnaces is around 30 percent lower than for regenerative furnaces. This type of furnace is primarily used in operations that need high flexibility and have limited initial capital outlay. In small operations, the use of regenerators is economically not viable. Recuperative furnaces are usually adopted for small capacity installations, although high-capacity furnaces (up to 400 tons per day) also exist. Unit melter (or direct-fired) furnaces are not necessarily equipped with recuperators, but currently most are. Recuperative and unit melter furnaces typically require limited earthwork for their installation.

Oxy-fuel Furnaces

Oxy-fuel melting involves the replacement of combustion air with oxygen. The elimination of nitrogen from the combustion atmosphere reduces the volume of the waste gases and the use of heat recovery systems is avoided. Furnace energy use is reduced because the system heats oxygen rather than air (which is 80 percent nitrogen) to combustion temperatures. Some oxy-fuel furnaces use waste gases to preheat batch materials and cullet. The specific NO_x production (kg / kg glass) is significantly reduced, but, because of the reduced flue gas flows, NO_x concentrations will be much higher than normal. Oxy-fuel furnaces have a basic design similar to unit melters, characterized by multiple lateral burners and one waste gas exhaust port. Their implementation should carefully consider cost trade-offs, as discussed in the next section.

Electric Furnaces

Electric furnaces consist of a refractory melting structure, having electrodes inserted either from the side, the top, or more commonly the bottom of the furnace. The electric furnaces are commonly small and particularly used for special glass. Electric heating eliminates the formation of combustion by-products with the replacement of fossil fuels and batch carry-over and therefore, furnace emissions are greatly reduced. Also, electric furnaces may be substantially sealed, and so are preferred when air emissions from batch are particularly polluting.

.Discontinuous Batch Melters

These melters are used when smaller amounts of glass are needed, especially in situations in which the glass formulation changes regularly. Pot furnaces or day tanks are used to melt batches of raw material. Some melters employ simple recuperators, having concentric cylindrical geometry and reaching preheating air temperatures of 300°C to 400°C. However, most of these furnaces do not have preheating air systems installed.

Electric and Oxygen Boosting

Totally electrically heated furnaces exist, but more often electric “boost” heating is used to supplement heating from fuel combustion in regenerative or recuperative furnaces. Electric boosting creates the conditions needed to heat particular zones of glass in which heating with normal flame (bottom flame) proves to be difficult or a specific temperature profile is wanted. Electric energy can also be used when a short–term production increase is needed or to increase furnace output beyond that achievable without major rebuild. The typical electric energy amount in electric boosting is between 4 and 10 percent of the total energy used. Similarly, oxygen boosting (replacing combustion air with oxygen in a limited number of burners) Is used to increase furnace output under certain circumstances. Usually 10 to 30 percent of combustion air is substituted with oxygen.

Oxy-fuel and electric furnaces show consistent reductions in furnace fuel usage, and because waste heat recovery systems are not necessary with the substantially reduced waste gas volume, often also in investment costs. However, a correct balance of economical, energy and environmental aspects of these technologies should account for the energy and environmental aspects related to oxygen and electricity production. The relative cost of electricity and fossil fuel is the major issue pertaining to the economic viability of these techniques, and must be considered on a case-by-case basis.

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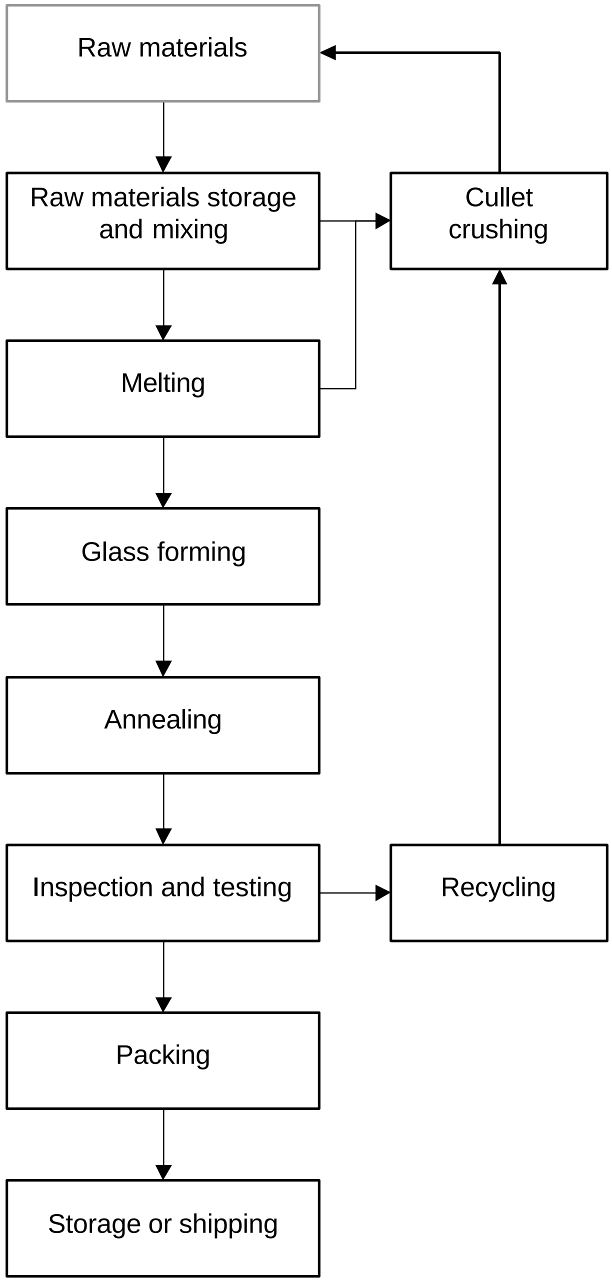
Figure A.1: Glass Manufacturing Process



Note: External cullet, not presented in this figure, is also a raw material used. Since it is washed before use, it cannot be treated with the other raw materials. External cullet is usually stored as delivered – then washed and added to the batch – without storage of clean cullet.