



Regional Haze Four Factor Analysis

Owens-Brockway Glass Container Inc.,
9710 NE Glass Plant Road, Portland, OR
97220

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Acronyms and Abbreviations

Name	Description
BART	Best Available Retrofit Technology
CCF	catalytic ceramic filters
CEM	Continuous Emission Monitor
COMs	Continuous Opacity Monitors
CPH	Cullet pre-heating
ESP	electrostatic precipitator
EU	Emission Unit
FGR	Flue gas recirculation
HEST	hot end surface treatment
LNB	Low-NOx Burner
MACT	Maximum Available Control Technology
MEK	Methyl ethyl ketone
MBTT	mono-butyl-tin trichloride
NH ₃	Ammonia
NOx	nitrogen oxides
O-B	Owens-Brockway
ODEQ	Oregon Department of Environmental Quality
PM	particulate matter
RBLC	RACT/BACT/LAER Clearinghouse
SCR	selective catalytic reduction
SIP	State Implementation Plan
SO ₂	sulfur dioxide

1. INTRODUCTION

Owens-Brockway Glass Container, Inc. (O-B) is required to prepare this Regional Haze Four Factor Analysis by the Oregon Department of Environmental Quality (ODEQ). As part of the regional haze State Implementation Plan (SIP), ODEQ is required to develop and implement air quality protection plans to reduce haze in Class I areas, which includes national parks and wilderness areas. During this second implementation period of the federal Regional Haze program, ODEQ is required to update the SIP to address the long-term strategy for regional haze visibility impairment in each of the twelve Class I areas within Oregon as well as the Columbian River Gorge National Scenic Area and those Class I areas outside of Oregon impacted by emission sources within Oregon.

1.1 Facility and Process Description

The O-B facility (Facility) is a glass manufacturing plant capable of producing glass containers and located at 9710 NE Glass Plant Road in Portland. Due to the Facility location and historical emissions, ODEQ has identified the Facility as a significant source of regional haze precursor emissions, specifically nitrogen oxides (NO_x), sulfur dioxide (SO₂), and particulate matter (PM). A summary of the relative precursor pollutant emissions by emission unit (EU) is shown in Table 1¹.

Table 1: Relative Precursor Emissions by Emission Unit

Equipment		Facility Percentage (%) ¹		
EU ID	Equipment Description	NO _x	SO ₂	PM
EU1	Raw material handling – conveyor/elevator silos	---	---	0.14
EU2	Cullet crusher	---	---	8.76
EU3	Conveyors, weigh bins, surge bin, mixers chargers	---	---	0.22
EU4	Glass melting, Furnace A	53.69	50.84	41.95
EU4	Glass melting, Furnace D	44.74	49.02	35.75
EU5	Hot-end surface treatment	---	---	0.18
EU5	Mold Swabbers	---	---	9.78
EU6	Other natural gas burning equipment ²	1.30	0.11	0.21
EU7	Boiler	0.28	0.02	0.03
EU10	Machine repair dust collector	---	---	1.49
EU10	Mold bench dust collector	---	---	1.49

1. Based 2019 emission inventory

2. Includes refiners, forehearts, lehrs, mold/burnout oven, mold heat oven, and quick fire oven

The Facility produces glass by importing and mixing raw materials which are fed into and are melted by furnaces operating at temperatures greater than 2,350°F. The molten glass is cooled slightly and then shaped into containers.

Raw materials including sand, salt cake, limestone, and soda ash are delivered to the Facility via railcars and trucks to an unloading pit. Elevators transport the raw materials to designated storage silos in the batch house. Individual components are weighed on scales located under each silo and conveyed to the mixer where the cullet (i.e., recycled glass) is added. The batch house baghouse abates dusts generated during the raw materials transport and mixing operations.

The Facility currently purchases ecology cullet (i.e., crushed glass) from another company and no longer accepts recycled bottles to process in-house to make cullet. The cullet received is pre-sorted according to color. The Facility also uses cullet generated in-house as feed for its glass melting furnaces.

¹ Note that all tables in the report body do not include sensitive facility information, such as emissions values and direct/indirect costs. These details are contained in expanded versions of each table located in Appendix A.

Raw materials, cullet and minor ingredients are combined in the mixer to form batch material which is placed into a surge bin, and liquid caustic (i.e., wetting agent) is added to the bin as needed. Batch material is then transferred from the surge bin to the batch charger that feeds the glass-melting furnace.

The Facility operates two glass melting furnaces "A" and "D", which are both continuous regenerative furnaces capable of producing about 98,550 and 82,125 tons per year of glass respectively. The shells of Furnaces "B" and "C" physically occupy space but are not functional; Furnace B was shut down after 1978 and Furnace C was last operated in 1990. Furnace A has dual side-ports with south and north stacks to exhaust the furnace emissions, alternating between the two stacks every 30 minutes. Furnace-D is an end-port furnace with a single stack.

Typically the end-port furnace consumes less energy (i.e., less natural gas fuel usage leading to lower emissions) than a comparable cross-fired/side-port furnace. However, the side-port furnaces can be built for larger melting capacity and are more efficient than several small end-port furnaces. Continuous Opacity Monitors (COMs) installed on each of the three furnace exhaust stacks measure opacity from furnaces A and D.

The batch-mixture is charged into the furnace at the same rate as the molten glass is pulled out to achieve steady state operation. As the pre-mixed batch enters the melting furnace through the feeder, it initially floats on the top of the molten glass already in the furnace. Raw materials melt and pass through the melter and eventually through a "throat" at the bottom of the furnace that leads into the refiner. As the molten glass flows through the refiner, the glass temperature decreases and becomes more uniform prior to entering the forehearth, where it is cooled to a uniform temperature and desirable viscosity prior to the forming machine.

As the molten glass leaves the feeder (forehearth), it is cut into "gobs", with each gob being enough glass for one container. After the gob has been sheared from the feeder, it falls through a series of gob delivery and into the appropriate section of the forming machine.

Mold preparation is an inherent part of the bottle-forming process. The mold preparation involves cleaning, lubricating, curing and heating molds when they are not being used in the forming machines. (Note: While a mold is in use, the operator periodically swabs molds with a graphite/oil solution as needed. This accounts for the emissions from the forming machines). A defective mold is purged from the production line for maintenance and repair. A purged-mold is cleaned in the burnout ovens and grit blasters, and then solid film lubricant is applied in the mold coating spray booth and cured in the mold curing ovens. The repaired mold's temperature is elevated in the mold heat ovens and quick fire ovens prior to re-entering the bottle forming production line.

Once the glass containers are formed, the hot end surface treatment (HEST) process applies mono-butyl-tin trichloride (MBTT). The HEST process deposits a layer of tin oxide (SnO₂) onto the glass surface. The exhaust from the HEST process vents through an abatement device. Ammonia is added to HEST hood exhaust prior to the abatement device so it can react with the excess MBTT to form solid particulate matter (PM) that can be collected in the baghouse. Following the HEST process, the bottles are annealed in the lehr, which is a long oven that reheats and then cools the containers in a way that relieves stresses in the glass.

Between the forming machine and the lehr, hot-faulty bottles are purged from the production line and fall into a hopper containing water placed below the production line in the basement to become in-house cullet. After the lehr, a cold end spray is applied. The glass containers are then quality-inspected and defective bottles are kicked to a belt conveyor that also goes to the basement for in-house cullet. An oil/water separator treats and recirculates the catch water used in the dunk-buckets. In addition to rejecting faulty bottles, the inspection process gathers statistical information to trace the faulty containers being produced to the defective mold. This is accomplished by reading the mold number on the container, which was encoded as a numeral or binary code of dots on the container by the mold that made it. Operators also perform a range of manual inspections on samples of

containers. The I.S. forming machine allows operators to take one or more sections out of the production line for repairs without shutting down the entire production line.

Finally the finished bottles are coded and packaged for shipping. A bottle coder (ink-jet printer) prints tiny identification numbers on the glass containers as they rapidly move through the conveyor. Methyl ethyl ketone (MEK) is used as a clean-up solvent and as the ink (carrier) solvent. MEK emissions are grouped under aggregate insignificant activities. Lastly, the finished glass containers are packed into cartons or bulk-loaded for shipping.

The Facility operates a boiler rated at 10.5 MMBtu/hr and small space heaters strictly for space heating. There are also hot water heaters to heat water for showers and restrooms. Space heaters and water heaters are categorically insignificant activities.

Maintenance activities include four “Safety-Kleen” parts cleaners, welding operations, and minor machining and painting activities. The plant has one vertical fixed roof storage tank for storing fuel oil and several horizontal tanks storing propane. There are also storage tanks for used oil, machine lube oil, and ammonia. The Quality and Standards (Q/S) lab uses bench scale laboratory equipment for chemical and physical analysis.

1.2 Four Factor Analysis Methodology

The methodology used for the Four Factor Analysis is based on the EPA’s Guidance on Regional Haze SIPs for the Second Implementation Period (EPA-457/B-19-003, August 2019). First, all available control technologies were identified using a combination of the EPA’s RACT/BACT/LAER Clearinghouse (RBLC) database, control technologies listed in the EPA Cost Control Manual, and prior knowledge and experience in the environmental field. Next, technically infeasible options were eliminated based on site-specific details or a lack of commercially-demonstrated precedents cited in the RBLC database. Lastly, the remaining technically feasible options were assessed using the four statutory factors described in the EPA guidance document. These four factors are outlined below:

1. Cost of control
2. Time necessary to install controls
3. Energy and non-air quality environmental impacts
4. Remaining useful life

ODEQ contacted O-B by certified mail dated December 23, 2019. The letter identified the Facility as a significant source of regional haze precursor emissions, and required O-B to prepare a four factor analysis for the emission units and precursor pollutants. Based on a review of the Facility emissions, it has been determined that the four-factor analysis should include a review of control technologies for all sources of NOx, SO₂, and PM emissions.

2. SOURCE CATEGORY ANALYSIS

2.1 NOx Emissions Sources

2.1.1 Glass Melting Furnaces

The majority of the NOx emissions (i.e., 98.43%) from the Facility result from the combustion processes of the glass melting furnaces. The internal temperature of the furnace is maintained at above 2,350°F. At this temperature, thermal NOx is created through the homogenous gas phase reaction of N₂ and O₂ in the air. Thermal NOx is the primary form of NOx emitting from both furnaces. Other forms of NOx formation, such as fuel NOx, are considered to be insignificant since the furnaces are being fueled by natural gas which typically has no fuel bound nitrogen. Both furnaces are currently equipped with low-NOx burners (LNBS) and electric boost as NOx control methods.

2.1.1.1 Control Options

The following NOx control options were identified for glass container melting furnaces using the RBLC database, the EPA Cost Control Manual, and environmental consulting experience and judgment.

Oxy-firing

Oxy-firing is a combustion control method that combusts the fuel along with pure oxygen in the furnace burners as opposed to ambient air. This process reduces the amount of NOx produced as thermal NOx by minimizing the amount of nitrogen in the combustion air steam, thus reducing the reaction of N₂ and O₂.

Flue Gas Recirculation

Flue gas recirculation (FGR) can reduce NOx emissions by reintroducing the exhaust gas into the combustion air stream before it reaches the burner. Flue gas contains less oxygen and, therefore, reduces the flame temperature and this retards the oxidation of atmospheric N₂ into NOx. In addition, flue gas is relatively cooler than the flame, which also decreases the peak flame temperature and reduces production of thermal NOx. Reducing the flame temperature, however, may not be feasible since the furnace is meant to operate at temperatures higher than 2,350°F.

Cullet Pre-heating

Cullet pre-heating (CPH) reduces the formation of NOx by addressing the inherent inefficiencies of the glass melting furnaces. In the glass container sector, a furnace requires approximately 8 to 10 MMBtu to produce one ton of glass. Cullet pre-heaters are designed use recovered heat from the flue gas, which reduces the energy consumption needed for glass melting. Currently-available cullet preheaters are estimated to account for 8 to 12 percent of the total energy needed for the glass-melting process. Pre-heating can be either through direct or indirect contact.

Selective Catalytic Reduction

Selective catalytic reduction (SCR) can be used to treat the post-combustion NOx by reducing it to diatomic nitrogen (N₂), water, and oxygen. Ammonia or urea can be injected into the flue gas upstream of a catalyst bed to act as a reducing agent for the NOx. The catalyst lowers the activation energy required to reduce NOx. Depending on the catalyst, the optimal temperature for NOx reduction lies between 470 to 1,000°F. A properly maintained SCR system can reduce NOx emissions by 70 to 90 percent, more than an SNCR system, but have lower operating costs and higher capital costs.

Selective Non-catalytic Reduction

Reduction of NOx can also be achieved without the use of a catalyst through selective non-catalytic reduction (SNCR). Similar to the SCR process, NOx is reduced to N₂, water, and oxygen by injecting ammonia or urea into the flue gas, but since there is no catalyst, this option requires a higher temperature range of about 1,700 to 2,000°F. The SNCR system can reduce emissions by 30 to 60 percent and up to 50 to 90 percent with the addition of a low-NOx burner (LNB).

Catalytic Ceramic Filters

Catalytic ceramic filters (CCF) manufactured by Tri-Mer Corporation remove emissions of NOx, SO₂, and PM. The CCF system is comprised of high temperature, light-weight ceramic filters impregnated with a NOx catalyst (i.e., vanadium pentoxide) as the primary method of treating the exhaust. The low-porosity ceramic filters also serve to filter out PM. Upstream of the filter, aqueous ammonia is injected to aid in the conversion of NOx emissions to N₂ and water vapor in the catalyst-embedded filter. A sorbent (i.e., hydrated lime) is also injected upstream of the filters to treat SO₂ by conversion to calcium sulfate solids, a PM that is then removed by the filters.

2.1.1.2 Eliminating Technically Infeasible Options

Flue Gas Recirculation

The reintroduction of the combustion gas into the air stream would reduce the amount of oxygen available to produce NOx, but it would also decrease the peak flame temperature. Temperature within the furnace must be maintained at above 2,350°F for proper melting and mixing of the raw materials. Since the recirculation would decrease the temperature below the required 2,350°F, FGR is considered technically infeasible.

Selective Non-catalytic Reduction

Exhaust temperatures from the furnaces are below 1000°F, which is below the optimal temperature range of 1600°F to 2100°F required for the SNCR reaction to occur. SNCR reactions do not occur at lower temperature, thus decreasing the NOx removal efficiency and increase the ammonia slip potential. Furthermore, upon review of the RBLC for glass manufacturing during the previous 20 years, SNCR did not appear as a source of NOx control for other facilities. Therefore, SNCR is considered technically infeasible as it is not commercially available as a control technology for the furnaces.

2.1.1.3 Cost of Compliance

Costs for each control device were determined based on direct (i.e., operational and maintenance) and indirect (i.e., equipment and installation) costs that were converted to an annualized capital investment factor (see Appendix B). Tables 2 and 3 present the annualized capital cost effectiveness, for Furnaces A and D, respectively, without consideration of direct or indirect operating costs. In annualizing costs, a 20-year useful life for control systems was assumed (except where noted otherwise) with an average loan interest rate of 7% based on O-I input. For the feasible NOx control options, the cost of compliance was evaluated at two levels. First, if the annualized cost of capital investment was high (i.e., chosen to be control options above \$10,000/ton pollutant removed), without considering annual direct and indirect costs, then that control option could be deemed cost prohibitive and removed from consideration. Based on the initial screen, two NOx controls were removed from consideration as cost prohibitive based on annualized capital cost. For the two remaining NOx controls, a second more detailed assessment of both capital investment and ongoing annual expenses was evaluated.

Table 2: NOx Emissions Capital Cost Effectiveness for Furnace A

Control Device	Control Efficiency (%)	Annualized Capital Cost Effectiveness (\$/ton NOx)
OxyFuel	85	11,147
CPH	5	37,369
SCR	62.5	1,347
CCF	90	4,185

Table 3: NOx Emissions Capital Cost Effectiveness for Furnace D

Control Device	Control Efficiency (%)	Annualized Capital Cost Effectiveness (\$/ton NOx)
OxyFuel	85	12,152
CPH	5	43,007
SCR	62.5	1,491
CCF	90	3,943

As presented in Table 2 and 3, the cost effectiveness of the oxyfuel conversion is \$11,147 and \$12,152 per ton NOx removed for furnaces A and D, respectively. The cost effectiveness of the cullet pre-heating is \$37,369 and \$43,007 per ton NOx removed for furnaces A and D, respectively. Both oxyfuel conversion and cullet pre-heating are considered cost-prohibitive based on the high annualized capital cost per ton abated.

In the next step, the total costs associated with control effectiveness is determined based on the total annualized costs, including capital investment, direct, and indirect annual costs. Tables 4 and 5 summarize the NOx control effectiveness for Furnaces A and D, respectively. Additional cost input information is presented in Appendix B. With all costs considered, costs effectiveness values greater than \$15,000/ton pollutant removed was considered cost-prohibitive. Based on this criteria, SCR or CCF would be feasible control options for the glass furnaces.

Table 4: NOx Emissions Control Effectiveness for Furnace A

Control Device	Control Efficiency (%)	Cost Effectiveness (\$/ton NOx)
SCR	62.5	3,800
CCF	90	6,734

Table 5: NOx Emissions Control Effectiveness for Furnace D

Control Device	Control Efficiency (%)	Cost Effectiveness (\$/ton NOx)
SCR	62.5	4,354
CCF	90	6,687

2.1.1.4 Time Necessary for Compliance

Sources are generally given between two and five years to implement changes for compliance with new regulations. Maximum Available Control Technology (MACT) standards typically allow three years for compliance and Best Available Retrofit Technology (BART) emission limitations require compliance no more than five years after regional haze SIP approval by the EPA. Combustion modifications and post-combustion NOx controls require significant time for engineering, construction, and facility preparedness. Two to five years would typically be appropriate, depending on the size of the unit and control options selected.

2.1.1.5 Energy and Non-Air Impacts

SCR and CCF require additional electricity and reagent costs that are included in the indirect cost calculations in determining the overall cost effectiveness. These technologies may present several adverse environmental impacts. Unreacted ammonia in the exhausted flue gas (i.e., ammonia slip) and the products of secondary reactions between ammonia and other species present in the flue gas can cause the formation of additional condensable particulate matter such as ammonium sulfate $[(\text{NH}_4)_2\text{SO}_4]$. The ammonium sulfate can corrode downstream exhaust handling equipment, as well as increase the opacity or visibility of the exhaust plume.

2.1.1.6 Remaining Useful Life

Furnace A was installed at the Facility in 1956. In 1983, Furnace A was modified to increase the size by 40%. Furnace D was installed in 1970 and was converted from an electric to a gas furnace in 1986. The ODEQ requires a 20-year horizon for the four factor analysis, however, the remaining useful life is estimated at up to 10 years due to the age of the furnaces. The estimated remaining useful life contributes to the selected duration of the capital expenditure recovery period.

2.1.2 Other Natural Gas Burning Equipment

Other natural gas-burning equipment at the facility accounts for about 1.3% of the NOx emissions at the Facility (see Table 1). The primary contributors of these emissions are the glass conveyance equipment (i.e., refiners and forehearts, and lehrs). The refiners and forehearts are required for a controlled cool-down of the molten glass following the melting furnaces while still maintaining high temperatures in excess of 2,000°F. Lehrs are linear ovens designed to slowly cool down (i.e., anneal) the formed bottles as they are transported to the final stages prior to packaging. The process also uses other small gas-fired ovens during the bottle treatments, and some small ovens are used in the maintenance shop and are not related to the glass-making process. While there are NOx emissions associated with the miscellaneous gas-burning equipment, their emissions are considered negligible compared to the glass furnaces.

To convey molten glass while maintaining high temperatures, refiners and forehearts use an array of side-mounted small tubular fuel jets, typically with diameters less than half an inch, spread throughout the entire length of the glass flow path for even heat distribution. The conveyance path is surrounded by refractory brick to maintain heat. Emissions escape into the building space via period openings in the refractory on the “ceiling” of the conveyance equipment that use adjustable dampers to control the temperature retained in each section.

After reviewing the RBLC, LNBs are the only control method in application in the last 20 years for glass manufacturing facilities, specifically for the annealing lehrs. The Facility operates four annealing lehrs (one of which is electric), one lehr for each of the four manufacturing lines. LNBs are a combustion modification technology that controls the fuel and air mixing at the burner that optimizes the flame structure to reduce the flame temperature, consequently reducing the formation of thermal NOx. Additionally, the flame structure reduces the amount of oxygen in the hottest part of the flame, which improves burner efficiency. The LNB is a physically larger, and more complex unit than

conventional burners, and for effective implementation the gas-fired equipment must be physically compatible.

At the Facility, the heated conveyance systems downstream of the furnace are not viewed as feasible candidates for retrofit technology. The gas combustion jets in the molten glass conveyance equipment are too small and not compatible with LNB technology. The physical configuration of the exhaust points for the refiners and forehearts present major challenges to capture the emissions while also maintaining the function of the equipment. While LNB technology has been proven for use in lehrs and might be technically feasible, the Facility has determined this would be considered cost prohibitive due to the low fraction of site emissions that would be abated.

2.1.3 Boiler

The Facility generates NOx emissions through the utilization of a 10.5 MMBtu/hr boiler that is used for space heating and hot water. NOx emissions are generated as a result of the combustion of natural gas as a fuel source. The boiler is also designed to use diesel as a backup fuel source, but natural gas has been used exclusively since at least 2009. Since natural gas typically has no fuel-bound nitrogen, NOx emissions due to fuel source are minimal. While there are NOx emissions associated with the boiler, they are considered negligible comparatively (about 0.28% of facility-wide NOx emissions). However, NOx emissions control of boilers is very common, thus the options will be evaluated further in the following sections.

2.1.3.1 Control options

The following two NOx control options were identified for smaller, gas-fired boilers using the RBLC database. LNBs and SCRs have been commercially demonstrated in practice.

Low-NOx Burners

LNBs are a combustion modification technology that control the fuel and air mixing, promoting so-called "staged combustion" at the burner. This feature optimizes the flame structure to reduce the flame temperature, consequently reducing the formation of thermal NOx. Additionally, the flame structure reduces the amount of oxygen in the hottest part of the flame, which improves burner efficiency.

Selective Catalytic Reduction

SCR can be used to treat and reduce post-combustion NOx to N₂, water, and oxygen. Ammonia or urea can be injected into the flue gas upstream of a catalyst bed to act as a reducing agent for the NOx. The catalyst lowers the activation energy required to reduce NOx. Depending on the catalyst, the optimal temperature for NOx reduction lies between 470° to 1,000°F. A properly maintained SCR system can reduce NOx emissions by 70 to 90 percent, but has generally high operating costs and capital costs.

2.1.3.2 Eliminating Technically Infeasible Options

While neither of the control options considered are very practical for this size boiler and the amount of potential emissions reduced, both could be considered technically feasible. LNB had been previously considered by the Facility and studied for this boiler, and the Facility determined at that time that retrofit would be cost prohibitive.

2.1.3.3 Cost of Compliance

For the NOx control options, the capital costs for LNB were evaluated as these values were readily available at the time of the analysis. The cost of compliance was evaluated to assess whether the annualized cost of capital investment alone was sufficiently high to show the option was cost

prohibitive. Table 6 presents the NOx control effectiveness for LNB for the boiler based on the annualized cost of capital investment.

Table 6: NOx Emissions Capital Cost Effectiveness for Boiler

Control Device	Control Efficiency (%)	Annualized Capital Cost Effectiveness (\$/ton NOx)
LNB	50	24,114

As presented in Table 6, the capital cost effectiveness of the LNB conversion is \$24,114 per ton NOx removed, primarily because the boiler is a small source of NOx. Consequently, LNB retrofit of the boiler is considered cost-prohibitive.

SCR has a much higher capital investment, and significant direct and indirect annual costs as compared to LNB. If SCR were evaluated for capital cost effectiveness, the cost per ton abated would be greater than LNB. Therefore, the application of SCR is also considered cost-prohibitive.

2.1.3.4 Time Necessary for Compliance

Sources are generally given between two and five years to implement changes for compliance with new regulations. MACT standards typically allow three years for compliance and BART emission limitations require compliance no more than five years after regional haze SIP approval by the EPA. Combustion modifications and post-combustion NOx controls on the small boiler would require significant time for engineering, construction, and facility preparedness. Two to five years would typically be appropriate, depending on the size of the unit and control options selected.

2.1.3.5 Energy and Non-air Impacts

The addition of an LNB burner has minimal adverse impacts once installed, provided it can be tuned to operate correctly into the retrofit boiler. There are potential for developing hot spots or vibration issues within the boiler that may shorten the life of some components.

2.1.3.6 Remaining Useful Life

The boiler at the Facility is expected to remain operational for the next 20 years.

2.2 SO₂ Emissions Sources

2.2.1 Glass Melting Furnaces

The majority of the SO₂ emissions from the Facility (99.87%) result from the glass melting furnaces. Most of the emitted SO₂ is due to sulfur oxides being released from the batch. Sulfur is also produced in the combustion of natural gas but only in trace amounts stemming from added sulfur-containing odorants for natural gas leak detection.

2.2.1.1 Control Options

Dry scrubbers and semi-dry scrubbing systems were identified as SO₂ control options for glass container melting furnaces using the RBLC database. These controls have been commercially demonstrated and are considered readily available.

Dry Scrubbers

Dry scrubbers pneumatically inject powdered sorbent directly into the furnace or downstream exhaust. The alkaline sorbent reacts with the SO₂ in the furnace exhaust gas, forming sulfate solids. Dry scrubbers are used in conjunction with PM control equipment (i.e., cyclone, baghouse or electrostatic precipitator [ESP]) to remove the dry waste product, thus this system controls multiple pollutants. The flue gas is generally cooled prior to entering the PM control device. Water can also be injected along with the sorbent to enhance SO₂ removal.

Furnace injection requires flue gas temperature between 1,740°F to 1,830°F in order to decompose the sorbent into porous solids with high surface area. Duct injection requires the dispersion of a fine sorbent spray into the flue gas downstream of the furnace air preheater. The injection must occur at flue gas temperatures between 300°F and 350°F for more efficient SO₂ removal.

Dry scrubbers have significantly lower capital and annual costs than wet systems because they are less complex, demand less water, and generate less waste. Dry injection systems are typically more flexible to install and use less space than wet scrubbing systems, therefore, they can be good candidates retrofit applications. SO₂ removal efficiencies are significantly lower than wet systems, between 50% and 60% for calcium based sorbents. Sodium based dry sorbent injection into the duct can achieve up to 80% control efficiency.

Based on review of the RBLC, dry scrubbing systems have been used in practice for glass furnaces. While the RBLC listed this technology as being used for a float glass line that produces plate glass, this technology is in use at other O-B container glass facilities. Therefore, it is considered technically feasible and will be considered for this analysis.

Semi-Dry Scrubbing Systems

Semi-Dry scrubbing systems (sometimes called spray dryers) introduce the flue gas into an absorbing vessel (dryer) where the gas is contacted with a finely atomized alkaline slurry that is usually a calcium-based sorbent. The acid gas in the stream is absorbed and neutralized by the slurry droplets. The reaction forms solid salts that are removed by a particulate control device. The heat of the flue gas is used to evaporate the water droplets thus leaving a filtered flue gas to exit the absorbing vessel. Semi-dry scrubbing systems usually can achieve control efficiencies ranging from 80 to 90 percent.

2.2.1.2 Eliminate Technically Infeasible Options

Semi-Dry Scrubbing Systems

Semi-dry scrubbing systems are typically more efficient at removing SO₂ than a dry scrubbing system; however, they are also harder to maintain. Improper operation can cause "concrete" to form within the exhaust ducts, which in turn results in severe maintenance issues and furnace down-time. Due to this

potential issue, retrofit of semi-dry scrubbing systems is viewed as technically infeasible for the glass melting furnaces.

2.2.1.3 Cost of Compliance

Costs for the control device was determined based on direct and indirect costs that were converted to an annualized capital investment factor (see Appendix B). It is recognized that use of a dry scrubber with an electro-static precipitator (ESP) to capture particulate matter is an integrated system. Because this combined system will reduce both SO₂ and PM, the cost effectiveness calculations are performed differently to account for multiple pollutant reductions. Section 2.4 discusses the proposed control options that reduce multiple pollutants and their overall cost effectiveness.

2.2.2 Other Natural Gas Burning Equipment

Similar to the furnaces, the refiners, forehearts, lehrs, and ovens use natural gas as the fuel source which is generally accepted as best available control technology for SO₂. While there are SO₂ emissions associated with the miscellaneous gas burning equipment, they are considered negligible (about 0.13% for all the other natural gas burning equipment combined). No SO₂ emissions are emitted from the glass being conveyed; the majority of the SO₂ emissions occur within the furnace and thus are captured in the furnace exhaust stream previously discussed. Due to the small size of the emissions from other gas-fired equipment, there is no further analysis of controls considered for these sources.

2.2.3 Boiler

As stated in previous sections, combustion of natural gas results in low levels of SO₂ emissions. The boiler accounts for 0.02% of facility-wide SO₂ emissions, and therefore is considered negligible in the consideration of sources of SO₂.

2.3 PM Emission Sources

2.3.1 Glass Melting Furnaces

The majority of the PM emissions (i.e., 78%) from the Facility are from the two glass melting furnaces (A and D). Particulates are generated from carry-over of feed material from the furnace batch and volatilization/ condensation of materials released from the glass melt. These emissions are either collected on the surface of the refractory bricks in the furnace/regenerator structure or be emitted into the atmosphere through the exhaust stacks.

2.3.1.1 Control Options

The following three PM control options were identified for glass container melting furnaces using the RBLC database. Baghouses, ESPs, and CCF systems have been commercially demonstrated and considered available.

Baghouses

Among the most widely used control devices for PM, baghouses use long cylindrical bags to filter particulates from an exhaust stream. Dust-laden gas or air is sent to a baghouse through hoppers and is directed to the baghouse compartment. The gas is drawn through the filter bag, and as a result, a layer of dust forms on the surface of the filter. Once a sufficient pressure drop is created, the filter bag is cleaned by either shaking or utilizing a burst of compressed air. The dust is collected in a hopper where the material can be properly disposed of or recycled back into the process. Properly functioning baghouses typically have control efficiencies greater than 99%. A "hot" baghouse may be designed for a furnace application that can accept elevated temperature flows.

Electrostatic Precipitators

ESPs are used for the filtration of dust and fine particulates from a gas stream. An ESP uses the force of an induced electrostatic charge to remove PM. The most basic type of precipitator consists of a row of thin vertical wires followed by a row of flat vertical metal plates. A negative voltage is applied between the wires and plates. As dust-laden gas is sent through the spaces between the wires and plates, the particles are ionized and diverted towards to grounded plates. Particles build up on the plates and are removed from the air stream where they are eventually collected in hoppers below the ESP. Properly functioning ESPs typically have control efficiencies greater than 95%.

Catalytic Ceramic Filters

CCF system manufactured by Tri-Mer Corporation removes emissions of PM that may be emitted as oxides. The system is comprised of high temperature, light-weight ceramic filters as the primary method of treating the exhaust. The low-porosity filter acts to control PM emissions.

2.3.1.2 Eliminate Technically Infeasible Options

All three control options are technically feasible and will be considered further for cost analysis.

2.3.1.3 Cost of Compliance

Costs for each control device were determined based on direct (i.e., purchase of equipment) and indirect (i.e., design, installation, operational, maintenance) costs that were converted to an annualized capital investment factor (see Appendix B). The cost of compliance was evaluated to assess whether the annualized cost of capital investment alone was sufficiently high to show the option was cost prohibitive. For the purposes of sizing control devices for Furnace A, the exhaust flow rate was considered to be the average of the north and south stacks as the flow alternates every 30 minutes as discussed in Section 1.1. Tables 7 and 8 present the PM control effectiveness for Furnaces A and D, respectively.

Table 7: PM Emissions Control Effectiveness for Furnace A

Control Device	Efficiency	Cost Effectiveness (\$/ton)
Baghouse	99%	28,252
ESP	95%	24,361

As presented in Table 7, the cost effectiveness for the baghouse is \$28,252 per ton of PM removed, and the cost effectiveness of the ESP is \$24,361 per ton of PM removed. For Furnace A, both the baghouse and ESP particulate controls are considered cost-prohibitive based on the high annualized capital cost per ton abated, which is primarily due to high retrofit costs for the Portland facility.

Table 8: PM Emissions Control Effectiveness for Furnace D

Control Device	Efficiency	Cost Effectiveness (\$/ton)
Baghouse	99%	16,007
ESP	95%	21,030

As presented in Table 8, the cost effectiveness for the baghouse is \$16,007 per ton of PM reduced, and the cost effectiveness for the ESP is \$21,030 per ton of PM reduced. For Furnace D, both the baghouse and ESP particulate controls are considered cost-prohibitive based on the high annualized capital cost per ton abated, which is primarily due to high retrofit costs for the Portland facility.

Since the CCF system controls NOx and SO₂ in addition to PM, the costs for the CCF are presented as part of the multi-pollutant control section, Section 2.4.

2.3.1.4 Time Necessary for Compliance

EPA guidance suggests that the best guide to determine the time necessary to implement an emission control device is prior experience with the implementation of a similar device on a similar source. Sources are generally given between two and five years to implement changes for compliance with new regulations. MACT standards typically allow three years for compliance and BART emission limitations require compliance no more than five years after regional haze SIP approval by the EPA. Additional time would be required to design, permit, and finance the project, and it is estimated to take two to five years to fully implement a baghouse.

2.3.1.5 Energy and Non-Air Impacts

Baghouses require additional electricity cost that is included in the indirect cost calculations in determining the overall cost effectiveness. This technology generates large quantities of collected dust. If the dust cannot be recycled or sold, then it must be shipped off-site to a landfill or disposed of in some other manner. Although dust is being removed from the air, it is ultimately taking up space at a landfill.

2.3.1.6 Remaining Useful Life

A 20-year time period has been assigned to amortize the capital costs associated with installing baghouses on the glass furnaces. The remaining life of the furnaces is expected to exceed the amortization period of the baghouse system. Therefore, the remaining useful life of the furnaces has no effect on the feasibility of installing baghouses.

2.3.2 Mold Swabbing

The second largest source of PM emissions (i.e., 10%) from the Facility are from the mold swabbing process. Mold swabbing is a necessary step in the production of glass containers, and the process cannot be practically modified. The glass bottle molds are periodically swabbed manually with a graphite/oil solution to create a thin layer of carbon between the mold and the glass bottles. This layer

of carbon reduces the amount of friction between the mold and glass bottles and prevents the hot glass from sticking to the mold. Due to the high operating temperatures, the swabbing oil volatilizes and releases some visible smoke inside the facility. This operation is conducted on an open shop floor that is highly ventilated due to significant thermal draft in the hot end... The emitted fumes and PM are considered fugitive emissions, and not practically captured. Given the nature of the mold swabbing operation, and the small portion of facility-wide PM emissions from this source, no control technologies were considered in this analysis.

2.3.3 Cullet Crusher

The third largest source of PM emissions (i.e. 9%) from the Facility is from the cullet crusher. Here recycled glass bottles are crushed into small pieces to eventually be mixed with raw materials before entering the furnace. The crushing process results in airborne glass particulates that are ideally controlled with a baghouse. There is currently no control technology connected to the cullet crusher.

2.3.3.1 Control Options

The following PM control option was identified for the cullet crusher using the RBLC database. Baghouses have been commercially demonstrated and considered available.

Baghouses

Among the most widely used control devices for PM, baghouses use long cylindrical bags to filter particulates from an exhaust stream. Dust-laden gas or air is sent to a baghouse through hoppers and is directed to the baghouse compartment. The gas is drawn through the filter bag, and as a result, a layer of dust forms on the surface of the filter. Once a sufficient pressure drop is created, the filter bag is cleaned by either shaking or utilizing a burst of compressed air. The dust is collected in a hopper where the material can be properly disposed of or recycled back into the process. Properly functioning baghouses typically have control efficiencies greater than 99%.

2.3.3.2 Cost of Compliance

Costs for the baghouse as a control device was determined based on direct (i.e., purchase of equipment) and indirect (i.e., design, installation, operational, maintenance) costs that were converted to an annualized capital investment factor (see Appendix B). The cost of compliance was evaluated to assess whether the annualized cost of capital investment alone was sufficiently high to show the option was cost prohibitive. Table 9 presents the PM control effectiveness for the cullet crusher.

Table 9: PM Emissions Control Effectiveness for Cullet Crusher

Control Device	Efficiency	Cost Effectiveness (\$/ton)
Baghouse	99%	46,348

As presented in Table 9, the cost effectiveness of installing a baghouse for the cullet crusher is \$45,277 per ton of PM reduced. The control technology is considered cost-prohibitive based on the high annualized capital cost per ton abated, which is due to the high retrofit costs for the Portland facility, and relatively low level of PM emissions for this source.

2.3.4 Raw Materials Loading/Unloading, Transport, and Mixing

Raw materials account for a small source of PM emissions (i.e. 0.4%) from the Facility. Raw material (e.g., sand, limestone, and soda ash) are initially transported into elevated bins via bucket elevators where they can be fed by gravity into a weigh hopper. The raw materials are then sent to a mixer to be combined with cullet to ensure homogenous mixing. The final mixture is sent to an elevated batch storage bin until it is ready to be sent to the glass melting furnace. The various raw material loading/unloading, transport, and mixing steps occur in an enclosed system that is vented to a batch

baghouse (RMBH-2) to reduce airborne particulates by approximately 99%. Since this process is controlled, PM from this source contributes a small portion of facility-wide PM emissions. Additional control technologies were not considered in this analysis.

2.3.5 Boiler

The 10.5 MMBtu/hr is used to provide space heating and hot water, and accounts for a small portion of facility PM emissions (i.e. 0.03%). The boiler PM emissions are generated as a result of the combustion of natural gas as a fuel source. However, natural gas combustion results in low emissions of filterable PM. Since the boiler contributes a small portion of to the facility-wide PM emissions, this analysis did not consider additional control technologies.

2.3.6 Miscellaneous Natural Gas-Fired Equipment

Miscellaneous natural gas-fired equipment including refiners, forehearts, lehrs, and ovens account for a small portion of facility PM emissions (i.e., 0.2%). Similar to the boiler mentioned above, these pieces of equipment have burners that use natural gas as a combustion fuel source and generate a small amount of particulates. Since the combination of these miscellaneous natural gas-fired equipment accounts for a small portion of facility-wide PM emissions, this analysis did not consider additional control technologies.

2.3.7 Hot-End Surface Treatment

Hot-end surface treatment (HEST) accounts for a small portion of facility PM emissions (i.e. 0.2%). Molded glass bottles are sent through the HEST process where mono-butyl-tin trichloride (MBTT) is deposited onto the surface of the glass. The exhaust is currently vented to a baghouse to control PM emissions. Prior to the exhaust reaching the baghouse, ammonia is injected into the exhaust stream to react with excess MBTT to form solid particulate matter that the baghouse can collect and filter out. Since this process is currently controlled and emissions are relatively low, this analysis did not consider additional control technologies.

2.3.8 Machine Repair and Mold Bench

Machine repair and mold grinding operations account for a small portion of facility PM emissions (i.e. 3%). Machine repair and mold grinding are performed sporadically on an as-needed basis. Both of these processes create PM emissions and vent to two dust collectors, machine repair dust collector (MRD-1) and mold bench dust collector (MBD-1). Since this process is currently controlled, and emissions from machine repair and mold grinding operations are relatively low, this analysis did not consider additional control technologies.

2.4 Multi-Pollutant Control Options

As described in preceding sections for individual pollutants, for the two glass furnaces there are three options considered in this analysis that offer abatement of multiple pollutants. Because the furnaces are the largest pollutant sources at the facility, the relatively higher compliance costs can be compared to the benefit of combined pollutant reductions.

- CCF is capable of removing NO_x, SO₂, and PM in a single integrated emissions control system. First, the exhaust is treated with a sorbent injection to remove SO₂. Next, ammonia is injected into the exhaust stream. The exhaust passes through a series of low-porosity ceramic filters that are impregnated with a NO_x catalyst which promotes the reduction of NO_x into gaseous nitrogen and water and removes PM from both the glass making process as well as the sorbent. The CCF system removes 90% of NO_x and SO₂ emissions as well as 99% of PM.

- Dry sorbent injection used for SO₂ control must be used in conjunction with a PM control device, such as an ESP. This results in a multi-pollutant control effectiveness that will be discussed further in this section.
- It is also technically feasible to incorporate a SCR system downstream of a dry scrubber to create a control train that provides abatement of NO_x, SO₂ and PM. The cost effectiveness analysis of this option combines the results of the control cost evaluation of the separate systems.

2.4.1.1 Cost of Compliance

For multi-pollutant control devices, the sum of the multiple pollutant abatement levels is used determining the cost effectiveness calculation. The annualized costs are adjusted slightly from those presented in the previous sections to account for extra reagents or other considerations when looking at multiple pollutants. Tables 10 and 11 present the control effectiveness for Furnaces A and D, respectively.

Table 10: NO_x, SO₂, and PM Emissions Control Effectiveness for Furnace A

Control Device	Pollutant	Control Efficiency	Multi-Pollutant Cost Effectiveness (\$/ton)
CCF	NO _x	90%	5,256
	SO ₂	90%	
	PM	99%	
Dry Scrubber + ESP	SO ₂	95%	15,066
	PM	95%	
Dry Scrubber + ESP + SCR	NO _x	62.5%	8,056
	SO ₂	95%	
	PM	95%	

Table 11: NO_x, SO₂, and PM Emissions Control Effectiveness for Furnace D

Control Device	Pollutant	Control Efficiency	Multi-Pollutant Cost Effectiveness (\$/ton)
CCF	NO _x	90%	5,035
	SO ₂	90%	
	PM	99%	
Dry Scrubber + ESP	SO ₂	90%	13,664
	PM	95%	
Dry Scrubber + ESP + SCR	NO _x	62.5%	6,883
	SO ₂	95%	
	PM	95%	

As shown above, the cost effectiveness for the dry scrubber with ESP option for both furnaces are borderline for consideration as being cost effective. The CCF controls all three pollutants to a high level on both furnaces, which results in cost effectiveness values under \$5,300 for each furnace. Thus, CCF control technology is considered cost-feasible when considering its ability to reduce emissions from multiple pollutants. Similarly, because of the combined level of abatement achieved when a dry scrubber and ESP is combined with a SCR, this second multi-pollutant control option is considered to be cost-feasible for either of the Portland furnaces.

2.4.1.2 Time Necessary for Compliance

Sources are generally given between two and five years to implement changes for compliance with new regulations. MACT standards typically allow three years for compliance and BART emission limitations require compliance no more than five years after regional haze SIP approval by the EPA. Combustion modifications and post-combustion NOx controls require significant time for engineering, construction, and facility preparedness. Two to five years would typically be appropriate, depending on the size of the unit and control options selected.

2.4.1.3 Energy and Non-Air Impacts

CCF requires additional electricity and reagent costs that are included in the indirect cost calculations in determining the overall cost effectiveness. This technology may present several adverse environmental impacts. Unreacted ammonia in the exhausted flue gas (i.e., ammonia slip) and the products of secondary reactions between ammonia and other species present in the flue gas can cause the formation of additional condensable particulate matter such as ammonium sulfate $[(\text{NH}_4)_2\text{SO}_4]$. The ammonium sulfate can corrode downstream exhaust handling equipment, as well as increase the opacity or visibility of the exhaust plume.

Each of the multi-pollutant control options involve substantial expenditure of resources during operation. For the ESP options in particular, the high electricity cost of the PM control device represents a significant energy penalty. For SCR and CCF option, there are significant reagent costs and retrofit costs that will be large compared to the operating margins of the Portland facility.

2.4.1.4 Remaining Useful Life

A 10-year time period has been assigned to amortize the capital costs associated with installing a CCF system on the glass furnaces. The remaining life of the furnaces is expected to exceed the amortization period of the CCF system. Therefore, the remaining useful life of the furnaces has no effect on the feasibility of installing the CCF system.

3. CONCLUSION

O-B prepared this four factor analysis to provide information to help prepare ODEQ's updated long-term strategy. Several technologies were determined to be commercially available for the various emission units based on precedents documented in the RBLC database and other examples provided by O-B.

The cost of compliance is the primary consideration among the four factors that determine the practical feasibility of emission controls. Per the results of this high-level analysis, four technologies that would control the emissions from the furnaces were considered to be economically feasible. However, more detailed engineering assessments of these options for the Portland facility may indicate that site-specific retrofit costs will prove that these options are cost-prohibitive. The candidate control options that satisfy the four-factor analysis are:

- For control of NOx only, SCR or CCF appear to be cost-feasible;
- Combined control of NOx, SO₂ and PM, by CCF appears to be cost-feasible; and
- Combined control of NOx, SO₂, and PM, by a control train consisting of dry scrubber/ESP followed by SCR could be feasible, although retrofit costs for this more-complex option were not completely defined in this study.

For all other emission sources, the candidate technologies were either technically infeasible or economically infeasible due to the small emission contribution from the individual source.