Technology Benchmarking Report
Hexavalent Chromium
Owens Corning Composite Materials Canada LP
Guelph Plant

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The attached Technology Benchmarking Report was prepared in accordance with s.32 of O. Reg. 419/05 and the guidance in the MOE documents "Guide to Requesting an Alternative Air Standard" dated December, 2007 and "Guideline for the Implementation of Air Standards in Ontario" dated March 2009.

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Executive Summary

This Technology Benchmarking Report (TBR) has been prepared to support the Owens Corning Guelph Glass request for a site specific annual standard for hexavalent chromium under Section 32 of Ontario Regulation 419/05: Air Pollution – Local Air Quality (O. Reg. 419/05). This report (TBR) is a required element of the request for the site specific standard and has been prepared in accordance with the Ministry of the Environment and Climate Change (MOECC) publications "*Guide to Requesting an Alternative Air Standard*" (GRAAS), December, 2007, and the "*Guideline for the Implementation of Air Standards in Ontario*" (GIASO), March 2009.

The Owens Corning facility is located at 247 York Road in Guelph Ontario. The facility produces textile glass yarn and fiberglass for reinforcements for commercial and industrial markets worldwide. This facility is the sole producer of fiberglass for reinforcements in Ontario and Canada and has been operating in Guelph since 1951. Due to the nature of the process, the facility operates continuously 24 hours per day, 365 days per year. Detailed process descriptions and documentation of emission estimates are located in the Emission Summary and Dispersion Modeling (ESDM) Report.

This is a companion document to the ESDM Report where modeling indicates that the facility would not meet the future hexavalent chromium standard and that a site specific standard is necessary. This report provides an assessment of the available technologies to reduce point of impingement (POI) concentrations of hexavalent chromium using the top down approach prescribed by Appendix A of the MOECC GRAAS guidance document.

This Technical Benchmarking Report:

- Identifies all available technologies to reduce the POI concentration of hexavalent chromium;
- Assesses the commercial availability of each of the technologies identified and screens out those options which are not commercially available;
- Assesses the technical feasibility of each of the identified technologies and screens out options that are not feasible; and
- Ranks the technically feasible pollution mitigation options, and combinations of options (pollution control strategies) based on reductions in POI concentrations.

Fifteen (15) individual technologies in the following categories were assessed:

- Material Substitutions (2 options);

- Process Changes (4 options); and
- Add-On Controls (9 options)

An additional category of "Other" was added for re-engineering of exhaust points to overcome site specific dispersion challenges. While this is not a required option for consideration, it is another method for the facility to reduce the predicted POI concentrations in the surrounding community.

The technically feasible individual technologies and combinations of options were modelled and ranked based on their potential to reduce the predicted POI concentrations. The following table summarizes the assessment of these pollution control strategies.

Pollution Control Strategy Description	Ranking	Overall % Decrease in POI
Electrostatic Precipitator (DEP/WEP) or Dust Collector (DC) on furnace and forehearth stacks combined with various material substitution and process changes.	1 - 5	91% - 95%
Install state of the art oxygen/gas combustion controls system and use improved superstructure construction techniques on the front end of the process (forehearths). Re-engineer several stacks to overcome site specific dispersion challenges.	6	88.5%
Scrubber installation on the forehearth stack and conversion of the forehearth conversion to air/gas combustion. This has combination assessed with and without the use of low sublimation chromium refractory.	7 - 8	75% - 77%
Forehearth conversion to air/gas combustion	9	73%
All other pollution control strategy options have been assessed and modelled and achieve lower decreases in the overall % POI.	10 – 13	Below 50%

The above strategies include the planned reconfiguration of the facility as well as the control strategies listed. Additional details related to all of these control options are located in the Technology Benchmarking report. These pollution control strategies are further assessed in the Economic Feasibility Assessment Report (companion document) prior to the development of the Action Plan required for the Site Specific Standard Application.

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1. Introduction

1.1 Background

In 2011, O.Reg. 419/05 was amended to introduce new air standards for a number of compounds including hexavalent chromium along with a 5 year phase in period for these standards. On July 1, 2016, a new hexavalent chromium air standard will come into effect. The future standard has been set at 0.00014 micrograms per cubic meter ($\mu g/m^3$) on an annual average basis. The standard is protective of human health. This new air standard represents a 99% reduction from the current standard for hexavalent chromium.

O.Reg. 419/05 contains provisions to request a Site Specific Standard for a contaminant listed in Schedule 3 if a facility is unable to demonstrate compliance with the air standard by July 1, 2016. The Owens Corning Guelph facility is requesting a Site Specific Standard for hexavalent chromium. The Technology Benchmarking Report is a required element of an application for a Site Specific Standard.

1.2 Purpose

The purpose of this Technology Benchmarking Report is to identify and evaluate all possible pollution control options for hexavalent chromium using a top down analysis approach. The feasibility of all pollution control options has been assessed and all feasible options ranked to determine the most effective option for the facility. This process identifies all technologies and determines a default preferred pollution control strategy. This document, along with the Economic Feasibility Report, will be used to determine the most appropriate pollution control option combination for the facility.

This document is prepared in accordance with the MOE publications "*Guide to Requesting an Alternative Air Standard*" dated December, 2007, "*Guideline for the Implementation of Air Standards in Ontario*" dated March 2009, and "*Air Dispersion Modeling Guideline for Ontario*", March 2009.

The objectives of this Technology Benchmarking Report are to:

- Develop a list of all pollution control methods available in the following categories:
    - Material Substitution
    - Process Change
    - Add-on Controls
- Assess the technical feasibility of each method available and their combinations
- Rank the pollution control strategies based upon the greatest reduction to the maximum POI concentration

2. Identification and Description of Sources

2.1 Facility Description

The Owens Corning Guelph Plant is located at 247 York Road, in Guelph, Ontario. The facility produces textile glass yarn and fiberglass for reinforcements for commercial and industrial markets worldwide. This facility is the sole producer of fiberglass for reinforcements in Ontario and Canada and has been operating in Guelph since 1951. Due to the nature of the process, the facility operates continuously 24 hours per day, 365 days per year. The facility currently processes approximately 22,000 tonnes of molten glass per year.

Glass fibers are produced by melting raw materials in gas fired furnaces and transporting the molten glass through forehearth channels to “bushings” where it is mechanically pulled to form the fibers. Subsequently, the fibers are used to make glass yarns, mat and reinforcements. The raw materials used to manufacture these high-tech glass fibers consist of dry solids, in powder and granular form, including clay, sand, limestone, dolomite and nepheline syenite (a naturally occurring igneous rock). The furnace and forehearth structures that contain and transport molten glass are lined with various types of refractory brick. Chromium-containing refractory is universally used by the fiberglass industry as the material to construct the molten glass channel siderails. Chromium containing refractory is used due to its superior corrosion resistance which significantly reduces waste and provides acceptable operational efficiency. This refractory is a source of di- and tri-valent chromium which is partially converted to the hexavalent form in furnace and forehearths prior to emission.

The sources of hexavalent chromium emissions from the facility are:

- Furnace & Forehearth Stacks (Source IDs: B01, B11 & B38)
- Furnace Hall General Ventilation Exhausts (Source IDs: B08, B10, B34, B35, C78 & C80)

The Owens Corning Guelph facility produces a special type of E glass known as Advantex.® Compared to other traditional boron containing E glasses, Advantex® has a very low environmental footprint. The Owens Corning Guelph facility produces continuous filament fiberglass that is used as a reinforcement in plastic parts.

2.1.1 T107 Furnace and Forehearth Emissions

Glass melting occurs in a natural gas-fired furnace, also referred to as a melter. The melter uses an oxygen/natural gas fired combustion system. The batch of mixed raw material is fed into the rear of the furnace and melts to form a molten homogeneous glass.

Molten glass flows from the melter via channels into the forehearths leading to the fiber forming areas. The channels and forehearths are also referred to as the front end. Like the melter, the front end is heated with natural gas and uses an oxygen/gas fired combustion system to maintain the glass in a molten state. The front end at this facility is fully enclosed, limiting fugitive emissions and allowing for a controlled combustion atmosphere.

Validated source testing for hexavalent chromium was conducted on the following sources in 2014:

- T107 Furnace Stack (Source B1)
- T107 West Forehearth Stack (Source B11)
- T107 East Forehearth Stack (Source B38)

The calculation methodology for the furnace and forehearth stack emissions can be found in found in Section 6 and Appendix F of the ESDMR.

2.1.2 Furnace Hall General Ventilation

Currently there are a total of seven (7) general exhausts (Source IDs: B08, B10, B32, B34, B35, C78 & C80) above the furnace, forehearths and channels. These general exhausts remove the radiant heat emitted into the building from furnace and forehearth operations. Three (3) of these exhausts were selected as representative and source testing for hexavalent chromium was conducted in 2014.

The calculation methodology for hexavalent chromium emissions from the furnace hall general ventilation exhausts can be found in Section 6 and Appendix F of the ESDMR.

2.2 Source Inventory

The Source Inventory table is provided in Appendix C of the ESDMR. It includes:

- source ID number
- description
- site coordinates
- exhaust stack diameter, flow rate, temperature, HAR, HAG
- type of source

A separate source summary table has been provided in Appendix C of the ESDMR for the Section 32 contaminant to highlight sources that are significant to the Site Specific Standard request.

2.3 Emission Inventory

The Emission Inventory is provided in Appendix D of the ESDMR. For all significant sources and contaminants, it presents:

- contaminant name and CAS#
- source ID number and description
- maximum contaminant emission rate
- estimation method
- data quality classification
- percentage of overall facility emissions
- averaging period

The summary of the contribution of each source to the maximum POI concentration for hexavalent chromium can be found in Section 3 below.

3. Current Facility Emissions & Modelled Concentrations

The emission estimates of hexavalent chromium for the current operations at the facility have been modelled for comparison to the future annual standard. Details of the modeling are located in Section X of the ESDMR. The following information is provided as suggested in Appendix A of the "*Guide to Requesting an Alternative Air Standard*" dated December, 2007.

The following table outlines the source contribution to the maximum POI concentration, as well as the source contribution at three (3) specific sensitive receptors, which are dwellings. These receptors were selected by first determining all sensitive receptors in the surrounding area and then selecting the most impacted receptors in each direction. The maximum POI location is along the south-east property line. The modelling files for the current operating scenario can be found in Appendix K of the ESDMR.

Table 1 Relative Source Contributions to POI Concentration

Source (Group)	Emission Rate (g/s)	Percent of Total Emissions (%)	Contribution to Point of Impingement Concentrations			
			At Point of Maximum Concentration (ug/m3)	At Receptor 1 (ug/m3)	At Receptor 2 (ug/m3)	At Receptor 3 (ug/m3)
ALL	2.35E-04	100%	2.08E-02	1.62E-03	1.36E-03	8.07E-04
B01	3.55E-05	15%	3.50E-04	6.67E-05	6.50E-05	3.06E-05
B11	1.51E-04	64%	1.82E-02	1.30E-03	1.03E-03	5.75E-04
B38	3.32E-05	14%	4.04E-03	2.08E-04	2.05E-04	1.56E-04
General Exhausts[1]	1.57E-05	7%	1.13E-03	5.87E-05	6.29E-05	4.49E-05
Date and Time of Maximum (year)			2012	2011	2009	2013

[1]Source group of general exhausts (Source IDs B08, B10, B34, B35, C79 & C80)

The 2016 standard for hexavalent chromium is an annual standard therefore a year is provided rather than the date and time.

As shown in the table above, the majority of hexavalent chromium emissions currently generated are exhausted from the conventional forehearth (also referred to as the 107B or west forehearth) exhausting through Source B11. Source B38 is a dedicated exhaust for the CFM forehearth channel (also referred to as the 105 or east forehearth). The emissions from the CFM forehearth are approximately five times lower than the emissions from the conventional forehearth. Emissions from the general ventilation exhausters in the furnace hall essentially consist of any trace amounts that do not get directly exhausted through the process stacks. There are currently seven (7) general ventilators operating, constituting approximately 7% of the total facility emissions for hexavalent chromium.

The forehearths were the primary consideration in establishing technical pollution control strategies based on their contribution (80%) to both emission rates and POI concentrations (94%).

Appendix A contains a summary table showing the maximum location, year and concentration for each source. Note that the location of the overall maximum POI may not necessarily be the same as the location of each individual source maximum.

The frequency, average and median of the concentrations which exceed the POI provides additional context and assists with understanding the potential impact on the nearby receptors. The following table outlines this data for the maximum POI location and the three most impacted sensitive receptors.

Table 2 Frequency and Average Concentration of Hexavalent Chromium

All Sources	Units	Maximum Receptor	Receptor 1	Receptor 2	Receptor 3
Frequency above Standard [1]	**(%)**	100%	100%	100%	100%
Average Concentration over 5 years	**(ug/m^3)**	0.0202	0.0015	0.0012	0.0007
Median Concentration over 5 years	**(ug/m^3)**	0.0200	0.0015	0.0013	0.0008

[1] % of time exceedance occurs at the receptor

The modelling files used in this determination can be found in Appendix K of the ESDMR.

4. Pollution Control Options

The following section identifies and references all possible technologies to reduce the POI concentration of hexavalent chromium.

4.1 Information Resources

The following readily available information resources were reviewed by Owens Corning:

- Clean Air World
- RACT/BACT/LAER Clearing House (RBLC database)
- MACT Standards
- Technical Literature
- Control Equipment Vendor Information
- Engineering Experience
- Industrial Ventilation Handbook 28th Edition
- Air Pollution Control 4th Edition
- Air Pollution Engineering Manual 2nd Edition

A search of the RBLC database by Owens Corning personnel was conducted to identify emission control technologies utilized in the past 20 years for all sources of chromium emissions in all industries during that period. The following category was searched:

- Chromium / Chromium Compounds, -3 & -6 (CAS No. 7440-47-3)

The RBLC search results were primarily from industries which are dramatically different from the composite fiberglass industry such as steel, resource recovery, power generation, electro-plating, etc. The control methods identified were dry filtration (baghouse, fabric filter, etc.), electro-static precipitator (ESP), and wet scrubber.

This review of information resources has resulted in the identification of several potential pollution control options for this facility. See Appendix B and Section 4.2 for the results of this review.

4.2 Initial Identification of Pollution Control Options

The pollution control options identified for this facility have been grouped by source or by source group for similar sources in the following three (3) required categories:

- *Materials Substitution* - Materials substitution consists of any pollution control options that result in a decrease of the POI concentration by substituting one material used in the process with another, along with any associated technology that is required with the substitution.

- *Process Changes* - Pollution control options resulting in a decrease of the POI concentrations due to process changes fall into this category. A process change is any change to the production processes, work practices and pollution prevention activities.
- *Add-on Controls* - Add-on controls are any pollution control devices that reduce air emissions after they have been produced.

These three categories are prescribed by the MOECC GRAAS guidance document. An additional optional category of “Other” has been added for the re-engineering of the exhaust points to overcome site specific dispersion challenges. This is not a required option for consideration; however, it is another method for the facility to reduce their impact on the surrounding community. The following table outlines all pollution control options that have been identified for this facility.

Table 3 Initial Identification of Pollution Control Options

Category	Individual Option Description
Add on Control	Dust collector/baghouse (DC)
	Dry Electrostatic Precipitator (DEP)
	Wet Electrostatic Precipitator (WEP)
	Low Pressure Cyclone
	HEPA Filter
	Spray Chamber Scrubber with upstream heat exchanger for hot sources
	Cyclone Spray Chamber with upstream heat exchanger for hot sources
	Low Pressure Venturi Scrubber with upstream exchanger for hot sources
	High Pressure Venturi Scrubber
Material Substitution	Substituting with zircon refractory
	Substituting with Low Sublimation Chromium refractory
Process Change	Conversion of forehearths to air/gas combustion
	Substituting with electric energy
	Use of more accurate combustion control skids with constructing front end superstructures (two technologies must be combined to be effective)
	Using substoichiometric combustion ratio
Other	Re-engineering the exhaust points to overcome site specific dispersion challenges

At this stage in the assessment the feasibility of the pollution control options had not been considered. A brief description of each option is located in the table below:

Table 4 Description of Pollution Control Options

Dust collector/baghouse (DC)
Typically composed of a blower, dust filter, filter cleaning system and a dust removal system to capture particulate. They are commonly used in the fiberglass industry on hot-end sources.
Dry Electrostatic Precipitator (DEP)
Removes particulate by releasing an electrostatic charge into the gas stream and the particles are collected on an oppositely charged surface.
Wet Electrostatic Precipitator (WEP)
Removes particulate by releasing an electrostatic charge into the gas stream. It is designed for a different type of gas stream than DEPs and therefore the gas stream is wetted and the particle collection surface is typically flushed with water.
Low Pressure Cyclone
Uses centrifugal force to remove particulate from the gas stream.
HEPA Filter
High-efficiency particulate arrestance or HEPA is a type of air filter consisting of a mat of randomly arranged fibers, often composed of fiberglass.
Spray Chamber Scrubber
Removes larger particulate by inertial or diffusional impact along with reaction or absorption in a liquid. A heat exchanger would be required for use on hot sources.
Cyclone Spray Chamber
Similar to a spray chamber but also uses centrifugal force to drop out larger diameter particulate.
Low Pressure Venturi Scrubber
A wet scrubber that uses the energy from the inlet gas stream to atomize the liquid being used to scrub the gas stream at a lower pressure of around 2-5 kPa.
High Pressure Venturi Scrubber
A wet scrubber that uses the energy from the inlet gas stream to atomize the liquid being used to scrub the gas stream. High pressure typically means over 10 kPa.
Using zircon refractory in melter front end
Replacement of existing chromium oxide refractory with a non-chromium (zircon) refractory.
Using low sublimation chromium refractory
Replacement of existing chromium oxide refractory with a newly developed chromium oxide refractory designed to release less chromium from the solid to gaseous state.
Conversion of forehearths to air/gas combustion
Flue gases from air/gas combustion have a lower water vapour concentration due to the volume of nitrogen in air that does not enter the combustion reaction. Anticipated to reduce free oxygen.
Substituting with electric energy
Eliminates flue gas. Volatiles above the glass surface do not exit the space above the glass; instead, condense and coat the inside of the refractory superstructure in a covered front end.
Use of more accurate combustion control skids with constructing tighter front end superstructures (two technologies must be combined to be effective)

Using state of the art gas and oxygen flow measurement & flow metering equipment to better control the combustion ratio which impacts the combustion atmosphere by reducing excess oxygen which contributes to the formation of hexavalent chromium. Improved channel superstructure construction techniques are also needed to prevent air ingress into the controlled combustion atmosphere.
Using Substoichiometric combustion ratio
Creating a reducing instead of oxidizing atmosphere in the combustion area to prevent/reduce the formation of hexavalent chromium.
Re-engineering the exhaust points to overcome site specific dispersion challenges
Modifications to stack heights, velocities, and/or locations to improve dispersion.

For additional details on the options described above, please see Appendices B & C.

5. Technically Feasible Pollution Control Options

The pollution control options identified for the Owens Corning Guelph facility in the previous section consist of all possible options without consideration of technical feasibility. This is part of the top-down approach. In this stage, each pollution control option was reviewed and the technical feasibility assessed based on criteria set out in Appendix A of the GRAAS guidance.

Initial screening allows for the removal of technically infeasible options prior to the modelling assessment. This assessment was based on criteria such as:

- Physical or chemical restrictions;
- site-specific technical issues;
- lack of performance data on new or emergent technologies;
- resource availability;
- final product specifications;
- engineering principles; or
- significant safety concerns that cannot be reasonably mitigated

The following table presents the initial screening of the technical feasibility for the pollution control options.

Table 5 Technical Feasibility Screening Assessment Summary

Category	Individual Option Description	Feasible
Add on Control	Dust collector/baghouse (DC)	Y
	Dry Electrostatic Precipitator (DEP)	Y
	Wet Electrostatic Precipitator (WEP)	Y
	Low Pressure Cyclone	N
	HEPA Filter	N
	Spray Chamber Scrubber	Y
	Cyclone Spray Chamber	Y
	Low Pressure Venturi Scrubber	Y
	High Pressure Venturi Scrubber	N
Material Substitution	Substituting with zircon refractory	N
	Substituting with low sublimation chromium refractory	Y

Category	Individual Option Description	Feasible
Process Change	Conversion of forehearths to air/gas combustion	Y
	Substituting with electric energy	N
	Use of more accurate combustion control skids with constructing front end superstructures (two technologies must be combined to be effective)	Y
	Using Substoichiometric combustion ratio	N
Other	Re-engineering the exhaust points to overcome site specific dispersion challenges	Y

5.1 Explanation of Technical Infeasibility

Based on the MOECC GRAAS guidance provided in Section 3.0, the following options have been deemed to be technically infeasible as explained below.

5.1.1 Low Pressure Cyclone

A low pressure cyclone uses centrifugal force to remove particulate from the gas stream. They are typically used as a pre-cleaner to remove larger diameter particulate. The bulk of the hexavalent chromium emitted from this facility is very small diameter particulate; therefore this equipment is not technically feasible for this facility. Additionally, low pressure cyclones are not typically used on hot sources.

5.1.2 HEPA Filter

High-efficiency particulate arrestance or HEPA is a type of air filter that consists of a mat of randomly arranged fibers, often composed of fiberglass. This technology is unproven for the capture of hexavalent chromium from hot sources and unproven in this industry and therefore would require pilot testing. In addition, HEPA filters are designed to be used on relatively clean air streams. If used on particulate-laden air streams, such as those found in the fiberglass industry, HEPA filters would require constant cleaning and maintenance and could not reasonably be operated as a stand-alone device under these conditions.

5.1.3 High Pressure Venturi Scrubber

This type of high pressure wet scrubber uses the energy from the inlet gas stream to atomize the liquid being used to scrub the gas stream. High pressure typically means over 10 kPa. This technology has not been used in the fiberglass industry on hot sources and would require pilot scale testing to verify it would actually remove hexavalent chromium from the air stream. Use of a wet scrubber would create an additional waste stream since it would simply transfer the hexavalent chromium to water which would then have to undergo treatment to remove the hexavalent chrome.

In addition, a venturi scrubber would require pre-cooling of a high temperature air stream in order to avoid vaporizing the scrubbing liquid. The use of a heat exchanger is not technically feasible on the hot end (furnace stacks). This is due to the fact that particulate generated in the hot end has a propensity to plate out on metal during significant temperature changes. If a heat exchanger were used, these particles would plate out inside the heat exchanger tubes, fouling them in a manner that would render the heat exchanger unusable. Therefore, the use of a high pressure venture scrubber is only considered for the cooler forehearth stack.

5.1.4 Zircon Refractory

Zircon is a glass contact refractory that has no chromium content. The use of zircon is now limited in OC composite glass melters and front ends to glass contact paving (floor) areas where wear is low or the electrically non-conductive attribute of zircon requires it's use. Decades ago, zircon refractory was used for front end siderails and glass contact melter sidewalls but the corrosion that occurred at the glass surface level was so significant that the use of zircon in these locations was eliminated with the introduction of chromic oxide refractories in fiberglass front ends which commenced in the 1980s.

Accelerated lab corrosion test data illustrates the corrosion related benefit of chromic oxide refractory. The corrosion rate is approximately 16x lower for chromic oxide exposed to Advantex.® glass than zircon. Corrosion increases with glass temperature which explains the accelerated corrosion rate for Advantex vs. traditional boron containing E glass. As the hottest glass is at the surface of the glass bath in a front end channel, the siderails experience the highest corrosion rates of the refractory blocks in a front end. In 2012, the possibility of going back to zircon front end siderails was evaluated and rejected due to the negative impacts. Supplier information provided in Appendix E clarifies that zircon refractory (specifically ZS1300 or zirconium silicate containing refractory) is not recommended for melter sidewalls or front end siderail applications for reinforcement furnaces.

Zircon causes defects in the glass called stoning, in which particles of refractory end up in the glass. The particles disrupt the fiberizing process due to the very fine diameter of the fibers required. The result is large amounts of waste that cannot be recycled back into the furnace. The use of chromic oxide for front end siderails results in less stoning. Reduced stoning has a positive impact on conversion efficiency (CE) which is defined as the mass ratio of glass fiber & binder leaving forming as good product to the mass of the glass and binder supplied as inputs. Improved CE reduces environmental impact by reducing the energy and emissions per unit of finished goods made and by reducing waste to landfill.

Additional information is located in Appendix E for confidential and commercially sensitive information related to the feasibility of this option.

5.1.5 Low Sublimation Chromium Refractory

Recent years have seen the development of a chromic oxide refractory that was formulated for a lower rate of total chrome volatilization. The manufacturer's published data on emissions is related to total chromium volatilization, not the generation of the hexavalent form of chromium. Currently there is insufficient data to confirm that there is a beneficial impact from the use of this low sublimation chromium refractory on hexavalent chromium emissions. However, lab testing continues.

A trial was done in Guelph where low sublimation chromic oxide was used with normal levels of excess oxygen, however the trial yielded no discernable reduction in hexavalent chromium emissions that could be assigned to the low sublimation refractory. Although this technology is not considered feasible for implementation, it has been included as an option for the forehearth sources.

5.1.6 Substituting with Electrical Energy

The use of electrical energy instead of natural gas combustion to maintain molten glass temperatures in the furnace and forehearths was examined as it would essentially eliminate flue gases. By using electric heating exclusively, flue gases from fossil fuel combustion are eliminated. Volatiles above the glass surface do not exit the space above the glass but rather condense and coat the inside of the refractory superstructure in a covered front end as there is no flue gas leaving the space.

Electrodes submerged in the glass are currently used in conjunction with fossil fuel combustion to provide heat to melt glass in melters but are not used in OC Composite Solution Business (CSB) front ends (channels and forehearths).

Several trials of the use of electric energy instead of natural gas combustion have been conducted but results have been mixed. This technology is still in the developmental stage for the type of glass manufactured at this facility in part due to the much higher temperatures required for the manufacturing of Advantex ® glass.

Additional details related to these trials are provided in Appendix E.

5.1.7 Substoichiometric Combustion

Operating the system (forehearth channels) at a reducing (substoichiometric) instead of an oxidizing atmosphere in the combustion area was evaluated. If combustion maintains a reducing atmosphere, chromium volatiles would exist in the trivalent not hexavalent form.

However, this reducing atmospheric environment interferes with the redox state of the glass causing the glass to be greener from the reducing atmosphere's impact on iron in the glass resulting in off-specification final product. This change in color would not be acceptable to some customers.

A further challenge is that substoichiometric combustion in a melter can cause damage to the metal melter stack when unburned gas combusts after mixing with dampering air above the refractory stack and below the metal stack.

Additionally, substoichiometric combustion is known to cause fouling of front end oxy/gas burners. Carbon deposits on the burner tip are known to deflect the flame so that it impinges on the burner block which melts the refractory causing stoning contamination and the need for hot repair of the front end superstructure.

The use of substoichiometic combustion is not considered technically feasible at this facility.

5.2 Technical Feasibility by Source

With the options that remain technically feasible overall, source specific technical limitations were then evaluated.

The general ventilation exhausts have not been included in the assessment of add on controls due to the low concentration of hexavalent chromium and extremely small contribution to the maximum POI concentration from the facility in comparison to other source types. Emission reductions from the general ventilation exhausters are best addressed through process controls or material substitutions which reduce the generation of hexavalent chromium. Add on control devices are typically designed and operated for exhaust streams with high concentrations of particulate. In the case of the general ventilation exhausts, with high volumetric flowrates combined with extremely small concentrations create technical challenges in the design and operation of add on control devices. Please see the documentation in the ESDMR for additional details.

The use of more accurate combustion control skids and improved construction techniques is only considered for the forehearth sources. The melter is already operated with a pressure control loop to minimize air ingress. Advanced combustion controls are already installed on the melter so excess oxygen is maintained at a very small percentage.

The following table indicates which technology is feasible for each of the sources at the facility.

Table 6 Summary of Technical Feasibility by Source

Category	Individual Option Description	Furnace	Forehearth	General Exhausts
Add on Control	Dust collector/baghouse (DC)	✓	✓	
	Dry Electrostatic Precipitator (DEP)	✓	✓	
	Wet Electrostatic Precipitator (WEP)	✓	✓	
	Spray Chamber Scrubber		✓	
	Cyclone Spray Chamber		✓	
	Low Pressure Venturi Scrubber		✓	
Material Substitution	Substituting with low sublimation chromium refractory		✓	✓
Process Change	Reduction of water vapor from flue gas & reducing temperature in combustion (accomplished by conversion to air/gas combustion)	✓	✓	✓
	Use of more accurate combustion control skids with constructing front end superstructures (two technologies must be combined to be effective)		✓	✓
Other	Re-engineering the exhaust points to overcome site specific dispersion challenges	✓	✓	✓

These technically feasible pollution control options were further assessed.

6. Ranking of Technically Feasible Pollution Control Options

The ranking of the technically feasible pollution control options and combinations has been conducted based on a top-down analysis, from the greatest reduction to the least reduction. This approach was used to identify the options which are most effective at minimizing the POI concentration for each source or group of similar sources.

6.1 Initial Ranking of Pollution Control Options

The initial ranking was conducted by assessing each individual option and each individual source or source group. The ranking can be based on either modelled POI concentrations or emissions metrics. In this case, the ranking of individual options was based upon POI reduction efficiency achieved by the hot sources. The hot sources were the focus of the ranking because they have a much higher contribution to the site-wide POI results. The individual options are ranked within each category of add on controls, material substitutions and process changes. For example, the DC/DEP/WEP options have the top ranking for the add on control category, and the conversion to air/gas combustion has the top ranking for the process change category. The results of the initial ranking can be found in the following table:

Table 7 Initial Ranking of Pollution Control Options

Category	Individual Option Description	Reduction Efficiency			Ranking
		Furnace	Forehearth	General Exhausts	(based on hot sources)
Add on Control	Dust collector/baghouse (DC)	95%	95%	NA	1
	Dry Electrostatic Precipitator (DEP) [1]	95%	95%	NA	1
	Wet Electrostatic Precipitator (WEP)	95%	95%	NA	1
	Spray Chamber Scrubber	NA	20%	NA	2
	Cyclone Spray Chamber	NA	20%	NA	2
	Low or High Pressure Venturi Scrubber	NA	20%	NA	2
Material Substitution	Substituting with Low Sublimation Chromium refractory	NA	10%	0%	1

Category	Individual Option Description	Reduction Efficiency			Ranking
		Furnace	Forehearth	General Exhausts	(based on hot sources)
Process Change	Conversion to air/gas combustion	NA	86%	50%	1
	Use of more accurate combustion control skids with constructing front end superstructures (two technologies must be combined to be effective)	NA	50%	50%	2
Other	Re-engineering the exhaust points to overcome site specific dispersion challenges	75%	90%	65% [2]	NA

[1] preferred technology with same efficiency.
[2] only applies to B33 (new general exhaust for T105 furnace)

6.2 Default Combination for Each Source

Once the initial ranking of pollution control options was completed, the options were then combined to determine the most effective, technically feasible combination. These combinations are pollution control strategies. These combinations were developed by applying the best add-on control plus the best material substitution plus the best process change (the default combination).

As many of the add-on control options achieved the same reduction efficiency, several technologies were assessed as a single option for the purpose of developing the combinations for modeling. For example, the dust collector and electrostatic precipitators had the same reduction efficiency, so they were assessed as "DEP/WEP or DC" and paired with the best technologies from other groups.

The following table outlines the technically feasible pollution control strategies for this facility.

Table 8 Default Combinations and Final Assessment of Technical Feasibility

Combination Description[1]	Combination ID	Overall Percent Reduction	Ranking
Electrostatic Precipitator (DEP/WEP) or Dust Collector on furnace and forehearth stacks combined with the use of Low Sublimation Chromium (LSC) refractory and conversion of the forehearths to air/gas combustion	G_R1	95.23%	1
Electrostatic Precipitator (DEP/WEP) or Dust Collector on furnace and forehearth stacks combined with conversion of the forehearths to air/gas combustion	M_R1	95.16%	2
Electrostatic Precipitator (DEP/WEP) or Dust Collector on furnace and forehearth stacks combined with the use of LSC refractory and the installation of more accurate combustion controls in combination with front end superstructures to prevent air ingress	H_R1	94%	3
Electrostatic Precipitator (DEP/WEP) or Dust Collector on furnace and forehearth stacks combined with incorporating more accurate combustion control skids and construction of frontend superstructures	N_R1	93%	4
Electrostatic Precipitator (DEP/WEP) or Dust Collector on furnace and forehearth stacks	V_R1	91%	5
Incorporating more accurate oxygen/gas combustion control systems and improved superstructure construction techniques for the front end and re-engineering exhaust stacks impacted by reconfiguration	E_R9	88.5%	6
Scrubber on forehearth stack, use of Low Sublimation Chromium (LSC) refractory and forehearth conversion to air/gas combustion	I_R3	77%	7
Scrubber on forehearth stack and forehearth conversion to air/gas combustion	O_R2	75%	8
Forehearth conversion to air/gas combustion	S_R1	73%	9
Scrubber on forehearth stack, use of Low Sublimation Chromium (LSC) refractory and incorporating more accurate combustion control skids and construction of front end superstructures	J_R2	50%	10
Scrubber on forehearth stack and incorporating more accurate combustion control skids and construction of front end superstructures	P_R2	48%	11
Incorporating more accurate combustion control skids and construction of front end superstructures	T_R1	39%	12
Scrubber on forehearth stack	W_R2	27%	13

[1] Additional detail for the pollution control options is provided in Section 4.2
LSC = Low sublimation chromium

Each scenario was assessed using AERMOD to determine the POI reduction for each combination. The modelling files for all scenarios can be found in Appendices L through M of the ESDMR. The combinations were ranked based on the anticipated POI concentration reduction using the top down approach prescribed in Appendix A of the GRAAS MOECC guidance document.

See Appendix D of this report for the full assessment including POI concentrations.

6.3 Final Selection of Preferred Pollution Control Combination

A final assessment was conducted comparing the default pollution control combination (PCC) to the preferred pollution control combination, along with the current scenario to provide perspective on the anticipated POI concentration reductions. The default pollution control combination applies the first ranked add on control with the first ranked material substitution and the first ranked process change. If this combination is technically feasible this is deemed the *default technically feasible pollution control combination*. The preferred pollution control combination is a technically feasible option chosen as part of the Action Plan and takes into consideration economic feasibility. The results of this assessment are outlined in the table below.

Table 9 Detailed Ranking and Final Selection of Preferred Option

	Combination Description	Source ID (group)	% POI Reduction by Source Group	Overall % of Schedule 3 Future Standard
Current				14851%
Default PCC Combination (technically feasible)	Electrostatic Precipitator (DEP/WEP) or Dust Collector on furnace and forehearth stacks combined with the use of Low Sublimation Chromium (LSC) refractory and conversion of the forehearths to air/gas combustion	Furnace	65%	709%
		Forehearth	99%	
		General Exhausts	28%	
2nd Best Technically Feasible PCC	Electrostatic Precipitator (DEP/WEP) or Dust Collector on furnace and forehearth stacks combined with conversion of the forehearths to air/gas combustion	Furnace	65%	719%
		Forehearth	99%	
		General Exhausts	28%	
3rd Best Technically Feasible PCC	Electrostatic Precipitator (DEP/WEP) or Dust Collector on furnace and forehearth stacks combined with the use of LSC refractory and the installation of more accurate combustion controls in combination with front end superstructures to prevent air ingress	Furnace	65%	952%
		Forehearth	98%	
		General Exhausts	28%	

	Combination Description	Source ID (group)	% POI Reduction by Source Group	Overall % of Schedule 3 Future Standard
4th Best Technically Feasible PCC	Electrostatic Precipitator (DEP/WEP) or Dust Collector on furnace and forehearth stacks combined with incorporating more accurate combustion control skids and construction of frontend superstructures	Furnace	65%	971%
		Forehearth	97%	
		General Exhausts	28%	
5th Best Technically Feasible PCC	Electrostatic Precipitator (DEP/WEP) or Dust Collector on furnace and forehearth stacks	Furnace	65%	1335%
		Forehearth	96%	
		General Exhausts	4%	
6th Best Technically Feasible PCC (Preferred)	Incorporating more accurate oxygen/gas combustion control systems and improved superstructure construction techniques for the front end and re-engineering exhaust stacks impacted by reconfiguration	Furnace	-55%	1703%
		Forehearths	93%	
		General Exhausts	27%	

In the preferred technically feasible combinations, the relative contribution from the furnace increases due to the facility reconfiguration which includes the elimination of the 107 furnace and restart of the 105 furnace. This is partially due to the incorporation of an uncertainty factor to the furnace emission rate as well as a reflection of the 105 furnace stack configuration. The dispersion characteristics of the 105 furnace stacks, even after the re-engineering are not as good as the 107 furnace stack.

Details for the calculation of the uncertainty factor can be found in Appendix M of the ESDMR. The remaining pollution control options and their detailed ranking are located in Appendix D.

6.4 Frequency of Exceedance at Specific Receptors

The default and preferred pollution control combinations were assessed and ranked according to the POI concentration results from the AERMOD assessment. Each option was modelled to determine the predicted concentration at the location of the maximum POI, as well as the impacted receptors. A frequency analysis was also completed for each option which assessed the frequency of exceedence at the most impacted receptors. The table below presents, for each option; the percent of the standard, the exceedance frequency at the receptor with the highest exceedance frequency, and the corresponding maximum POI at that receptor. The table also includes the current scenario for context. The modelling files for the default and preferred options can be found in Appendices Q & R of the ESDMR.

Table 10 Frequency of Exceedance

Ranking	Combination Description	Overall % of Sch 3 Future Standard	POI Exceedence Frequency (Receptor with the highest % Frequency)[2]	% of Max POI at Specified Receptor
Current	Current facility configuration	14851%	100%	1158%
Best (Default) Technically Feasible PCC[1]	Electrostatic Precipitator (DEP/WEP) or Dust Collector on furnace and forehearth stacks combined with the use of Low Sublimation Chromium (LSC) refractory and conversion of the forehearths to air/gas combustion	709%	0% [3]	42%
Preferred Technically Feasible PCC	Incorporating more accurate oxygen/gas combustion control skids and construction of front end superstructures and re-engineering exhaust stacks impacted by reconfiguration	1703%	100%	451%

[1] PCC is Pollution Control Combination
[2] Receptor with the highest percent frequency of exceedance is always a nearby dwelling.
[3] No exceedance at sensitive receptor

7. Closure

The technically feasible combinations presented in this report are further assessed in the Economic Feasibility Report and provide the basis for the Action Plan. These separate documents are included in the application requesting a site specific standard for hexavalent chromium.

8. Statement of Limitations

LEHDER Environmental Services Limited ("LEHDER") prepared this report ("Report"), for the sole benefit and exclusive use by Owens Corning Composite Materials Canada LP, Guelph Facility.

LEHDER has performed the work as described in the Scope of Work and, made the findings and conclusions set out in the Report in a manner consistent with the level of care and skill normally exercised by members of the environmental science profession practicing under similar conditions at the time the work was performed.

In preparing this Report, LEHDER has relied in good faith on information provided by others as noted in this Report and has assumed the information provided by those individuals is both factual and accurate.

The material in this report reflects LEHDER's best judgement in light of the information available to it at the time of preparing the Report. Any use which a third party makes of the Report, or any reliance on or decisions made based on it, are the responsibility of such third parties. LEHDER accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions taken based on the Report.

Appendix A Summary of the Max Concentration by Source – Full Table

Summarization of the Maximum Concentration of Each Source of CrVI												
Contaminant:	**Hexavalent Chromium (CrVI)**											
Source ID	**Maximum Receptor**			**Receptor 1**			**Receptor 2**			**Receptor 3**		
	Location (x,y)	**Date (year)**	**Concentration (ug/m3)**	**Location (x,y)**	**Date (year)**	**Concentration (ug/m3)**	**Location (x,y)**	**Date (year)**	**Concentration (ug/m3)**	**Location (x,y)**	**Date (year)**	**Concentration (ug/m3)**
ALL	562050.1E 4821511.6N	2012	2.08E-02	561865.8E 4821472.0N	2011	1.62E-03	561825.8E 4821532.0N	2009	1.36E-03	562375.8E 4821792.0N	2013	8.07E-04
B01	562064.0E 4821525.9N	2010	3.50E-04	561865.8E 4821472.0N	2009	6.67E-05	561825.8E 4821532.0N	2009	6.50E-05	562375.8E 4821792.0N	2013	3.06E-05
B11	562050.1E 4821511.6N	2012	1.82E-02	561865.8E 4821472.0N	2011	1.30E-03	561825.8E 4821532.0N	2009	1.03E-03	562375.8E 4821792.0N	2013	5.75E-04
B38	562064.0E 4821525.9N	2010	4.04E-03	561865.8E 4821472.0N	2011	2.08E-04	561825.8E 4821532.0N	2009	2.05E-04	562375.8E 4821792.0N	2013	1.56E-04
GENEXHTS	562064.0E 4821525.9N	2010	1.13E-03	561865.8E 4821472.0N	2011	5.87E-05	561825.8E 4821532.0N	2009	6.29E-05	562375.8E 4821792.0N	2013	4.49E-05

Appendix B Identification of Pollution Control Options

Owens Corning - Guelph Plant
Identification of All Technical Options
Issued January 16, 2015

Individual / Combined Option Description	Technically Feasible	Feasible with Significant Implementation Concerns	Not Feasible	Comments	Additional Comments / Details
Facility reconfiguration	Yes			Assessed as part of ranking	
Reconfigured Stacks - New Furnace/FH Stacks and combined discharge of RE through a single new stack	Yes			Assessed as part of ranking	
Dry Electrostatic Precipitator (DEP) - Modified DF		Industrial hygiene concerns. Concerns with generating a waste stream. Separate building required to house the unit.		Assessed as part of ranking	
Dry Electrostatic Precipitator (DEP) (hot sources only)		Industrial hygiene concerns. Concerns with generating a waste stream. Separate building required to house the unit.		Assessed as part of ranking	
Dry Electrostatic Precipitator (DEP) (hot sources only) and reconfigured discharge of REs		Industrial hygiene concerns. Concerns with generating a waste stream. Separate building required to house the unit.		Assessed as part of ranking	
DEP (hot sources only) modified DF and Use of low sublimation brick, more accurate combustion control skids and constructing Front End Superstructures (FH & RE only)			Contribution to reductions in hex chrome emissions is uncertain. LSC brick is still in the prototype stage. Industrial hygiene concerns. Concerns with generating a waste stream. Separate building required to house the unit.	No further assessment	
DEP (hot sources only) modified DF (dispersion factor) and Use of of low sublimation brick, more accurate combustion control skids and constructing Front End Superstructures (FH & RE only) and reconfigured discharge of REs			Contribution to reductions in hex chrome emissions is uncertain. LSC brick is still in the prototype stage. Industrial hygiene concerns. Concerns with generating a waste stream. Separate building required to house the unit.	No further assessment	
DEP (hot sources only) modified DF and more accurate combustion control skids and constructing Front End Superstructures (FH & RE only) and reconfigured discharge of REs		Industrial hygiene concerns. Concerns with generating a waste stream. Separate building required to house the unit.		No further assessment	
DEP (hot sources only) modified DF and Convert forehearth to air/gas		Industrial hygiene concerns. Concerns with generating a waste stream. Separate building required to house the unit.		Assessed as part of ranking	
DEP (hot sources only) modified DF and Convert furnace/forehearth to air/gas and reconfigured discharge of Res		Industrial hygiene concerns. Concerns with generating a waste stream. Separate building required to house the unit.		Assessed as part of ranking	
Replacing zircon refractory in melter front end for chromic oxide refractory in melter		Available but not used in the composites glass industry due to e-glass having higher corrosivity. Zircon causes defects in the glass, adversely affecting fiberizing and creating large amounts of waste.		No further assessment	Not used in the manufacturing of e-glass due to the higher corrosivity of the glass. Zircon causes defects in the glass, adversely affecting fiberizing. Additionally, Zircon life would be less than half that of chromic oxide refractory.
Replacing zircon refractory in melter front end for chromic oxide refractory in melter and reconfigured Stacks - New Furnace/FH Stacks		Available but not used in the composites glass industry due to e-glass having higher corrosivity. Zircon causes defects in the glass, adversely affecting fiberizing and creating large amounts of waste.		No further assessment	Not used in the manufacturing of e-glass due to the higher corrosivity of the glass. Zircon causes defects in the glass, adversely affecting fiberizing. Additionally, Zircon life would be less than half that of chromic oxide refractory.
Replacing zircon refractory in melter front end for chromic oxide refractory in melter and reconfigured Stacks - New Furnace/FH Stacks and combined discharge of RE through a single new stack		Available but not used in the composites glass industry due to e-glass having higher corrosivity. Zircon causes defects in the glass, adversely affecting fiberizing and creating large amounts of waste.		No further assessment	Not used in the manufacturing of e-glass due to the higher corrosivity of the glass. Zircon causes defects in the glass, adversely affecting fiberizing. Additionally, Zircon life would be less than half that of chromic oxide refractory.

Individual / Combined Option Description	Technically Feasible	Feasible with Significant Implementation Concerns	Not Feasible	Comments	Additional Comments / Details
Convert forehearth to air/gas		Environmental impact of increasing NOx and GHG emissions.		Assessed as part of ranking	Using air in combustion instead of oxygen is anticipated to reduce hexavalent chromium emission generation by reduction of water vapor from flue gas and reducing combustion flame temperature.This technology also reduces free oxygen as a % of exhaust flow, reducing hexavalent chromium formation.
Convert forehearth to air/gas and reconfigured Stacks - New Furnace/FH Stack		Environmental impact of increasing NOx and GHG emissions.		Assessed as part of ranking	Using air in combustion instead of oxygen is anticipated to reduce hexavalent chromium emission generation by reduction of water vapor from flue gas and reducing combustion flame temperature.This technology also reduces free oxygen as a % of exhaust flow, reducing hexavalent chromium formation.
Convert forehearth to air/gas and reconfigured Stacks - New Furnace/FH Stacks and combined discharge of RE through a single new stack		Environmental impact of increasing NOx and GHG emissions.		Assessed as part of ranking	Using air in combustion instead of oxygen is anticipated to reduce hexavalent chromium emission generation by reduction of water vapor from flue gas and reducing combustion flame temperature.This technology also reduces free oxygen as a % of exhaust flow, reducing hexavalent chromium formation.
Use of low-sublimation (LSC) brick in the forehearth/channels, more accurate combustion control skids and constructing Front End Superstructures (FH & RE only)		At prototype stage. Contribution of each component to reductions in hex chrome emissions is uncertain.		No further assessment (for the combination)	Reduction Efficiency Ranged from 30% to 72% reduction. Assessed at 50% reduction
Use of more accurate combustion control skids combined with constructing front end superstructures	Yes			Assessed as part of ranking	Combination of these 2 technologies is technically feasible. Would not be effective as a stand alone option.
Wet Electrostatic Precipitator (WEP)		Concerns with generating a liquid waste stream. Separate building required to house the unit. Control efficiency same as for DEP, with a dry waste considered more manageable than a liquid waste.		No further assessment	
Dust Collector		Industrial hygiene concerns. Concerns with generating a waste stream. Separate building required to house the unit. Did not evaluate further as ESP is preferred over DC based on reduced risk of catastophic failure.		No further assessment	Equivalent efficiency to Electrostatic precipitator but there are concerns of reliability of DC vs EP. Maintenance costs for DC are higher than EP. Only EP was considered moving forward.
HEPA Filter			Technology has not been demonstrated at a similar facility for the manufacturing of composite glass.	No further assessment	Not been used in the control of hexavalent chromium or particulate on the hot end (furnace, forehearth, etc.) in the fiberglass industry. HEPA would need to be a secondary control device, and would provide very low incremental improvement.
Low Pressure Cyclone			Technology has not been demonstrated at a similar facility for the manufacturing of composite glass.	No further assessment	Not typically used on hot sources and small diameter particulate. Ideal for pretreatment of sources with large diameter particulate.
Spray Chamber Scrubber (hot sources)			Not suitable technology for sources with elevated temperatures.	No further assessment	
Cyclone Spray Chamber (hot sources only)			Not suitable technology for sources with elevated temperatures.	No further assessment	
Low Pressure Venturi Scrubber (hot sources only)			Not suitable technology for sources with elevated temperatures.	No further assessment	
Spray Chamber Scrubber (cold sources only)		Concerns with generating a liquid waste stream. Low removal efficiency compared to other potentially feasible technologies. Not appropriate for use on sources with very small concentrations.		No further assessment	Provides very low incremental improvement because only technically feasible on low temperature sources.
Cyclone Spray Chamber (cold sources only)		Concerns with generating a liquid waste stream. Low removal efficiency compared to other potentially feasible technologies. Not appropriate for use on sources with very small concentrations.		No further assessment	Provides very low incremental improvement because only technically feasible on low temperature sources.
Low Pressure Venturi Scrubber (cold sources only)		Concerns with generating a liquid waste stream. Low removal efficiency compared to other potentially feasible technologies. Not appropriate for use on sources with very small concentrations.		No further assessment	Provides very low incremental improvement because only technically feasible on low temperature sources.

Individual / Combined Option Description	Technically Feasible	Feasible with Significant Implementation Concerns	Not Feasible	Comments	Additional Comments / Details
High Pressure Venturi Scrubber			Not a demonstrated technology for the control of hex chrome emissions from furnaces/forehearths in the composite glass industry.	No further assessment	Not been used in the control of hexavalent chromium or particulate on the hot end (furnace, forehearth, etc.) in the fiberglass industry
Substituting with SEFPRO C12LS (low sublimation chromium refractory)			Contribution to reductions in hex chrome emissions is uncertain. More evaluation of this technology would be required before moving beyond the prototype stage.	No further assessment	Due to the combination of technologies implemented for the CFM prototype, cannot accurately determine any contribution to reductions.
Substituting with electric energy			Not feasible. This technology has not been demonstrated (commercialized) for use in forehearths for composite glass applications.	No further assessment	Several trials have been conducted with mixed results. Some technical issues would still need to be resolved. Not a demonstrated feasible technology ready for installation.
Using Substoichiometric combustion ratio			Not feasible due to final product specifications. Also risk of equipment damage.	No further assessment	Not technically feasible because it will influence the redox state of the glass resulting in unacceptable colour change. Substoichiometric combustion in the melter can cause damage to the metal melter stack when unburned gas combusts after mixing with dampering air above the refractory stack and below the metal stack.

FH: Forehearth(s)

RE: Room Exhausts (general ventilation of furnace hall)

LSC: Low Sublimation Chromium Refractory

DF: Dispersion Factor (modified DF refers to stack changes to reduce POI concentration)

Appendix C Initial Screening for Technical Feasibility

Technology Benchmarking Assessment - Process Changes (does not include Add On Controls) **: hexavalent chromium emission reduction**
per Guide to Requesting An Alternative Air Standard Version 1.0, Ontario Regulation 419, Request for Approval under Section 32

Step 1: Develop a list of all methods available for use to reduce Point of Impingement (POI) concentrations based on:
- a comparison of methods used by other glass manufacturing facilities
- a review of requirements and pollution control strategies from other jurisdictions
- assessment of transferring technology and control strategies from other industrial sectors with the same contaminants
- consideration of less polluting processes/practices including pollution prevention and changes in materials used

Notes:
a) This chart summarizes technology process changes that could reduce the generation of the hexavalent chromium air emissions.
End of stack pollution collection is considered separately in another document.
b) Factors affecting the formation/rate of formation of chromium compounds in glass furnace flue glasses include:
1) alkalis from the glass, 2) water vapor from combustion, 3) high temperature 4) chromium from refractory or batch ingredients, and 5) oxygen.
c) Per Section 2.3 of Appendix A of "Guide to Requesting an Alternative Air Standard", Ontario Regulation 419, this Technology Benchmarking Assessment makes **no judgement on the feasibility** of materials or processes identified (at this stage).
d) the new emission targets for hexavalent chromium for Ontario are more stringent than the U.S. or Europe so the review of approaches to meet requirements in other jurisdiction is not covered in this assessment.

Technology	Description	
1.0 Material Substitution		
1.1 Substitute zircon refractory for chromic oxide refractory in melter and front end glass contact sidewalls where the glass contact refractory has exposure to the combustion gases above the glass surface.	Zircon is a glass contact refractory that has no chromium content and has been used in OC Composite glass front end for paving. Zircon has been used in the past for siderails before chromic oxide refractories started to be used in fiberglass front ends.	The use of zircon is now limited in OC composite glass melters and front ends to glass contact paving (floor) areas where wear is low or the electrically non-conductive attribute of zircon requires it's use.
2.0 Process Change		
2.1 Reduce the water vapour from flue gases in the combustion space by using air/gas combustion instead of oxy/gas combustion.	Flue gases from air/gas combustion have a lower water vapour concentration than flue gases from oxygen/gas combustion due to the volume of nitrogen in air that does not enter the combustion reaction but is present in the combustion space which dilutes the concentration of water vapour present.	High temperature sintered chromium oxide based refractories have unequalled resistance against high temperature corrosion by molten SiO_2-Al_2O_3- Fe_2O_3-CaO/MgO slags and by certain glass wool compositions, in an oxidizing environment.
2.2 Reduce the temperature of the flame in the combustion space by using air/gas combustion instead of oxy/gas combustion.	An air/gas flame has a temperature of ~3500 F. An oxygen/gas flame has a temperature of ~5000 F. Temperature impacts the rate the volatilization reaction occures. (Note that regardless of which oxidant is used, the temperature of the combustion space flue gases is ~2600 F which is still high enough to be a factor in hexavalent chromium air emissions.)	
2.3 Substitute a chromic oxide refractory that is formulated for a lower rate of high temperature volatilization for the chromic oxide refractories currently used.	SEFPRO has a new chromic oxide, C12LS (Low Sublimation) that has been formulated to be more resistant to volatilization. SEFPRO's data on emissions is related to total chromium volatilization not specifically the generation of the hexavalent form of chromium.	
2.4 Substitute electric energy for fossil fuel energy for the melting of glass in the melter and the heating of glass in the front end.	Electrodes submerged in the glass are currently used in conjunction with fossil fuel combustion to provide heat to melt glass in melters but are not used in OC Composite Solution Business (CSB) front ends. By using electric joule heating exclusively, flue gases from fossil fuel combustion are eliminated. Volatiles above the glass surface do not exit the space above the glass but rather condense and coat the inside of the refractory superstructure in a covered front end as there is no flue gas leaving the space.	
2.5 Reduce excess oxygen available in the combustion space above the glass through the use of more accurate combustion control skids	Less excess O2 in the combustion space reduces the rate of hexavalent chromium compound generation. By replacing the existing control skids which control the flow of gas and O2 using a single actuator and 2 linkages to curtain valves with a mass flow controller, much tighter control of ratio is achieved as flow is measured and more accurate flow control can be achieved with mass flow controllers.	
2.6 Reduce excess oxygen available in the front end combustion space above the glass by constructing front end superstructures that do not allow tramp air to leak into the combustion space.	Melter and front end combustion spaces operate with only a slight positive average pressure relative to ambient air pressure. Localized areas of negative pressure in the combustion space can allow tramp air to enter the combustion space which increases the amount of oxygen available for the reaction that generates hexavalent chromium compounds.	
2.7 Use a substoiciometric combustion ratio so the combustion atmosphere is reducing not oxidizing	If combustion maintains a reducing instead of an oxidizing atmosphere, chromium volatiles would be in the trivalent not hexavalent form.	A reducing atmosphere would change the redox state of the glass causing the glass to be greener from the reducing atmosphere's impact on iron in the glass. This change in color would not be acceptable to some customers.

Technology	Description	Min Particle Size
Low Pressure Cyclone	Used for removal of coarse dust from an air stream. Typically used as a precleaner to more efficient dust collectors. Not suitable for collection of fine particles.	20
Electrostatic Precipitator	Uses high voltage electrical current to ionize particles in air stream, then collects particulate on collector plates. High removal efficiencies with high capital costs. Low pressure drop unit. Requires cooling of high temperature air streams. High capital costs, low operating costs.	0.25
Fabric Filter/Dust Collector	Remove particulate by straining, impingement, interception, diffusion, and electrostatic charge. Results in good overall particulate removal. High capital and operating costs.	0.25
HEPA Filter	Used as a final filter and has a very low capacity for contaminants. Requires inlet air stream to very clean. Results in very clean air. Very high operating costs and/or cleaning required.	
NaOH Wet Scrubber	Not applicable. These scrubbers are designed to capture chrome emissions in the form of a mist or vapor. Wet scrubbers have difficulty capturing sub-micron particulate.	1
Spray Chamber Scrubbers	Wet collector. Generally used only as a pretreatment device for coarse dust. Transfers contaminants to waste water which then requires treatment.	
Cyclone Spray Chambers	Wet collector. Used for removal of coarse dust from an air stream. Typically used as a precleaner to more efficient dust collectors. Not suitable for collection of fine particles. Transfers contaminants to waste water which then requires treatment.	
Low Pressure Venturi Scrubbers	Wet collector. Generally used only as a pretreatment device for coarse dust. Transfers contaminants to waste water which then requires treatment.	10
High Pressure Venturi Scrubbers	Wet collector. No track record of success in the glass industry. Transfers contaminants to waste water which then requires treatment. Very high energy usage required for removal of fine particulates.	1

Dust Collectors
ESP
Fabric Collectors
Wet Collectors
Dry Centrifugal Collectors

Filters
HEPA

Dust Collectors - Designed for heavier loads from industrial processes - Concentrations from 0.1-100 grains/ft3

Air Filters - Designed to remove low dusc concentrations of the magnitude found in atmospheric air. - Typically used for concentrations less than 1 grain/1000 ft3

99%

Ultramicroscopic Particle Removal

Type	Min Size	Efficiency
Wet Collectors	0.8	50%
Cloth Arrestors	0.1	92%
ESP	0.1	90%
Cyclones	6	50%

From Industrial Ventilation Handbook 28th Edition Figure 8-14

Appendix A, Section 3.0 – Develop a List of Technically Feasible Pollution Control Options: Add-On Controls

3.1 Screening Out of Pollution Control Options (Availability)

Technology	Commercially Available in the Fiberglass Industry?	Reason Not Commercially Available
Low Pressure Cyclone	Yes	
Electrostatic Precipitator	Yes	
Fabric Filter/Dust Collector	Yes	
Spray Chamber Scrubbers	Yes	
Cyclone Spray Chambers	Yes	
Low Pressure Venturi Scrubbers	Yes	
HEPA Filter	No	Not used in industry. Research and trial work would be required.
High Pressure Venturi Scrubbers	No	Not used in industry. Research and trial work would be required.
NaOH Wet Scrubber	No	Designed to capture chrome vapor in the plating industry, not chrome particulate. Has never been used in fiberglass industry.

3.2 Technical Feasibility (Applicability)

Technology	Physical Restrictions?	Chemical Restrictions?	Resource Availability?	Final Product Specifications?	Engineering Principles?	Safety Concerns?	Reason for Lack of Feasability
Low Pressure Cyclone	No	Yes	No	No	Yes	Yes	Use would contribute to hexavalent chromium contamination in water discharge. Would result in low removal efficiency and no removal of fine particulate.
Electrostatic Precipitator	No	No	No	No	No	Yes	Use would cause exposure to concentrated levels of hexavalent chromium in dust. Would require pre-treatment of airstream to remove large particulate.
Fabric Filter/Dust Collector	No	No	No	No	No	Yes	Use would cause exposure to concentrated levels of hexavalent chromium in dust
Spray Chamber Scrubbers	No	Yes	No	No	Yes	Yes	Use would contribute to hexavalent chromium contamination in water discharge. Would result in low removal efficiency and no removal of fine particulate.
Cyclone Spray Chambers	No	Yes	No	No	Yes	Yes	Use would contribute to hexavalent chromium contamination in water discharge. Would result in low removal efficiency and no removal of fine particulate.
Low Pressure Venturi Scrubbers	No	Yes	No	No	Yes	Yes	Use would contribute to hexavalent chromium contamination in water discharge. Would result in low removal efficiency and no removal of fine particulate.

Appendix D Default Combinations Assessment

Combination ID	Combination Description[1]	Source ID (group)	Contribution to Maximum POI Concnetration by Source (ug/m3)	% POI Reduction by Source Group	Maximum POI Concentration (ug/m3)	Overall % of Schedule 3 Future Standard	Overall Percent Reduction	Ranking
Current	Current facility configuration	Furnace	2.90E-04		2.08E-02	14851%		
		Forehearth	1.96E-02					
		General Exhausts	1.05E-03					
G_R1	Electrostatic Precipitator (DEP/WEP) or Dust Collector on furnace and forehearth stacks combined with the use of Low Sublimation Chromium (LSC) refractory and conversion of the forehearths to air/gas combustion	Furnace	1.02E-04	64.68%	9.92E-04	709%	95.23%	1
		Forehearth	1.29E-04	99.34%				
		General Exhausts	7.61E-04	27.63%				
M_R1	Electrostatic Precipitator (DEP/WEP) or Dust Collector on furnace and forehearth stacks combined with conversion of the forehearths to air/gas combustion	Furnace	1.02E-04	64.68%	1.01E-03	719%	95.16%	2
		Forehearth	1.43E-04	99.27%				
		General Exhausts	7.61E-04	27.63%				
H_R1	Electrostatic Precipitator (DEP/WEP) or Dust Collector on furnace and forehearth stacks combined with the use of LSC refractory and the installation of more accurate combustion controls in combination with front end superstructures to prevent air ingress	Furnace	1.02E-04	64.68%	1.33E-03	952%	94%	3
		Forehearth	4.70E-04	97.60%				
		General Exhausts	7.61E-04	27.63%				
N_R1	Electrostatic Precipitator (DEP/WEP) or Dust Collector on furnace and forehearth stacks combined with incorporating more accurate combustion control skids and construction of frontend superstructures	Furnace	1.02E-04	64.68%	1.36E-03	971%	93%	4
		Forehearth	4.96E-04	97.47%				
		General Exhausts	7.61E-04	27.63%				
V_R1	Electrostatic Precipitator (DEP/WEP) or Dust Collector on furnace and forehearth stacks	Furnace	1.02E-04	64.7%	1.87E-03	1335%	91%	5
		Forehearth	7.59E-04	96.1%				
		General Exhausts	1.01E-03	4.1%				
E_R9	Incorporating more accurate combustion control skids and construction of front end superstructures and re-engineering exhaust stacks impacted by reconfiguration	Furnace	4.50E-04	-55.3%	2.38E-03	1703%	89%	6
		Forehearths	1.30E-03	93.4%				
		General Exhausts	7.62E-04	27.5%				
I_R3	Scrubber on forehearth stack, use of Low Sublimation Chromium (LSC) refractory and forehearth conversion to air/gas combustion	Furnace	2.05E-03	-606.46%	4.87E-03	3481%	77%	7
		Forehearth	2.07E-03	89.45%				
		General Exhausts	7.61E-04	27.63%				
O_R2	Scrubber on forehearth stack and forehearth conversion to air/gas combustion	Furnace	2.05E-03	-606.46%	5.10E-03	3644%	75%	8
		Forehearth	2.29E-03	88.28%				
		General Exhausts	7.61E-04	27.63%				
S_R1	Forehearth conversion to air/gas combustion	Furnace	2.05E-03	-606.5%	5.68E-03	4054%	73%	9
		Forehearth	2.87E-03	85.3%				
		General Exhausts	7.61E-04	27.6%				
J_R2	Scrubber on forehearth stack, use of Low Sublimation Chromium (LSC) refractory and incorporating more accurate combustion control skids and construction of front end superstructures	Furnace	2.05E-03	-606.46%	1.03E-02	7373%	50%	10
		Forehearth	7.51E-03	61.62%				
		General Exhausts	7.61E-04	27.63%				
P_R2	Scrubber on forehearth stack and incorporating more accurate combustion control skids and construction of front end superstructures	Furnace	2.05E-03	-606.46%	1.07E-02	7674%	48%	11
		Forehearth	7.94E-03	59.46%				
		General Exhausts	7.61E-04	27.63%				
T_R1	Incorporating more accurate combustion control skids and construction of front end superstructures	Furnace	2.05E-03	-606.5%	1.27E-02	9091%	39%	12
		Forehearth	9.92E-03	49.3%				
		General Exhausts	7.61E-04	27.6%				
W_R2	Scrubber on forehearth stack	Furnace	2.05E-03	-606.5%	1.52E-02	10864%	27%	13
		Forehearth	1.22E-02	37.9%				
		General Exhausts	1.01E-03	4.1%				

[1] Additional details for the pollution control options are provided in Section 3.2

[2] In some scenarios the furance contribution to the total POI concentration increases due to differences in dispersion

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