Wingra Engineering, S.C.
Environmental Engineering Consultants

September 23, 2021

National Parks Conservation Association
Clean Air and Climate Program
Attn: Stephanie Kodish, Senior Director & Counsel
777 6th Street NW, Suite 700
Washington, DC 20001-3723

Subject: Four-Factor Reasonable Progress Analysis
GCC Rio Grande – Pueblo Cement Plant
Pueblo, Colorado

Dear Ms. Kodish:

The National Parks Conservation Association requested the preparation of a Four-Factor Reasonable Progress Analysis for GCC Rio Grande – Pueblo Cement Plant in Pueblo, Colorado. This analysis evaluates the feasibility of installing emission control equipment for air pollutants which are precursors to regional haze. The enclosed report describes the procedures and results of this analysis.

Should you have further questions, please contact me at (608) 255-5030.

Sincerely,

Wingra Engineering, S.C.

Steven Klafka, P.E., BCEE
Environmental Engineer

Enclosure

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GCC Rio Grande – Pueblo Cement Plant

Pueblo, Colorado

Four-Factor Reasonable Progress Analysis

September 23, 2021

Prepared by:

Steven Klafka, P.E., BCEE

Wingra Engineering, S.C.

Madison, Wisconsin

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1.0 INTRODUCTION

The Colorado Department of Public Health and Environment (CDPHE) Air Pollution Control Division is updating its regional haze state implementation plan to improve visibility in certain national parks and wilderness areas in the state. These are referred to as Class I areas for implementation of air pollution protection regulations.

CDPHE is evaluating the retrofit of emission control technology at large industrial sources to make reasonable progress toward natural conditions in Class 1 areas. To determine the effectiveness of retrofitting emissions control technology, USEPA requires states to use a Four-Factor Reasonable Progress Analysis (FFA).

The four statutory factors included in an FFA are:

- Costs of compliance
- Time necessary for compliance
- Energy and non-air quality impacts of compliance
- Remaining useful life of any potentially affected sources

CDPHE has identified the GCC Rio Grande – Pueblo Cement Plant located in Pueblo, Colorado as potentially having impacts on regional haze at surrounding Class I areas. CHPHE recently conducted its own FFA entitled, *Regional Haze Second 10-year Planning Period, Reasonable Progress Four-Factor Analysis of Control Options for GCC Rio Grande - Pueblo Cement Plant*, August 2021.

This report updates the CDPHE analysis by incorporating recent improvements in available air pollution control systems for cement kilns. The CDPHE analysis did not address these control methods.

2.0 FACILITY DESCRIPTION

GCC Rio Grande – Pueblo Cement Plant is located at 3372 Lime Road in Pueblo, Colorado. It manufactures Portland cement. This requires that a mixture of quarried materials, including limestone and clay, be heated at high temperatures in a rotary pre-heater/pre-calciner kiln. This kiln is the primary source of air pollution emissions at the plant and is identified as Emission Point 039. The plant has not been issued an air quality operating permit. It currently operates following the requirements summarized in Facility Wide Construction Permit No. 98PB0893 Issuance 8 Correction.[1]

The kiln has a rated capacity of 3,750 tons per day and is fired with coal, natural gas and tire derived fuel. Currently, emissions are controlled using the following methods:

- Particulate Matter (PM) – Baghouse
- Sulfur Dioxide (SO_2) – Scrubbing inherent in the contact of SO_2 with the alkaline materials in the kiln.
- Nitrogen Oxides (NO_x) – Use of Selective Non-catalytic Reduction or SNCR by injection of ammonia into the high temperature areas of the kiln.

Allowable and uncontrolled emissions in units of tons per year (tpy) from the kiln are summarized in Table 1. Uncontrolled emissions for PM and NO_x are based on USEPA emission factors of 250 and 4.2 lbs/ton, respectively. For SO_2, it has been assumed that there is no difference between the allowable and uncontrolled emissions since the uncontrolled emissions are naturally controlled by the kiln.

Supporting calculations are provided in Appendix A.

[1] Colorado Department of Public Health and Environment, Air Pollution Control Division, Field Inspection Report, January 22, 2020.

Table 1 - Allowable and Uncontrolled Emissions from GCC Rio Grande – Pueblo Cement Kiln (tpy)

Air Pollutant	PM_{10} (Filterable)	PM_{10} (Condensable)	PM_{10} (Total)	SO_2	NO_x	Total
Allowable	36.0	293.6	329.6	943.4	1,100.0	2,373.0
Uncontrolled	171,093.8	45,875.0	216,968.8	943.4	2,874.4	220,786.5

3.0 CDPHE FOUR-FACTOR ANALYSIS

The Four-Factor Analysis or FFA completed by CDPHE concluded that no emission control systems or methods are available for the GCC Pueblo kiln. No changes were made to the allowable emissions from the kiln or the GCC plant. A copy of their draft analysis is provided in Appendix B.

For the control of NO_x, CDPHE evaluated the use of Selective Catalytic Reduction (SCR) to replace the current Selective Non-catalytic Reduction (SNCR). CDPHE estimated the current SNCR is achieving a NO_x emission reduction of 53.6%. SCR has been shown to provide NO_x emission reduction of 90% or more. SNCR requires the injection of ammonia in high temperatures (1,600 to 2,000°F) while SCR requires the injection of ammonia at lower temperatures (450 to 800°F) where control occurs in a ceramic catalyst. CDPHE rejected the use of SCR to attain greater NO_x emission reductions due to the likelihood of catalyst plugging by PM, mostly the condensable form, and the lack of experience on cement kilns.

For the control of PM, CDPHE determined that the existing baghouse provided state of the art capture of filterable PM and no better controls were available. The large amount of condensable PM could be minimized by tight control of the ammonia injection used by the SNCR control system for NO_x. CDPHE concluded that "These inorganic ammonium salts form when excess ammonia from the SNCR, known as ammonia slip, reacts with chlorides and sulfates from the raw materials and coal."

For the control of SO_2, CDPHE did not evaluate control methods since actual emissions from the inherent scrubbing within the kiln were already low.

4.0 OTHER AVAILABLE EMISSION CONTROL SYSTEMS

There are practical impediments to using a traditional SCR control system for the kiln due to potential plugging by PM emissions. However, the shortcomings of traditional SCR have been overcome with the availability of recently available catalytic ceramic filter systems. These systems are in use throughout the U.S., but with limited application at cement plants. There is greater application of these systems at cement plants in Europe. These systems combine the PM removal conducted by a baghouse with the NO_x removal of SCR. In its FFA, the CDPHE did not evaluate the use of ceramic filter systems.

The advantages of catalytic ceramic filter systems are as follows:

1. Injection of ammonia at low SCR filter temperatures rather than the high SNCR temperatures, thus avoiding the formation of condensable PM within the kiln.

2. More efficient usage of ammonia reducing ammonia slip.

3. Larger reductions in NO_x emissions, as the control efficiency is increased from 53% (estimated by CDPHE for GCC) to greater than 90%.

4. Simultaneous capture PM emissions.

5. Simultaneous control of SO_2 emissions when combined with reagent injection.

There are two design alternatives for catalytic ceramic filters:

1. Stand-alone catalytic ceramic filter systems

2. Catalytic ceramic filter inserts for existing baghouses

Manufacturers of these filter systems include: Tri-Mer [2], GEA Bischoff [3], and Haldor Topsoe A/S [4]. All three firms were contacted for this study. They all cite the ability to control emissions in the cement industry. The first two firms offer catalytic ceramic filters. These catalytic ceramic filter systems combine into a single control device the traditional separate systems for each air pollutant, as the systems typically include a scrubber for SO_2 neutralization, baghouse for PM capture and SCR for NO_x control. Brochures for the catalytic ceramic filter control systems offered by these two firms are provided in Appendices C and D, respectively.

The last firm, Haldor Topsoe, produces both: 1) a catalytic filter candle (called TopFrax) and 2) a catalytic filter bag (called Cataflex). The filter candles are similar to those used inside the Tri-Mer and GEA systems. The catalytic filter bag, however, is a product that can be added to an existing

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[2] https://tri-mer.com/hot-gas-treatment/hot-gas-filtration.html
[3] https://www.gea.com/en/news/trade-press/2019/biscat-ceramic-catalyst-filter.jsp
[4] https://www.topsoe.com/products/catalysts/topfraxtm

baghouse. These catalytic filter bags have the advantage of reduced cost. They avoid the need for a separate stand-alone control system by instead inserting the catalytic filter bags into the fabric bags of the existing baghouse used to control PM emissions. Brochures for both the catalytic filter candles and bags provided by Haldor Topsoe are provided in Appendix E. Tri-Mer notes that it also has experience with the installation of catalytic filter bags on existing baghouses.

Tri-Mer has extensive experience in the U.S. using their catalytic filter control systems to simultaneously control PM, SO_2 and NO_x emissions from high temperature glass furnaces. Current installations in the U.S are summarized in Table 2.

Tri-Mer also has updated existing baghouses by replacing the fabric filter bags with catalytic ceramic filters. This approach modifies the baghouse to allow the control of NO_x emissions on the ceramic filter.

Table 2 - Tri-Mer Filter Projects in U.S.

Company	Location	Glass Type
Durand	Millville, NJ	Tableware
Anchor	Monaca, PA	Mixed
AGC	Church Hill, TN	Flat
Gallo	Modesto, CA	Container
AGC	Hill, KS	Flat
Adagh	Dolton, IL	Container
Kohler	Kohler, WI	Specialty
Guardian	Carleton, MI	Flat
PG Corporation	L.A. Basin	Specialty
Cardinal FG	Mooresville, NC	Flat
Cardinal FG	Durant, OK	Flat

Haldor Topsoe worked with FLSmidth to install a ceramic filter system after a baghouse used on the cement kiln at Cemex Southeast LLC cement plant in Demopolis, Alabama. This ceramic filter system was used to control hazardous organic compound emissions.[5] Haldor Topsoe have also used their catalytic filter bags to control NO_x emissions from cement kilns in Europe.

Figure 1 provides a diagram of a stand-alone catalytic ceramic filter system offered by Tri-Mer.

Figure 2 shows the catalytic filter bag inserts (called Cataflex) offered by Haldor Topsoe.

It is noteworthy that CDPHE recently completed an FFA for the Rocky Mountain Bottle Company which has a glass furnace equipped with the Tri-Mer system.

[5] https://www.cemex.com/documents/20143/49694544/IntegratedReport2019.pdf/4e1b2519-b75f-e61a-7cce-2a2f2f6f09dc

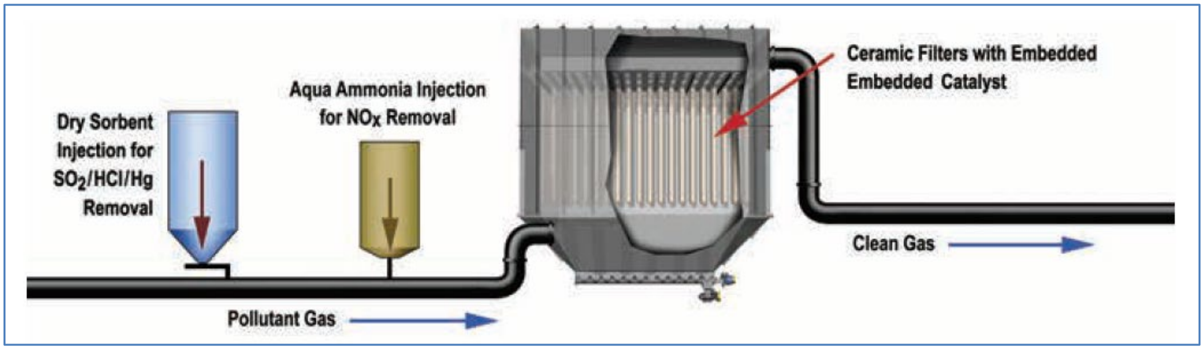

Figure 1 - Catalytic Ceramic Filter System

Figure 2 - Catalytic Filter Bag Insert

The configuration of the existing GCC Rio Grande – Pueblo cement plant has been discussed with the three vendors. Potential emission control options include the following:

1. Insertion of catalytic filters into the existing baghouse.

2. Installation of a ceramic filter system after the existing baghouse.

3. Replacement of the existing baghouse with a stand-alone ceramic filter system.

The least expensive option is the first – installing catalytic filter bags into the fabric bags of the existing baghouse or replacing the fabric bags with ceramic filter elements. This approach would retain the footprint of the existing baghouse and stack with the least physical modifications.

The remaining two options would be more costly and require the purchase of a stand-alone ceramic filter system. For the second option, the existing baghouse and SNCR system would be retained. There would be less air pollution emissions to control and additional cost to reheat the flue gas to the catalyst operating temperature. For the third option, the existing baghouse and SNCR system would be removed. There would be more air pollution emissions to control and no need to reheat the flue gas.

5.0 COSTS OF COMPLIANCE

Cost estimates were developed for the following three emission control alternatives not considered by CDPHE in its FFA:

1. Installation of a stand-alone Tri-Mer catalytic ceramic filter system, while retaining the existing baghouse and SNCR control system. This approach would simultaneously control PM, SO_2 and NO_x emissions.

2. Replacement of the existing baghouse with a stand-alone Tri-Mer catalytic ceramic filter system. This approach would simultaneously control PM, SO_2 and NO_x emissions

3. Replacement of the fabric filter bags of the existing baghouse with catalytic ceramic filter elements. This approach would add the control of NO_x emissions.

5.1 Cost of Catalytic Ceramic Filter System

For typical Best Available Control Technology analyses, order-of-magnitude cost estimates are typically generated.[6] The cost estimate is improved if it is based on actual vendor quotations for the required equipment. Developing air pollution control cost estimates is a time-consuming process. Rather than request budget quotations from vendors, a cost estimate was developed from a 2015 proposal for a Tri-Mer catalytic ceramic filter system sized for a 700 tons per day flat glass plant. This system was eventually installed in North Carolina and continues to operate successfully. This glass plant cost estimate reflects the retrofit of a new control system at an existing industrial facility.

The capital, installation and operating costs were adjusted to reflect the differences between the glass plant and the cement kiln at the GCC Rio Grande – Pueblo cement plant. Adjustments accounted for inflation, inlet air flow rates and uncontrolled emission rates of PM, SO_2 and NO_x. Supporting cost estimation calculations are provided in Appendix A.

If the existing baghouse is retained for the first option, the exit temperature of the flue gas would be too low for the use of a catalytic reduction system. The cost estimates include the cost of natural gas to reheat the flue gas to the control system operating temperature of 550 °F.

If the existing baghouse is removed and replaced with the catalytic filter system for the second option, it was assumed that operation of the cement plant gas cooler prior to the baghouse could instead be adjusted to increase the flue gas temperature to that required for the catalyst.

Table 3 summarizes the cost estimate for options 1 and 2. Because the catalytic ceramic filter system is a multi-pollutant control technology, cost effectiveness was calculated based on the total

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[6] USEPA, Air Pollution Control Manual, Sixth Edition, EPA/452/B-02-001 January 2002.

expected emission reductions of NO_x alone, and for PM, SO_2 and NO_x combined.

For the first option, adding a new ceramic catalytic filter system after the existing baghouse and SNCR system, the estimated cost effectiveness to is $6,211 per ton for the removal of NO_x emissions. The cost effectiveness is $3,550 per ton for the removal of combined emissions of PM, SO_2 and NO_x. This is based on controlling the allowable emissions exiting the current baghouse and SNCR system.

For the second options, replacement of the existing baghouse and SNCR system with a new ceramic catalytic filter system, estimated cost effectiveness is $1,889 per ton for the removal of NO_x emissions. The cost effectiveness is $29 per ton for the removal of combined emissions of PM, SO_2 and NO_x. This is based on controlling the uncontrolled emissions exiting the current cement kiln.

This analysis shows that either option has cost effectiveness values which are reasonable and fall within the range that has been accepted by regulatory agencies. The enclosed cost estimate would be improved if a budget quotation were obtained for the cement kiln at the plant.

Table 3 - Cost Estimate for Catalytic Ceramic Filter System

Capital Costs	GCC Rio Grande	GCC Rio Grande
Location of New Catalytic Filters	After Baghouse	Replace Baghouse
Emissions Basis	Allowable	Uncontrolled
Complete System Equipment and Installation	$31,278,404	$31,278,404
Capital Recovery Factor (CRF)	0.06878	0.06878
Annualized Capital Cost	$2,151,329	$2,151,329
Operating Costs		
Electricity	$831,274	$831,274
19% Aqueous Ammonia	$366,195.36	$956,893
Hydrated Lime	$768,162.99	$768,163
Labor for Operation and Maintenance	$178,033	$178,033
Natural Gas for Reheating Flue Gas	$1,854,147	$0
Annual Operating Costs	3,997,812	2,734,363
Combined Capital and Operating Costs		
Capital Costs	$31,278,404	$31,278,404
Annual Capital Costs	$2,151,329	$2,151,329
Annual Operating Costs	$3,997,812	$2,734,363
Annual Capital and Operating Costs	$6,149,141	$4,885,692
Inlet NO_x (tpy)	1,100	2,874
Inlet SO_2 (tpy)	943	943
Inlet PM (tpy)	36	171,094
Inlet NO_x, SO_2 and PM (tpy)	2,079	174,912
Outlet NO_x (tpy)	110	287
Outlet SO_2 (tpy)	236	240
Outlet PM (tpy)	2	7,129
Outlet NO_x, SO_2 and PM (tpy)	347	7,656
Removed NO_x (tpy)	990	2,587
Removed SO_2 (tpy)	708	704
Removed PM (tpy)	35	163,965
Removed NO_x, SO_2 and PM (tpy)	1,732	167,256
Cost Effectiveness ($ per ton of NO_x removed)	$6,211	$1,889
Cost Effectiveness ($ per ton of total removed)	$3,550	$29

5.2 Cost of Catalytic Filters

Tri-Mer was provided with the design specifications of the existing cement kiln. These are the same as those used to develop the preceding cost estimates for a stand-alone catalytic ceramic filter system.

Based on the design of the existing cement kiln and its air pollution control system, Tri-Mer prepared a proposal to replace the existing fabric filter bags in the baghouse with catalytic ceramic filter elements. This approach would continue to provide control of PM emissions, but add the ability to control NO_x emissions by 90% or more. If desired, reagent injection such as lime could be used to control SO_2 emissions. A copy of the Tri-Mer proposal is provided in Appendix F of this report.

Tri-Mer assumed the existing SNCR system would be discontinued so uncontrolled NO_x emissions would be controlled by the new filters. To achieve the required operating temperature of 550 °F, the exhaust flue gas of the cement kiln would no longer be cooled to a temperature required by the existing fabric bags.

Based on their estimated capital and operating cost estimates, Tri-Mer developed a cost effectiveness of $800 per ton of NO_x removed. This estimate is reasonable and falls within the range that has been accepted by regulatory agencies. The enclosed cost estimate would be improved if a budget quotation were obtained for the cement kiln at the plant.

Other benefits of this control option cited by Tri-Mer include the following:

- Minimal catalyst plugging
- Reduced ammonia slip
- Negligible catalyst deactivation
- Minor conversion of SO_2 to SO_3

Each of these addresses concerns raised by CDPHE for the use of SCR in its draft FFA.

6.0 TIME NECESSARY FOR COMPLIANCE

Based on prior projects, the time frame to obtain a quotation for a catalytic ceramic filter system or catalytic filter bags, issue a purchase order, complete engineering, construct and install the equipment is 12 months.

7.0 ENERGY AND NON-AIR QUALITY IMPACTS OF COMPLIANCE

Significant operating costs include electricity, ammonia reagent, hydrated lime reagent and labor. These costs are taken into account in the enclosed cost estimates. The cost estimates provided in this report incorporate electricity usage for control system fans.

The ammonia selected for the control of NO_x emissions is 19% aqueous ammonia. This is a less concentrated and safer alternative to anhydrous ammonia. This type of ammonia has no federal requirement to evaluate the potential impacts of an accidental release.

The calcium sulfate (i.e., gypsum) formed by the reaction of hydrated lime with SO_2 will be captured as dust by the ceramic filters. Calcium sulfate is a raw material in cement. It is possible the capture dust can be used as one of the ingredients in the production of cement and avoid landfilling.

8.0 REMAINING USEFUL LIFE OF ANY POTENTIALLY AFFECTED SOURCES

In its FFA, CDPHE concluded that GCC has not announced a closure date for the Pueblo kiln or its associated limestone quarry, and CDPHE assumed that the cement kiln will remain in operation for at least 20 years.

9.0 CONCLUSIONS

The draft FFA prepared by CDPHE for the GCC Rio Grande – Pueblo cement plant concluded there were no feasible control systems available to further reduce emissions. The use of catalytic ceramic filter systems was not considered by CDPHE. These systems are in operation in the U.S. and are suitable for cement kilns.

The enclosed estimates show that for the first option, adding a new ceramic catalytic filter system after the existing baghouse and SNCR system, the estimated cost effectiveness to is $6,211 per ton for the removal of NO_x emissions. The cost effectiveness is $3,550 per ton for the removal of combined emissions of PM, SO_2 and NO_x. This is based on controlling the allowable emissions exiting the current baghouse and SNCR system.

For the second option, replacement of the existing baghouse and SNCR system with a new ceramic catalytic filter system, estimated cost effectiveness is $1,889 per ton for the removal of NO_x emissions. The cost effectiveness is $29 per ton for the removal of combined emissions of PM, SO_2 and NO_x. This is based on controlling the uncontrolled emissions exiting the current cement kiln.

For the third option, replacement of the existing fabric filter bags with catalytic ceramic filter elements, the cost effectiveness would be $800 per ton for the removal of NO_x emissions.

All of these values represent a reasonable expenditure for the reduction of PM, SO_2, and NO_x emissions. There are no other impediments to the use of these control systems associated with time of installation, energy and non-air impacts, or the anticipated life of the existing cement plant.

Appendix A

Supporting Cost Calculations

Facility	GCC Rio Grande			Reference
	Pueblo Cement Plant			A
	Pueblo, Colorado			A
	Preheater/Precalciner Kiln			A
AIRS Point	039			A
Fuels	Coal, NG, TDF			A
Capacity (tons per day)	3,750			A
Current Control for PM	Baghouse			A
Current Control for SO2	Inherent Scrubbing			A
Current Control for NOx	SNCR			A
Exhaust Flow Rate (acfm)	306,708			B
Exhaust Temperature (F)	377			B
Exhaust Moisture (%)	8.2			B
	Air Pollutant	Units	Emission	
Allowable	PM10 (Filterable)	(tpy)	36.0	A
	PM10 (Condensable)	(tpy)	293.6	A
	PM10 (Total)	(tpy)	329.6	A
	SO2	(tpy)	943.4	A
	NOx	(tpy)	1,100.0	A
Allowable	PM10 (Filterable)	(lbs/ton)	0.1	Calculated
	PM10 (Condensable)	(lbs/ton)	0.4	Calculated
	PM10 (Total)	(lbs/ton)	0.5	Calculated
	SO2	(lbs/ton)	1.4	Calculated
	NOx	(lbs/ton)	1.6	Calculated
Allowable	PM10 (Filterable)	(lbs/hr)	8.2	Calculated
	PM10 (Condensable)	(lbs/hr)	67.0	Calculated
	PM10 (Total)	(lbs/hr)	75.3	Calculated
	SO2	(lbs/hr)	215.4	Calculated
	NOx	(lbs/hr)	251.1	Calculated
Uncontrolled	PM10 (Filterable)	(lbs/ton)	250.0	C
	PM10 (Condensable)	(lbs/ton)	67.0	A
	PM10 (Total)	(lbs/ton)	317.0	Calculated
	SO2	(lbs/ton)	1.4	D
	NOx	(lbs/ton)	4.2	A
Uncontrolled	PM10 (Filterable)	(lbs/hr)	39,062.5	Calculated
	PM10 (Condensable)	(lbs/hr)	10,473.7	Calculated
	PM10 (Total)	(lbs/hr)	49,536.2	Calculated
	SO2	(lbs/hr)	215.4	Calculated
	NOx	(lbs/hr)	656.3	Calculated
Uncontrolled	PM10 (Filterable)	(tpy)	171,093.8	Calculated
	PM10 (Condensable)	(tpy)	45,875.0	Calculated
	PM10 (Total)	(tpy)	216,968.8	Calculated
	SO2	(tpy)	943.4	Calculated
	NOx	(tpy)	2,874.4	Calculated

A - CDPHE, Regional Haze Second 10-year Planning Period, Reasonable Progress Four-Factor Analysis of Control Options for
B - GCC Rio Grande, ,Inc., Portland Cement Manufacturing Facility, Pueblo County, Colorado, Revised Initial Title V Operating
C - USEPA, AP42, Table 11.6-2 - Emission Factors for Portland Cement Manufacturing, January 1995.
D - Uncontrolled SO2 assumed to be same as allowable due to use of inherent scrubbing within kiln.

Air Pollutant	PM10 (Filterable)	PM10 (Condensable)	PM10 (Total)	SO2	NOx	Total
Allowable	36.0	293.6	329.6	943.4	1,100.0	2,373.0
Uncontrolled	171,093.8	45,875.0	216,968.8	943.4	2,874.4	220,786.5

	Reference	Original (2015)		Original (2021)	Reference	GCC Rio Grande	GCC Rio Grande
Location of New Catalytic Filters						After Baghouse	Replace Baghouse
Emissions Basis		Potential		Potential		Allowable	Uncontrolled
Capacity (tpd)	Quotation	700		700	2021 CDPHE	3,750	3,750
Current Flow (acfm)					Permit Application	306,708	306,708
Current Temperature (deg F)					Permit Application	377	377
Inlet Flow (acfm)	Quotation	96,745		96,745	Calculated	370,102	370,102
Inlet Temperature (deg F)	Quotation	550		550	Calculated	550	550
Inlet NOx (lbs/ton)	Quotation	18.0			Current Allowable	1.6	
Inlet SO2 (lbs/ton)	Quotation	4.0			Current Allowable	1.4	
Inlet PM (lbs/ton)	Quotation	1.2			Current Allowable	0.1	
Inlet NOx (tpy)	Calculated	2,299.5			Current Allowable	1,100	
Inlet SO2 (tpy)	Calculated	511.0			Current Allowable	943	
Inlet PM (tpy)	Calculated	153.3			Current Allowable	36	
NOx Removal (%)	IN vs OUT	90.0%			Same as Original	90.0%	
SO2 Removal (%)	IN vs OUT	75.0%			Same as Original	75.0%	
PM Removal (%)	IN vs OUT	95.8%			Same as Original	95.8%	
Outlet NOx (lbs/ton)	Quotation	1.8			Calculated	0.16	
Outlet SO2 (lbs/ton)	Quotation	1.0			Calculated	0.34	
Outlet PM (lbs/ton)	Quotation	0.1			Calculated	0.002	
Outlet NOx (tpy)	Calculated	230.0			Calculated	110.0	
Outlet SO2 (tpy)	Calculated	127.8			Calculated	235.9	
Outlet PM (tpy)	Calculated	6.4			Calculated	1.5	
Removed NOx (tpy)	Calculated	2,069.6			Calculated	990.0	
Removed SO2 (tpy)	Calculated	383.3			Calculated	707.6	
Removed PM (tpy)	Calculated	146.9			Calculated	34.5	
Removed NOx, SO2 and PM (tpy)	Calculated	2,599.7			Calculated	1,732.1	
Inlet NOx (lbs/ton)	Quotation	18.0		18.0	Uncontrolled (USEPA)		4.2
Inlet SO2 (lbs/ton)	Quotation	4.0		4.0	Current Allowable		1.4
Inlet PM (lbs/ton)	Quotation	1.2		1.2	Uncontrolled (USEPA)		250
Inlet NOx (tpy)	Calculated	2,299.5		2,299.5	Calculated		2,874.4
Inlet SO2 (tpy)	Calculated	511.0		511.0	Calculated		943.4
Inlet PM (tpy)	Calculated	153.3		153.3	Calculated		171,093.8
NOx Removal (%)	IN vs OUT	90.0%		90.0%	Same as Original		90.0%
SO2 Removal (%)	IN vs OUT	75.0%		75.0%	Same as Original		75.0%
PM Removal (%)	IN vs OUT	95.8%		95.8%	Same as Original		95.8%
Outlet NOx (lbs/ton)	Quotation	1.8		1.8	Calculated		0.42
Outlet SO2 (lbs/ton)	Quotation	1.0		1.0	Calculated		0.35
Outlet PM (lbs/ton)	Quotation	0.1		0.1	Calculated		10.42
Outlet NOx (tpy)	Calculated	230.0		230.0	Calculated		287.4
Outlet SO2 (tpy)	Calculated	127.8		127.8	Calculated		239.5
Outlet PM (tpy)	Calculated	6.4		6.4	Calculated		7,128.9
Removed NOx (tpy)	Calculated	2,069.6		2,069.6	Calculated		2,586.9
Removed SO2 (tpy)	Calculated	383.3		383.3	Calculated		703.9
Removed PM (tpy)	Calculated	146.9		146.9	Calculated		163,964.8
Removed NOx, SO2 and PM (tpy)	Calculated	2,599.7		2,599.7	Calculated		167,255.7
Capital Costs		Original (2015)	Inflation	Original (2021)	Adjustment Method	GCC Rio Grande	GCC Rio Grande
Location of New Catalytic Filters						After Baghouse	Replace Baghouse
Emissions Basis						Allowable	Uncontrolled
Complete System Equipment and Installation		$12,159,935	1.15	$13,983,925	Six-Tenths by Inlet Flow	$31,278,404	$31,278,404
Capital Recovery Factor (CRF)	CRF (20 yrs, 3.25%)	0.06878	CRF (20 yrs, 3.25%)		CRF (20 yrs, 3.25%)	0.06878	0.06878
Annualized Capital Cost		$836,360				$2,151,329	$2,151,329
Operating Costs							
Electricity		$188,953	1.15	$217,296	Ratio by Inlet Flow	$831,274	$831,274
19% Aqueous Ammonia		$665,665	1.15	$765,515	Ratio by Inlet NOx	$366,195.36	$956,893
Hydrated Lime		$361,810	1.15	$416,082	Ratio by Inlet SO2	$768,162.99	$768,163
Labor for Operation and Maintenance		$69,213	1.15	$79,595	Six-Tenths by Inlet Flow	$178,033	$178,033
Natural Gas for Reheating Flue Gas						$1,854,147	$0
Annual Operating Costs		$1,285,641				3,997,812	2,734,363
Combined Capital and Operating Costs							
Capital Costs		$12,159,935				$31,278,404	$31,278,404
Annual Capital Costs		$836,360				$2,151,329	$2,151,329
Annual Operating Costs		$1,285,641				$3,997,812	$2,734,363
Annual Capital and Operating Costs		$2,122,001				$6,149,141	$4,885,692
Inlet NOx (tpy)		2,300				1,100	2,874
Inlet SO2 (tpy)		511				943	943
Inlet PM (tpy)		153				36	171,094
Inlet NOx, SO2 and PM (tpy)		2,964				2,079	174,912
Outlet NOx (tpy)		230				110	287
Outlet SO2 (tpy)		128				236	240
Outlet PM (tpy)		6				2	7,129
Outlet NOx, SO2 and PM (tpy)		364				347	7,656
Removed NOx (tpy)		2,070				990	2,587
Removed SO2 (tpy)		383				708	704
Removed PM (tpy)		147				35	163,965
Removed NOx, SO2 and PM (tpy)		2,600				1,732	167,256
Cost Effectiveness ($ per ton of NOx removed)		$1,025				$6,211	$1,889
Cost Effectiveness ($ per ton of total removed)		$816				$3,550	$29

Notes:

Complete System Equipment and Installation includes: emission control system, controls, infrastructure, engineering design and project management, installation, services, batch recycle system, ammonia tank shelter.

Inflation multiplier from November 2015 to August 2021 = 1.15 - https://www.bls.gov/data/inflation_calculator.htm

Capital Recover Factor based on lifetime of operation and % interest from DOE, Four-Factor Analysis, https://ecology.wa.gov/Air-Climate/Air-quality/Air-quality-targets/Regional-haze

Natural Gas for Reheating Flue Gas to 550 F

Start Temp	(deg F)	377
Start Flow	(acfm)	306,708
Inlet Temp	(deg F)	550
Inlet Flow	(acfm)	370,102
Inlet Flow	(scfm)	193,479
Inlet Flow	(lbs/min)	14,511
Start h	(btu/lbs)	200.83
Inlet h	(btu/lbs)	243.48
Change h	(btu/lbs)	42.65
Fuel Required	(btu/hr)	37,133,434
Fuel Required	(therms/hr)	371.3
Nat Gas	($/therm)	0.57
Nat Gas	($/yr)	$1,854,147

Appendix B

CDPHE Four-Factor Analysis

Regional Haze Second 10-year Planning Period
Reasonable Progress Four-Factor Analysis of Control Options
for
GCC Rio Grande – Pueblo Cement Plant

August 2021

For the second Regional Haze 10-year planning period, Colorado evaluated all stationary sources in the state with oxides of nitrogen (NO_x), sulfur dioxide (SO_2), and particulate matter (PM) emissions over 25 tons per year (TPY) to determine which sources should be evaluated for potential additional emission controls depending on proximity to Class I areas (CIAs). Sources were included in the Reasonable Progress (RP) analysis if their total emissions of NO_x, SO_2, and PM, in TPY, divided by distance to the nearest CIA, in km, ("Q/d") was greater than 10, based on 2014 National Emissions Inventory (NEI) emissions. In Colorado, sources with a Q/d > 10 are considered potential contributors to CIA visibility impairment and are subject to the four-factor review process. Although a facility may have installed controls, changed fuel sources, or made other operational changes since 2014 that have reduced emissions, these sources are still subject to evaluation. For all RP sources, the four factor analyses are conducted using more current baseline emissions, typically 2016-2018 actual emissions. In determining RP under the Regional Haze program, states must consider the four factors explicitly set forth in the Clean Air Act, which are:

(1) costs of compliance,
(2) time necessary for compliance,
(3) energy and non-air quality environmental impacts of compliance, and
(4) remaining useful life.

The GCC Pueblo cement plant has a Q/d = 12.67. Accordingly, the GCC plant is subject to the RP four-factor review process. Great Sand Dunes National Park is the nearest Class I Area to GCC and is 85.3 km (53.0 miles) from the GCC Pueblo plant. GCC was not analyzed during the first Regional Haze planning period.

For the purposes of evaluating RP, the Division elected to focus its analysis on those individual emission units with actual baseline emissions (2016 - 2018 average emissions) of NO_x, SO_2, or PM_{10} equal to or exceeding 10 TPY. The Division established a *de minimis* threshold to focus the technical emission control analysis on significant emission sources where potential controls could provide a meaningful improvement in visibility if emission controls are determined to be cost effective.

Prior to the application of the four statutory factors, the Division followed a process similar to assessing the application of the Best Available Control Technology (BACT), by identifying the available emissions control technologies and then determining if they were technically and economically feasible.

I. Source Description

Facility AIRS ID:	101-0252
Owner/Operator:	GCC Rio Grande
Source Type:	Portland Cement Manufacturing
SCC:	305-006-23 (Kiln), 305-006-14 (Clinker Cooler)

305-006-09 (Primary Crusher)
Kiln Type: Preheater/Precalciner Kiln

The GCC facility manufactures Portland cement and is located in Pueblo, Colorado, about 53 miles from Great Sand Dunes National Park. The facility is located in an attainment area for all criteria pollutants.

The GCC Pueblo kiln is the newest Portland cement plant in Colorado and is a modern preheater/precalciner that is much more energy efficient than older kiln designs. This design is much more energy efficient than earlier wet cement kilns which combusted large quantities of fuel to boil off the water in the slurry. It's also more energy efficient than long dry kilns, including the modified long-dry kiln at the CEMEX Lyons facility. The GCC kiln utilizes a 5-stage single string preheater and precalciner where most of the fuel is fired. This requires less overall fuel, resulting in lower emissions of NO_x, SO_2, and PM.

The permitted kiln production rate is 3,750 tons per day of clinker, and on average yields approximately 130 tons of clinker per hour. The kiln is the main source of PM_{10} and NO_x emissions, but its SO_2 emissions are below the 10 TPY de minimis threshold. The clinker cooler is the only other significant sources of visibility impairing PM_{10}, but does not emit SO_2 or NO_x.

Process Description:

The basic process of producing Portland cement plant involves producing a raw meal consisting of quarried materials, including limestone (primarily $CaCO_3$, calcium carbonate) and clay (which contains silicate minerals and aluminum oxides), along with other ingredients such as sand (primarily SiO_2, silicon dioxide) and scale (iron oxides). These raw meal ingredients are finely ground and mixed in various ratios depending on the desired final cement product. This raw meal is heated to very high temperatures in a rotary kiln to form alite ($Ca_3O \cdot SiO_4$) which clumps together in nodules called clinker, the primary component of Portland cement. In this heating process, NO_x is produced from the high combustion temperatures, SO_2 is produced from sulfur in the coal and sulfur-containing compounds in the limestone, and CO_2 is produced from the fuel combustion and the decomposition of calcium carbonate into calcium oxide and carbon dioxide ($CaCO_3 \rightarrow CaO + CO_2$). The clinker is cooled, combined with other products, such as gypsum ($CaSO_4 \cdot 2H_2O$), and ground to produce a specific Portland cement formulation.

In the case of the GCC Pueblo facility, the process begins with extracting limestone and other raw materials from the co-located quarry, and processing them through a primary crusher at the quarry. Water injection is used to drill blast holes for explosives and sequential blasting is used to minimize emissions for the blasting operations. The primary crusher is mobile and is positioned to minimize transport distance of material to reduce particulate emissions. The crusher is also equipped with a baghouse to control PM emissions. The crushed material is transported to the limestone storage dome by a covered conveyor system. The material is then blended and transferred via another covered conveyor to raw material storage bins. This conveyor and the blending processes are controlled by baghouses.

These storage bins contain limestone and additive materials, such as sandstone and iron. The facility develops the raw material blend by weighing the limestone and additives on weigh scales and transferring these materials to the raw mill by covered conveyor. The raw mill mixes and crushes the materials and delivers the homogenized material to a raw meal storage silo. A conveyor then feeds the raw meal from the storage silo to the preheater/precalciner.

Pulverized coal from the coal mill is also fed to the preheater/precalciner, where it is fired. Some process gases from the kiln are used to dry the coal, while the remaining gases pass through the in-line raw mill. This helps conserve energy and the in-line raw mill acts as a scrubber for SO_2 and ammonia. The material leaving the preheater/precalciner is almost completely calcined as it enters the rotary kiln, which is located at a slight incline along its horizontal axis. The material travels towards the clinker discharge end where additional pulverized coal is fired for the clinkering process. The clinker is discharged from the kiln into the clinker cooler where it is cooled by air forced through the clinker bed by under-grate fans. Heated air from the clinker cooler is fed into the kiln as pre-heated combustion air, which improves the energy efficiency of the kiln. The cooled clinker is transferred to the clinker storage dome by a covered conveyor before being transferred by two covered conveyors to a clinker storage silo near the finish mill. Finish mill additives, such as gypsum, are delivered via truck or rail and transferred to an additive storage silo near the finish mill. Clinker and additives from the clinker storage silo and additive silo are fed to the finish mill which grinds the material to a fine powder to produce Portland cement. The Portland cement is stored in product silos and shipped via railcar or truck.

From an overall perspective, the manufacturing process can be viewed as two segments -- clinker production and cement production. The clinker storage allows the two processes to operate at different production rates. During periods of low demand for cement, clinker is accumulated. If cement is in very high demand, the clinker production can be supplemented by purchase of clinker from other sources. The overall result is the clinker production can operate at a relatively steady rate, while the cement production can operate in response to current or projected demands.

For sources identified through the above screening process as potentially impacting western Class I Areas, a *de minimis* threshold was established to focus technical emission control analysis on significant emission units where potential controls could provide a meaningful improvement in visibility. Emission points may include point or fugitive emissions, or both. Identified sources were asked to submit relevant four-factor information for all emission points with 2016 - 2018 average actual baseline emissions of NO_x, SO_2, and PM_{10} greater than or equal to 10 TPY. These points were evaluated to identify additional emissions controls to determine if additional emissions reductions are technically feasible and cost effective.

GCC submitted a Four-Factor Analysis for the Kiln (AIRS ID 039) and Clinker Cooler (AIRS ID 040) to the Division on October 30, 2019 with additional information submitted on March 27, 2020 and May 19, 2020.

The emission points potentially subject to evaluation at GCC Pueblo plant are shown in Table 1. Emission points with permitted emissions of less than 10 TPY of NO_x, SO_2 or PM_{10} were excluded.

Table 1: GCC Emission Points

AIRS Point	Description	Emission Type
039	Kiln	Point
040	Clinker Cooler	Point
069	Quarry Crusher Engine	Point

Table 2 lists the permitted and actual emissions for all units with permitted or actual emissions over 10 TPY. Kiln (039) and Clinker Cooler (040) emissions are the 2016-2018 averages reported in the four factor analysis submitted by GCC. Actual emissions for the Quarry Crusher Engine (069) are based on the average of 2016 and 2017 emissions reported on 2017 and 2018 APENs submitted to the Division.

Table 2: GCC Permitted and Average Annual Emissions

Point	Permitted PM_{10} (TPY)	Actual PM_{10} (TPY)	Permitted SO_2 (TPY)	Actual SO_2 (TPY)	Permitted NO_x (TPY)	Actual NO_x (TPY)
039 *	36.01 (F) 293.56 (C)	11.3 (F) 99.0 (C)	943.4	*1.1*	1,100.0	915.2
040 **	33.92	27.9	*N/A*	*N/A*	*N/A*	*N/A*
069	*N/A*	*0.8*	*6.3*	*5.2*	*19.3*	*5.9*

*The kiln PM limit marked with (F) is for filterable emissions and the PM limit marked with (C) is condensable emissions. GCC is the only Colorado cement kiln with a limit on condensable particulate matter.

**The clinker cooler only emits particulates, thus there are no SO_2 or NO_x permit limits or actual emissions.

As shown in Table 2, the actual NO_x, PM_{10}, and SO_2 emissions for the Quarry Crusher Engine (069) are below the 10 TPY threshold, and the engine will not be evaluated further. The actual SO_2 emissions for the Kiln (039) are below 10 TPY, so this pollutant will not be analyzed for the kiln. This analysis will focus on PM_{10} and NO_x emissions for the Kiln (039) and PM_{10} emissions for the Clinker Cooler (040). The kiln is the primary source of visibility impairing pollutants including NO_x and PM_{10}. The clinker cooler is another significant source of PM_{10} emissions.

II. Source Controls

Kiln (AIRS 039)

The GCC Pueblo kiln fires primarily low sulfur, high BTU coal from mines in Colorado. Coal specifications for 2018 are listed in Table 3. The kiln is also permitted to fires natural gas, tire-derived fuel (TDF), and many alternative, non-hazardous waste fuels. However, the kiln only uses natural gas for startup and primarily fires coal. When available, the kiln is fired with coal combined and some TDF which can reduce NO_x emissions. The kiln is permitted to fire a maximum of 198,418 TPY of fuel (coal and TDF). There is a facility-wide limit of 381,373 MMBtu/yr of natural gas which is used for the finish mill heater and for kiln startup. APENs submitted for the kiln do not provide an exact heat content for the natural gas, but designate it as pipeline natural gas, which typically has a heat content around 1,020 MMBtu/MMscf. The APEN also does not list the sulfur content of the natural gas, but pipeline natural gas is extremely low in sulfur.

Table 3: Coal Specifications (2018 APEN)

	Fuel Heating Value (Btu/lb)	Sulfur (% by weight)	Ash (% by weight)
Kiln	8,000-12,500	0.65	18

Table 4 depicts technical information for the GCC Pueblo kiln.

Table 4: Pueblo Kiln RP-eligible Emission Controls and Reduction (%)

	Portland Cement Kiln

Placed in Service	2008
Description	Preheater/precalciner kiln with 5-stage, single string preheater
Air Pollution Control Equipment	SO_2 -Inherent Scrubbing of the Cement Process in the Kiln and the In-line Raw Mill PM/PM_{10} - 2 Baghouses (Main Kiln, Coal Mill) NO_x - Selective Non-Catalytic Reduction
Emissions Reduction (%)	SO_2 - 99.99% * PM / PM_{10} - 99.99% / 99.99% ** NO_x - 53.6% ***

*SO_2 reductions based on actual SO_2 emissions measured by CEMS and input sulfur content. The sulfur input to the kiln is estimated as (Annual tons coal * Weight fraction of sulfur in coal) + (Annual tons of raw meal * Weight fraction of sulfur in raw meal).
**PM/PM_{10} reductions based on stack tests.
***NO_x reductions are based on the uncontrolled AP-42 emission factor for a preheater/precalciner kiln (4.2 lb/ton of clinker) compared to the 2016-2018 average 30-day emission rate (1.95 lb/ton of clinker). The Pueblo kiln was built with an SNCR, so the Division cannot compare pre-control and post-control emissions.

The source has not announced a closure date for the kiln, so the Division will assume a remaining useful life of 20 years for any control cost analysis.

Clinker Cooler (AIRS 040)

The clinker cooler employs a baghouse to control particulate emissions. Baghouses are typically a top-tier control for PM.

III. Reasonable Progress Evaluation of GCC Pueblo plant

a. SO_2

SO_2 emissions for the Kiln (039) are below the 10 TPY de minimis threshold and thus were not evaluated for SO_2 controls.

b. Filterable Particulate Matter (PM10)

Step 1: Identify All Available Technologies

Kiln (AIRS 039)

Filterable and condensable PM_{10} emissions from the kiln are greater than the 10 TPY threshold. As noted earlier, the GCC Pueblo kiln is the newest unit in Colorado and the only kiln with a condensable PM_{10} limit. Filterable PM emissions are solid and liquid particles at stack conditions and are typically controlled with fabric filter baghouses or electrostatic precipitators (ESPs). Filterable PM emissions can be measured using EPA reference methods that capture by the particulate matter in the filter segment of a sampling train. Over 99.9% of these filterable emissions are captured by the existing fabric filter baghouse. Electrostatic precipitators are the primary alternative for reducing filterable PM and can achieve over 99.9% control efficiency on some sources. However, the high resistivity of cement kiln dust makes them less effective than baghouses for controlling PM emissions from Portland cement kilns.[1]

Condensable PM emissions are vapors at stack conditions, but quickly condense after exiting the stack. The condensable emissions consist of organics (VOCs) and inorganics (primarily ammonium salts). The 2012 permit modification request from GCC states that the organic content in the raw materials is less than 1% and the volatile content of the coal is also low, which suggests that most of the condensable PM emissions from the kiln are inorganic ammonium salts. These inorganic ammonium salts form when excess ammonia from the SNCR, known as ammonia slip, reacts with chlorides and sulfates from the raw materials and coal. The most effective control methods for condensable PM emissions are limiting the available supply of ammonia, chlorides, sulfates, and other compounds that can form PM. Reducing ammonia slip limits the available ammonia to form these salts. The chloride content of the raw materials is limited to avoid alkali chloride deposits building up in the kiln preheater and chloride levels are typically low in coal. Firing low sulfur coal reduces sulfur input to the kiln, but most SO_2 emissions result from pyrite and other sulfur contaminants in the limestone, which vary depending on the limestone source. The cement production process is very effective at scrubbing SO_2 unless high pyrite levels limit this inherent scrubbing process. Since the GCC Pueblo kiln has very low SO_2 emissions without the use of a scrubber, the Division concludes that the raw materials have very low pyrite levels. Therefore, the most effective way to minimize condensable PM emissions is to limit ammonia slip. The in-line raw mill not only provides raw materials for the kiln, it also acts as a scrubber to further reduce ammonia emissions. When the raw mill is operating, GCC operates the SNCR to comply with the NO_x permit limit. The raw mill operates continuously when the kiln is operating, except for downtime associated with the maintenance or malfunctions of the mill. If the raw mill is shut down for maintenance or due to a malfunction, the SNCR stops injecting ammonia into the kiln to avoid a spike in ammonia emissions that could lead to a visible plume that exceeds the opacity limit for the kiln.

The baghouse on the GCC Pueblo kiln is a top tier control for filterable PM emissions, and the facility effectively minimizes condensable PM emissions by limiting ammonia slip from the SNCR and using fuel and raw materials with low sulfate and chloride levels. The Division has not identified any additional controls or work practices that would improve upon the existing filterable and condensable PM controls.

Clinker Cooler (AIRS 040)

The clinker cooler uses fans to circulate cool, ambient air over the hot clinker exiting the kiln. As the ambient air absorbs heat it becomes hotter and this hot air is returned to the kiln which improves the kiln's energy efficiency by reducing the amount of fuel that needs to be fired to heat the kiln. Cooler air from later stages of the clinker cooler passes through a baghouse for PM control before exiting a separate stack. GCC reports emissions based on the results of a stack tests which are below a BACT limit of 0.01 gr/dscf (grains per dry standard cubic foot). GCC reports PM control efficiency of 99.99% on its APEN submittals to the Division, which is in line with baghouse control efficiencies for other processes. EPA notes that clinker cooler are typically controlled using fabric filter baghouses, though it provides emission factors for other potential controls such as Electrostatic Precipitators (ESPs).[2] Although ESPs may provide similar control efficiencies to baghouses, ESPs often require

[1] North Carolina DEQ. "Carolinas Cement Company: Control Technology Analysis." Page 10 of 102. April 2008.

[2] EPA. AP-42 Emission Factor for Portland Cement Manufacturing, pages 7 and 14. January 1995.

shutdowns for maintenance, whereas baghouses can be maintained while the cooler is operating. Because the existing baghouse achieves high control efficiency and can be maintained during operation, the Division has determined that the GCC Pueblo clinker cooler already has top tier PM controls and no new particulate control measures have been identified that would significantly upon the existing fabric filter baghouse.

Step 2: Eliminate Technically Infeasible Options

Kiln (AIRS 039)

The Division has determined that the currently operating PM/PM_{10} controls on the kiln perform better than any of the identified control technologies. Therefore, there are no remaining technically feasible options other than the existing controls in operation for the GCC Pueblo kiln.

Clinker Cooler (AIRS 040)

The Division has determined that the currently operating PM/PM_{10} controls on the clinker cooler perform better than any of the identified control technologies. Therefore, there are no remaining technically feasible options other than the existing controls in operation for the GCC Pueblo clinker cooler.

Step 3: Evaluate Control Effectiveness of Each Remaining Technology

Kiln (AIRS 039)

Filterable PM_{10} emissions from the GCC kiln are reported based on a baghouse loading factor, but stack testing indicates that actual filterable emissions are much lower than the estimates based on the baghouse loading factor. Condensable PM_{10} emissions are reported based on emission factors determined through stack testing and approved by the Division. GCC reports the baghouses achieve 99.99% control efficiency on the APENs submitted to the Division, and the Division has not identified other control options with higher control efficiencies.

Clinker Cooler (AIRS 040)

Filterable PM_{10} emissions from the GCC clinker cooler are reported based on a baghouse loading factor, but stack testing indicates that actual filterable emissions are much lower than the estimates based on the baghouse loading factor. GCC reports the baghouses achieve 99.99% control efficiency on the APENs submitted to the Division, and the Division has not identified other control options with higher control efficiencies.

Step 4: Evaluate Factors and Present Determination

Factor 1: Cost of Compliance

Kiln (AIRS 039)

There are no associated costs of compliance since no options other than continuing to operate the existing PM controls on the kiln are considered technically feasible.

Clinker Cooler (AIRS 040)

There are no associated costs of compliance since no options other than continuing to operate the existing PM controls on the clinker cooler are considered technically feasible.

Factor 2: Time Necessary for Compliance

Kiln (AIRS 039)

There is no additional time required for compliance since no options other than continuing to operate the existing PM controls on the kiln are considered technically feasible.

Clinker Cooler (AIRS 040)

There is no additional time required for compliance since no options other than continuing to operate the existing PM controls on the clinker cooler are considered technically feasible

Factor 3: Energy and Non-Air Quality Impacts

Kiln (AIRS 039)

There are no specific energy and non-air quality impacts associated with the continued operation of the particulate controls on the kiln.

Clinker Cooler (AIRS 040)

There are no specific energy and non-air quality impacts associated with the continued operation of the particulate controls on the clinker cooler.

Factor 4: Remaining Useful Life

Kiln (AIRS 039)

GCC has not announced a closure date for the Pueblo kiln or its associated limestone quarry. Therefore, the Division assumes that the kiln will remain in operation for at least 20 years. Because no additional control options are considered technically feasible, remaining useful life does not impact cost estimates for additional controls.

Clinker Cooler (AIRS 040)

GCC has not announced a closure date for the Pueblo kiln or its associated limestone quarry. Therefore, the Division assumes that the clinker cooler will remain in operation for at least 20 years. Because no additional control options are considered technically feasible, remaining useful life does not impact cost estimates for additional controls.

Determinations

Kiln (AIRS 039)

Based upon its consideration of the four factors summarized herein and detailed in Appendix C, the Division recommends that RP for PM_{10} is the following:

1) The following existing PM_{10} emission limits shall remain in effect for this planning period:
   Kiln: 36.01 TPY (filterable, 12-month rolling average)
   293.56 TPY (condensable, 12-month rolling average)

The state assumes that the RP emission limits can be achieved through continued operation and maintenance of the existing fabric filter baghouse, good combustion practices, and good operation of the SNCR to minimize NO_x and excess ammonia emissions. The Division has determined that these limits are achievable without additional capital investment through the four-factor analysis.

Clinker Cooler (AIRS 040)

Based upon its consideration of the four factors summarized herein and detailed in Appendix C, the Division recommends that RP for PM_{10} is the following:

1) The following existing PM_{10} emission limit shall remain in effect for this planning period:
   Clinker Cooler: 33.92 TPY (12-month rolling average)

The state assumes that the RP emission limits can be achieved through continued operation and maintenance of the existing fabric filter baghouse. The Division has determined that this limit is achievable without additional capital investment through the four-factor analysis.

c. Nitrogen Oxides (NO_x)
Step 1: Identify All Available Technologies

Kiln (AIRS 039)

As noted earlier, the GCC Pueblo facility was not evaluated during the first round of Regional Haze because it had undergone a pre-construction PSD review and was recently constructed with many technologies to reduce NO_x including: an energy efficient multi-stage preheater, low-NO_x calciner, low-NO_x Burners (LNBs) with indirect firing, staged combustion (SCC), and a Selective Non-Catalytic Reduction (SNCR) unit. Table 5 shows the current limits and actual emissions for the 2016-2018 baseline period. As shown, the kiln is in compliance with the 12-month total and lb/ton of clinker limits. As shown in Table 4, the GCC Pueblo kiln achieves approximately 53.6% lower NO_x emissions than a baseline uncontrolled preheater/precalciner kiln using the NO_x controls listed above, as well as firing tire-derived fuel (TDF), when available. Unlike the CEMEX Lyons and Holcim Florence kilns, the GCC Pueblo kiln does not currently have a 30-day rolling average NO_x limit. The Division will discuss potential emission limit changes later in this analysis.

Table 5: Kiln Limits vs. Actual Emissions

	Limit	2016-2018 Actual Average [Min - Max]
12-Month Rolling Total (TPY)	1,100.0	915.18 [816.6 - 996.7]
12-Month Rolling Average (lb/ton of clinker)	2.32	1.97 [1.82 - 2.11]
30-day Rolling Average (lb/ton of clinker)	N/A	1.95 [1.61 - 2.70]

The Division reviewed EPA's RACT/BACT/LAER Clearinghouse (RBLC) for similar Portland cement kilns for the most recent 20 years and the EPA Menu of Control Measures for additional or improved potential control options. Most of the recently permitted kilns are multi-stage preheater/precalciner designs that are comparable to the GCC Pueblo kiln. However, cement kiln emissions are highly dependent on fuel and raw material composition, in addition to the general kiln design. The RBLC determinations provide an indication of the achievable emission rates at Portland cement kilns that are subject to the latest NSPS. Based on the startup date for the GCC Pueblo kiln, it is not subject to the NSPS limit of 1.50 lb/ton of clinker. The lowest emission permitted emission rate listed in the RBLC was the Universal Cement Plant in Illinois which was permitted in 2010 at 1.2 lb/ton of clinker. Illinois EPA deemed this to meet LAER and was achievable using a combination of staged combustion and SNCR. This facility was never constructed. The CEMEX North Brooksville Kiln 3 was permitted in 2007 at 1.5 lb/ton of clinker with SNCR or SCR or a combination of these two. The permit was withdrawn and this kiln was never constructed. Other determinations range from 1.5 lb/ton to 2.65 lb/ton of clinker and utilize SNCR, often combined with indirect firing, low-NOx burners, and staged combustion, all of which are utilized in the GCC Pueblo kiln.

The following kiln NO_x controls were considered, if technically feasible, for this planning period:

- -Fuel Substitution - Firing Tire-Derived Fuel (TDF)
- -Selective Non-Catalytic Reduction + Low- NO_X Burners (SNCR + LNB)
- -Staged and Controlled Combustion (SCC)
- -Selective Catalytic Reduction (SCR)

Step 2: Eliminate Technically Infeasible Options

Kiln (AIRS 039)

Fuel Substitution: Fuel substitution for Portland cement kilns involves firing a combination of fossil fuels and alternative fuels, such as non-hazardous waste and tire-derived fuel (TDF). In principal, converting a cement kiln to full natural gas combustion would significantly reduce SO_2 and PM_{10} emissions, but would not significantly reduce NO_X emissions.[3] However, a natural gas flame in the main kiln burner may not sufficiently dissipate heat which can reduce clinker production and may require raw meal reformulation to maintain product quality.[4] The lower heat transfer of a natural gas flame in the main kiln can also lead to higher temperatures that increase thermal NO_x production.[5] Although few kilns use natural gas as the primary fuel, many kilns, including the GCC Pueblo facility, fire natural gas at startup to minimize emissions while heating up the kiln. Discussions with other Colorado kiln operators confirmed that operating a kiln entirely on natural gas may require extensive modifications to the kiln design and controls and result in lower production capacity. When used correctly, alternatives fuels with high energy content (Btu/lb), such as TDF, can help safely dispose of waste tires and reduce NO_x emissions from the kiln. However, the kiln operator needs to maintain proper combustion conditions to avoid emissions increases from firing TDF. GCC is currently firing the kiln with low sulfur coal, as indicated in Table 3, natural gas for startup, and TDF, when available.

In 2002, CEMEX conducted a stack test with the long-dry kiln firing a combination of coal and TDF. The stack tests on this long-dry kiln suggested 24.4% reductions in NO_X emissions from firing TDF without exceeding the standards for any other criteria pollutants or hazardous air pollutants.[6] However, the reductions are highly kiln dependent and also dependent on the fuel being replaced. Simulations for fuel switching at Lafarge's Brookfield cement plant in Nova Scotia indicated that switching from a 100% blend of high sulfur coal and pet coke (50-50 blend, 3.5% overall weight % sulfur) to 30% TDF and 70% coal/pet coke blend would reduce fuel NO_x by 23%.[7] In contrast, EPA expects that firing TDF can reduce NO_x emissions by 33% on average, but in rare cases kilns may see NO_x increases around 20% as well as increases of other criteria pollutants. Overall, the Division expects that firing TDF can reduce NO_x emissions.

GCC is already permitted to fire TDF and utilizes the fuel when available. Colorado has the largest waste tire piles, known as monofills, in the country and combusting them at high heat

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[3] EPA. "Alternative Control Techniques Document Update - NOx Emissions from New Cement Kilns." Page 44 of 129. November 2007.

[4] IEEE Cement Industry Technical Conference. "From coal to natural gas: Its impact on kiln production, Clinker quality and emissions." 2013.

[5] EPA. "Alternative Control Techniques Document Update - NO_x Emissions from New Cement Kilns" November 2007.

[6] BART Analysis for CEMEX Lyons Cement Plant. Page 21

[7] Dalhousie University. "Use of scrap tires as an alternative fuel source at the Lafarge cement kiln, Brookfield, Nova Scotia, Canada" Page 23. July 21, 2015.

in a cement kiln not only reduces NO_x emissions from the kiln, it can also reduce the likelihood of large uncontrolled, monofill fires that release thick black clouds of smoke due to poor combustion conditions.[8] In order to use these tires on a consistent basis, cement manufacturers need a nearby monofill and may require government incentives to cover the cost of shredding the tires and transporting them to the facility, especially if the monofill is far from the cement plant. In recent years, GCC has struggled to identify a large, consistent supply of tires near the Pueblo area, and funding for Colorado's waste tire program has varied from year to year. Due to these issues, the Division considers it infeasible to mandate a minimum amount of annual TDF usage considering that GG is already permitted to use a significant amount of TDF as fuel. As more TDF becomes available, GCC will use more TDF. Therefore, a limit requiring a certain amount of TDF is not necessary. The Division will continue to work with GCC to evaluate the facility's future use of TDF and look for opportunities to reduce kiln emissions and Colorado's large stockpile of waste tires. Since TDF usage is currently permitted and utilized, when available, the Division will not analyze this option further.

SNCR: Fuel substitution, which is discussed above, affects the combustion process, while SNCR and SCR are post-combustion controls that treat the combustion products. Both controls inject an ammonia or urea reagent into the flue gas to convert NO_x to molecular nitrogen (N_2). These reactions require higher temperatures in an SNCR (1,600 to 2,000°F), compared to SCR (450 to 800°F), and provided lower control efficiency. SNCR systems typically have lower capital costs than an SCR, but the operating costs are higher due to high reagent use. SNCR design requirements and performance are discussed in more detail below.

$$4\ NO + 4\ NH_3 + O_2 \rightarrow 4\ N_2 + 6\ H_2O$$
$$2\ NO_2 + 4\ NH_3 + O_2 \rightarrow 3\ N_2 + 6\ H_2O$$

Above this temperature range, the NH_3 is oxidized to NO_x, thereby increasing NO_x emissions. Below this temperature range, the reaction rate is too slow for completion and unreacted NH_3 may be emitted from the pyroprocess. This temperature window generally is available at some location within rotary kiln systems. The NH_3 could be delivered to the kiln system through the use of anhydrous NH_3, or an aqueous solution of ammonium hydroxide [NH_3(aq)]or urea [$CO(NH_2)_2$]. A concern about application of SNCR technology is the breakthrough of unreacted NH_3 as "ammonia slip" and its subsequent reaction in the atmosphere with SO_2, sulfur trioxide (SO_3), hydrogen chloride (HCl) and/or chlorine (Cl_2) to form a detached plume of PM_{10}-$PM_{2.5}$. In addition to reacting with SO_x and chloride emissions from the kiln, the unreacted ammonia could react with NO_x or SO_x from other sources to form visibility impairing ammonium nitrate or ammonium sulfate, respectively. As discussed earlier, the in-line raw mill at the GCC Pueblo kiln is an important part of the emission control system that helps minimize unreacted ammonia emissions and the raw mill is operating when the kiln is operating, except for planned weekly mill maintenance and unexpected mill malfunctions.

The existing NO_x controls on the GCC Pueblo kiln, which include an SNCR, currently achieve average annual NO_x emissions of 1.97 lb/ton of clinker, which represents a 53% reduction in NO_x emissions, compared to an uncontrolled preheater/precalciner kiln. This agrees with EPA's SNCR performance data which indicates that the technology can achieve NO_x reductions

[8] Booth, Michael. "Colorado's tire dumps were supposed to be gone by now. They grew instead." Colorado Sun. January 19, 2021.

of 20 - 90%, with 50% as a reasonable long-term reduction.[9] It's important to note that achieving high NO_x (>60%) control efficiencies with an SNCR often results in high ammonia slip, as discussed in EPA's ACT for NO_x emissions from cement kilns.[10] As explained in the PM section above, ammonia slip from the SNCR can react with chlorides and sulfates from the raw materials and coal to form condensable PM emissions. In order to minimize both NO_x and condensable PM emissions, the SNCR is operated to limit excess ammonia injection and the in-line raw mill acts as a scrubber to further reduce ammonia emissions, when the mill is operating. If the raw mill is shut down for maintenance or due to a malfunction, the SNCR temporarily stops to avoid a spike in ammonia emissions that could lead to a visible plume that exceeds the opacity limit for the kiln. When the raw mill is restarted, the SNCR operates at higher ammonia injection rates to compensate for the higher NO_x emissions during the raw mill downtime, and to comply with the 1,100 TPY and 2.32 lb/ton of clinker limits. As discussed earlier, the SNCR on the GCC Pueblo kiln operates around 95% of the hours in a week, but is permitted on an "as-needed" basis to allow for the 8-hour weekly maintenance of the in-line raw mill. The kiln was initially permitted with a minimum required uptime for the SNCR, but modeling indicated that the increased ammonia emissions from the kiln would require a higher condensable PM limit. The permit was revised to reflect the "as-needed" SNCR operation to avoid a large increase in PM emissions for a limited reduction in NOx emissions. The Division still believes that requiring GCC Pueblo to operate the SNCR on a continuous basis without an allowance for maintenance of the in-line raw mill would increase ammonia slip and visibility-impairing condensable PM emissions. Given that the GCC Pueblo plant is located in an ozone attainment area and less than 10 miles from the populated Pueblo community, the Division does not believe the potential NO_x reduction is a valid trade-off for likely increases in ammonia emissions. Therefore, it is not recommending a change to continuous SNCR operations.

The Division and GCC have not identified any potential upgrades to the existing SNCR that would significantly improve its performance. The Division will continue to monitor the long-term performance of the SNCR and will work with GCC to ensure that the kiln achieves the maximum NO_x control at a reasonable cost without significant increases in PM or other emissions. SNCR changes will not be analyzed in further detail.

SNCR + LNB: Low-NO_x burners (LNB) are designed to create a multi-stage combustion process with less excess oxygen. LNBs create a fuel-rich primary combustion zone where the low oxygen levels result molecular nitrogen (N_2) formation, rather than NO_x, from nitrogen in the combustion air and fuel-bound nitrogen. The GCC kiln currently employs low-NO_x burners with the SNCR discussed above to achieve 53% NO_x reductions. The Division has not identified additional upgrades to the existing LNBs that would achieve additional NO_x reductions.

SCR: SCR systems are the most widely used post-combustion NO_x control technology for coal-fired and natural gas-fired boilers. However, the technology has seen very little use at US cement kilns. In SCR systems, vaporized ammonia (NH_3) injected into the flue gas stream acts as a reducing agent when passed over an appropriate amount of catalyst. The NO_x and ammonia react to form nitrogen and water vapor, as described in the equations in the SNCR section. The principal is similar to SNCR, which is currently installed at the GCC Pueblo kiln, but the SCR catalyst reduces the required flue gas temperature necessary for the NO_x

[9] EPA. National Emissions Standard for Hazardous Air Pollutants from the Portland Cement Manufacturing Industry - Cost Environmental Impact Data. August 6, 2010.
[10] EPA. "Alternative Control Techniques Document Update - NOx Emissions from New Cement Kilns." Page 17 of 129. November 2007.

reducing reaction. An optimized SCR design will provide the maximum level of NO_x reduction while maintaining low ammonia slip that could harm health and impair visibility. Detached plumes are possible with SCR, but less common than with SNCR.

EPA's ACT for NO_x emissions from cement kilns discusses SCR control for cement kilns. The document notes the SCR operating range depends on the catalyst material, and can range from 450°F to 800°F for base metal catalysts, to over 1,100°F for precious metal catalysts, though these are typically much more expensive. There are numerous challenges to operating an SCR on a cement kiln, including plugging and erosion of the catalyst caused by the high dust produced in the kiln. According to Benson[11], alkali and alkaline-earth rich oxides (sodium, magnesium, calcium and potassium) have strong influence on catalyst deactivation (*See also* Nicosia *et al.*, 2008, and Strege *et al.*, 2008). Calcium, in the form of limestone, is a staple of cement production, though sodium, potassium, and magnesium levels are tightly controlled in the raw meal to prevent swelling or cracking of the concrete. Also, alkalies and sulfur can potentially poison the catalyst.[12] The low levels of sulfur in the raw materials and inherent sulfur control of the cement process significantly reduces sulfur levels, but alkali levels could potentially impact the catalyst.

The two biggest remaining concerns for a potential SCR system at the GCC Pueblo facility are dust and site-specific design requirements. SCR systems can often be installed on coal-fired boilers in a "high dust" configuration, upstream of the particulate control device. However, this may not be feasible for cement kilns, including the GCC Pueblo kiln, due to the potential for catalyst plugging and erosion caused by the very high dust levels in a kiln. Therefore, the SCR would need to be installed in a "low dust" configuration, downstream of the baghouse. Unfortunately, the post-baghouse flue gas temperature has dropped below the ideal range for SCR operation and it would require reheating with a duct burner or heat exchanger using natural gas or coal. This reheating increases upfront capital costs for the system, ongoing operating and maintenance costs for fuel and burner/heat exchanger maintenance, and results in additional NO_x emissions that increase inlet NO_x levels to the SCR system. Lastly, at the time of the BART analysis, three cement kilns in Europe had installed SCR systems. Two were newer preheater kilns and the third was a smaller, traveling grate kiln. Although these kilns could achieve 80-90% NO_x reductions, it was unclear how well these results would translate to US cement kilns. As noted in the CEMEX BART analysis, the technology transfer of SCR systems from the power plant industry to the Portland cement industry requires substantial research and pilot testing before the technology could be considered commercially available.[13] A search of the RBLC indicates that the CEMEX North Brooksville Kiln #3 selected SNCR, SCR, or a combination of the two technologies to meet BACT for NO_x control. However, this permit was withdrawn, and this kiln was never constructed. Due to a lack of any commercially available SCR units on US cement kilns, the Division concluded that SCR was not technically feasible for retrofit on existing cement kilns at that time.

Since the CEMEX BART analysis was conducted, there has been a single US cement kiln, the Lafarge Joppa Kiln 1 in Illinois that installed an SCR for NO_x Control. Joppa Kiln 1 is a long dry kiln with LNB and a hot electrostatic precipitator (ESP) for PM control. The SCR is installed downstream of the ESP in a "low dust" arrangement. This SCR was required as part of 2010

[11] Benson, S. *et al.* "SCR catalyst performance in flue gases derived from subbituminous and lignite coals, Fuel Processing Technology, Vol. 86" (2005).
[12] Strege, J. et al., "SCR deactivation in a full-scale co-fired utility boiler, Fuel 87" (2008)
[13] Schreiber, R, *et al* "Evaluation of Suitability of Selective Catalytic Reduction and Selective Non-Catalytic Reduction for use in Portland Cement Industry", (2006)

consent decree (CD) with Lafarge that covered kilns at 13 facilities in 13 states.[14] Joppa Kiln 1 was the only kiln required to install an SCR. Lafarge was required to conduct a 12-month optimization study to determine the kiln's emission limit. The emission limit was ultimately set at 3.21 lb/ton of clinker using the formula prescribed in the consent decree: Limit = $\mu + 1.645*\sigma$, where μ is the mean of the 30-day rolling averages during the 12-month optimization period and σ is the standard deviation of the 30-day rolling averages. According to the Final Demonstration Report for the SCR, the mean was 1.99 lb/ton of clinker and the standard deviation was 0.75 lb/ton of clinker, resulting in an 80% reduction in NO_x compared to the baseline levels.[15] The average 30-day emission rate from Joppa Kiln 1 (1.99 lb/ton of clinker) using LNB + SCR is slightly higher than the current emissions from GCC Pueblo (1.95 lb/ton of clinker) with LNB + SNCR. Also, the NO_x emissions from Joppa Kiln 1 have much greater variability, as indicated by the standard deviation of 0.75 lb/ton of clinker, which is about 3.5 times larger than GCC Pueblo's standard deviation of 0.21 lb/ton of clinker. In addition, cost information for the Joppa SCR is not publicly available, so it's not possible to compare the cost effectiveness to the existing SNCR at GCC Pueblo.

Since the Joppa consent decree in January 2011, EPA has issued nine consent decrees against cement manufacturers, as shown in Table 6 below. This includes the CEMEX Lyons facility in Colorado. All of the facilities were required to install an SNCR to comply with NO_x limits, except for Essroc Logansport Kiln 1 and Kiln 2 in Indiana, which are both long wet kilns that are not comparable to GCC Pueblo. Both Logansport kilns were required to conduct 4-month SCR pilot studies.[16] If the pilots were deemed successful, the kilns would operate the SCR going forward based on a NO_x limit established during the pilot studies. If the studies were deemed unsuccessful, the kilns would install SNCR with a NO_x limit determined by EPA. "Success" for the SCR pilot studies included reducing NO_x by at least 80% while maintaining ammonia slip below 10 ppm without negatively impacting product quality or kiln reliability. Essroc completed these SCR studies and submitted the report to EPA, but EPA rejected them. Essroc filed for dispute resolution and, as a result, EPA required Essroc to run a second SCR study and submit the performance reports to EPA. Prior to the start of the second SCR study, EPA required Logansport Kiln 1 and Kiln 2 to establish tighter emission limits, but neither kiln was required to permanently install an SCR. Ultimately, EPA, Essroc, and the State of Indiana required Logansport Kiln 2 to install a water injection system with a NO_x limit of 4.75 lb/ton of clinker, on a 30-day rolling average. Logansport Kiln 1 was required to install a water injection system and an SNCR, and conduct a study to establish a NO_x emission limit that is no less stringent than 4.75 lb/ton of clinker. The Division was unable to obtain a copy of either the initial or second SCR pilot studies, but has concluded that neither Kiln 1 nor Kiln 2 is currently operating an SCR. This leaves the Joppa kiln as the only US cement kiln still operating an SCR for NO_x control. Table 9 demonstrates that the limit of 1.85 lb/ton of clinker imposed by the CEMEX Lyons consent decree matched the lowest emission limit set by consent decree up to April 2013. Although GCC's annual limit of 2.32 lb/ton of clinker is higher than CEMEX's limit, the current requirements for the facilities are very different: the GCC Pueblo facility is located in an attainment area whereas CEMEX is an ozone nonattainment area, GCC's SNCR was installed for BACT not due to a consent decree, and CEMEX is not subject to condensable PM or ammonia slip limits, both of which allows CEMEX to operate at higher ammonia injection rates to achieve greater control efficiency. Other than the Lafarge Joppa kiln 1 in Illinois, no US cement kilns have installed and continue to

[14] EPA. Consent Decree: Lafarge North America, Inc, Lafarge Midwest, Inc, and Lafarge Building Materials, Inc. January 2010.
[15] LAFARGE - U.S. EPA Consent Decree Final Demonstration Report, Joppa Kiln 1. April 2015.
[16] EPA. Consent Decree: Essroc Cement Corp. December 2011.

operate an SCR for NO_x control based on a consent decree. As discussed earlier, the Joppa kiln has a much higher emission limit and more NO_x emission variability than nearly all recent consent decrees, including GCC Pueblo. All of the other consent decree limits are based on SNCR controls, as shown in Table 6.

Table 6: EPA Cement Manufacturer Consent Decrees after January 2010

Company Name	CD Date	# of Facilities Included in CD	# of Kilns Included in CD	NOx Limit (Control Tech)
CEMEX Fairborn	Feb 2011	1	1	1.85 lb/ton (SNCR)
CalPortland	Dec 2011	1	1	2.5 lb/ton (SNCR)
Essroc (now Lehigh Cement)	Dec 2011	6	9	1.85 - 4.75 lb/ton (SNCR) *
CEMEX Lyons	Apr 2013	1	1	1.85 lb/ton (SNCR)
Ash Grove	June 2013	9	13	1.5 - 8 lb/ton (SNCR)
Holcim/ St. Lawrence	July 2013	1	1	1.8 lb/ton (SNCR)
CEMEX	July 2016	5	7	1.5 - 5.3 lb/ton (SNCR)
Lonestar/Buzzi	Aug 2016	1	1	1.5 - 2.9 lb/ton (SNCR) **
Lehigh	Dec 2019	11	14	1.5 - 8.2 lb/ton (SNCR)

* Essroc Logansport was required to conduct SCR pilot studies on Kilns 1 and 2. The pilot study reports were rejected by EPA and the source and EPA ultimately agreed to install water injection on both kilns. Kiln 1 was also required to install an SNCR. Both kilns have limits of 4.75 lb/ton of clinker.

** The two emission rates at the Lonestar facility are for firing waste (1.5 lb/ton) and not firing waste (2.9 lb/ton).

The Division also reviewed the RBLC to look for instances where SCR has been approved. As discussed earlier, the CEMEX North Brooksville Kiln 3 in Florida was permitted in 2007 with SNCR, SCR, or a combination of the two, but the permit was withdrawn and the kiln was never built. The only LAER determination listed in the RBLC was the Universal Cement plant in Illinois that was permitted at 1.2 lb/ton of clinker using staged combustion and SNCR, not SCR. LAER determinations seek the lowest achievable emission rate without consideration of cost, a more stringent standard than the BACT determination for GCC Pueblo, and SCR has not been selected as LAER for NO_x emissions from cement kilns. Under Regional Haze, states must consider cost of compliance when evaluating potential controls and the Division believes it is inappropriate to recommend essentially unproven technologies beyond LAER under Regional Haze.

The only existing US cement kiln with an operating SCR for NO_x control, the Lafarge Joppa Kiln 1, has very little publicly available information, including costs. Based on the information available to the Division, this SCR is achieving 80% control efficiency, which is higher than the 53% control efficiency of the GCC Pueblo SNCR, but without additional cement kilns using SCR for NO_x control it is unclear whether the technology could consistently achieve 80% control efficiency at other facilities, such as GCC Pueblo. Although the Joppa Kiln 1 SCR must maintain an ammonia slip limit, it is not subject a condensable PM limit, which may allow for higher ammonia injection rates to achieve greater NO_x reductions. SNCR technology has also been chosen over SCR under recent consent decrees, BACT, and LAER determinations. Given the limited potential NO_x reductions, unknown cost, and lack of SCR installations on comparable preheater/precalciner kilns, the Division still considers SCR technology infeasible for cement kilns and it will not be analyzed further.

Staged and Controlled Combustion (SCC): EPA's ACT NO_x Emissions from New Cement Kilns also discusses staged and controlled combustion control (SCC) for cement kilns. The document explains SCC as follows:

> *SCC works by staging the introduction of fuel, combustion air, and feed material in a manner to minimize NOx formation and reduce NOx to nitrogen. NOx formed in the kiln's combustion zone is chemically reduced by maintaining a reducing atmosphere at the kiln feed end by firing fuel in this region. The reducing atmosphere is maintained in the calciner region by controlling combustion air such that the calcining fuel is first burned under reducing conditions to reduce NOx and then burned under oxidizing conditions to complete the combustion reaction. Controlling the introduction of raw meal allows for control of the calciner temperature. Through these mechanisms, both fuel NOx and thermal NOx are controlled. The combustion chamber allows for improved control over the introduction of tertiary air in the calciner region, which helps to promote the proper reducing environment for NOx control.*

SCC generally involves the staging of both air and fuel. Indirect firing is required for air staging, and LNB achieve one form of staged combustion. Both are employed at the GCC Pueblo kiln. The version of SCC discussed here combines indirect firing with LNB in the kiln with a combustion of a large portion of the fuel in a preheater/precalciner with a tertiary duct to return air from the clinker cooler to the preheater/precalciner. The Division has not identified additional upgrades to the staged combustion that would achieve additional NO_x reductions.

Step 3: Evaluate Control Effectiveness of Each Remaining Technology

Table 7 summarizes each available technology and technical feasibility for NO_x control on the GCC Pueblo kiln.

Table 7: GCC Pueblo Kiln - NO_x Technology Options and Technical Feasibility

Technology	Emission Control Efficiency (%)	Technically Feasible? (Y = yes, N = no)
Baseline - LNB + SNCR + SCC (53% Control)	N/A	Y - installed
Fuel Substitution - Firing TDF	20 - 30%	Y - in use when available
SCR	N/A	N

The Division did not identify any additional controls that can achieve additional NOx reductions.

Emission Limit Tightening: Although the Division did not identify any additional NO_x control measures, it also evaluated tightening emission limits for the GCC Pueblo kiln. GCC currently has a 12-month rolling average emission NO_x limit of 2.32 lb/ton of clinker. The CEMEX Lyons and Holcim Florence kilns are subject to 30-day Rolling Average NO_x limits, and the Division considers this shorter averaging period helps reduce emission variability, in line with the goals of the Regional Haze program. As discussed earlier, the Division has determined that setting a higher SNCR uptime requirement would likely increase in ammonia and condensable PM emissions over the city of Pueblo, which is not a reasonable trade-off for the potential NO_x reductions. Therefore, the 30-day emission limit should be based on 2016-2018 baseline emissions under the currently permitted "as-needed" SNCR operating requirement. As shown in Table 5, the 30-day rolling averages for the GCC Pueblo kiln range from 1.61 - 2.70 lb/ton of clinker. This range is much larger than the 12-month rolling averages which range from 1.82 - 2.11 lb/ton of clinker. To account for the emission variability from cement kilns, the Division set RP limits for the Holcim Florence cement kiln based on the 99th percentile of the 30-day rolling averages, during the first Regional Haze planning period. Using this same metric would result in a NO_x limit of 2.65 lb/ton of clinker for the GCC Pueblo kiln. This emission rate is less than 2% lower than the maximum 30-day rolling average of 2.70 lb/ton of clinker. The Division believes this slightly lower emission limit would not provide meaningful emission reductions. Therefore, the Division considers a 30-day rolling average limit of 2.70 lb/ton of clinker to be appropriate. Although this emission rate is higher than the current annual limit of 2.32 lb/ton of clinker, the Division believes this higher emission rate allows the facility to properly maintain the in-line raw mill which can help avoid large increase in condensable PM emissions. Additionally, without additional control options or a consistent supply of TDF, GCC would likely need to increase ammonia injection rates to achieve greater NO_x reductions. As discussed in the SNCR analysis above, higher ammonia injection rates can provide higher NOx control efficiency, but the side effect is that the increased ammonia slip can result in a detached plume of sulfate, chloride, or nitrate particulates that impair visibility. Thus, the Division recommends a 30-day NO_x limit of 2.70 lb/ton and retaining the annual limit of 1,100 TPY. The facility has recently completed upgrades to increase clinker production and as the facility reaches maximum clinker production, the kiln will need to decrease its 12-month rolling average NO_x emissions from 1.97 lb/ton of clinker to approximately 1.87 lb/ton of clinker to remain within the 1,100 TPY limit. The Division will continue working with GCC to identify opportunities to reduce NO_x emissions without leading to significant increases in other pollutants.

Step 4: Evaluate Factors and Present Determination

Factor 1: Cost of Compliance

There are no associated costs of compliance since no options other than continuing proper operation of the kiln and the existing LNB + SNCR units are considered technically feasible and cost effective.

Factor 2: Time Necessary for Compliance

There is no additional time required for compliance since no options other than continuing proper operation of the kiln and the existing LNB + SNCR units are considered technically feasible and cost effective.

Factor 3: Energy and Non-Air Quality Impacts

There are no additional energy and non-air quality impacts associated with the continued proper operation of the kiln and LNB+SNCR units on the GCC Pueblo kiln.

Factor 4: Remaining Useful Life

GCC has not announced a closure date for the Pueblo kiln or its associated limestone quarry. Therefore, the Division assumes that the kiln will remain in operation for at least 20 years.

Because no additional control options are considered technically feasible and cost effective, remaining useful life does not impact cost estimates for additional controls.

Determinations

Upgrades to the existing NO_x control system were evaluated, and the state has determined that meaningful upgrades to the system are not available. Because the kiln will remain in operation for 20 years or more, the Division also evaluated emission limit tightening. The kiln is currently subject to a 12-month rolling average lb/ton of clinker limit, whereas the CEMEX Lyons kiln and Holcim Florence kiln are subject to 30-day rolling average limits. The Division has determined that the existing 12-month rolling average limits are set an appropriate level, and a new 30-day rolling average limit is appropriate to reduce short-term emission variability. This new 30-day rolling average will ensure the facility continues operating the SNCR as much as practicable while allowing the facility to properly maintain the in-line raw mill, which limits excess ammonia emissions that could lead to excessive condensable PM emissions or visible plumes. These emission limits avoid trading a slight NO_x decrease for an increase in other pollutants.

Based upon its consideration of the four factors summarized herein and detailed in Appendix C, the Division recommends that NO_x RP is complying with the following emission rate and annual limits:

1) The following NO_x emission limits shall remain in effect for this planning period:

Kiln: 2.70 lb/ton of clinker (30-day rolling average)
2.32 lb/ton of clinker (12-month rolling average)
1,100.0 TPY (12-month rolling average)

The state assumes that the RP emission limits can be achieved through continued proper operation and maintenance of the kiln, including the LNB and SNCR controls. The Division has determined that these emission limits are achievable without additional capital investment through the four-factor analysis.

Appendix C

Tri-Mer Brochure

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All-in-One Solution

Tri-Mer Ceramic Catalyst Filter Systems are state-of-the art for removing particulate (PM), SO2, HCl, mercury and heavy metals. Simultaneously, the ceramic catalyst filters destroy NOx, cement organic HAPs, and dioxins. Systems can be configured for any combination of the pollutants.

The system is completely dry, with no water consumption. Disposal of the dry collected waste is straightforward. Large gas flow volumes can be accommodated.

Particulate Control

Tri-Mer Ceramic Catalyst Filters are excellent at removing all sizes of particulate from gas sources above 300˚F, including PM10, PM2.5, and submicron. Typical outlet levels are less than 0.001 grains/dscf (2.0 mg/Nm^3) regardless of inlet loading.

NOx Control

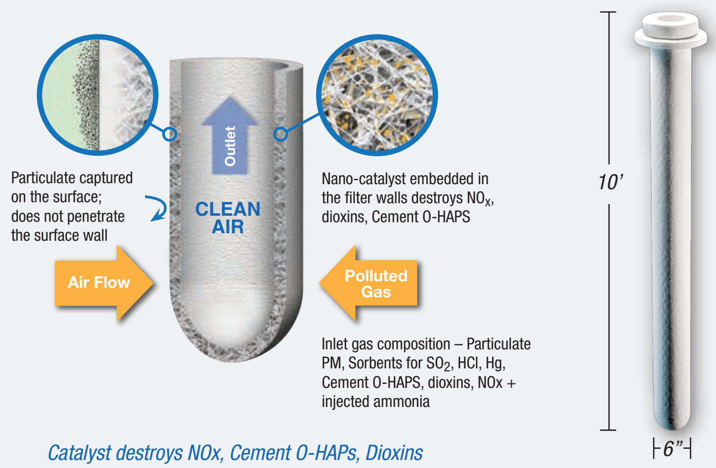
Catalytic filter tubes have nanobits of SCR catalyst embedded in the filter walls. Operating range is 350˚F to 950˚F. The exceptionally large reactive surface area of the micronized catalyst produces high NOx removal at temperatures notably lower than standard SCR. Good results start at 350˚F and improve to 95% removal at 450˚F and above (standard "big block" SCR requires 650˚F or higher for similar efficiency).

The unique structure of the filters captures process particulate on its outer surface, thus keeping it away from the nano-catalyst inside the filter walls. This prevents PM blinding and poisoning of the catalyst and greatly extends the catalyst life compared to standard SCR..

Cement O-HAPs and THC Control

Cement organic HAPS are also destroyed by the embedded catalyst. Good removal on the primary Cement O-HAPs occurs at temperatures over 400˚F, with excellent results on all Cement O-HAPS approaching 500˚F. Dioxins are also destroyed by the filters, typically with 95% efficiency or better at temperatures up to 500˚F.

Cut-away of Filter Tube with Embedded Nano-catalysts



Catalyst destroys NOx, Cement O-HAPs, Dioxins

SO2, HCl, Acid Gases, & Mercury Control

For dry scrubbing of acid gases, Tri-Mer filter systems use injection of hydrated lime or SBC upstream of the filters. Removal of SO2 is typically above 90% and HCl better than 97%. The approach for mercury depends on the Hg species in the gas. Activated carbon and other sorbents, some blended with the acid gas sorbents, are selected on a case-by-case basis.

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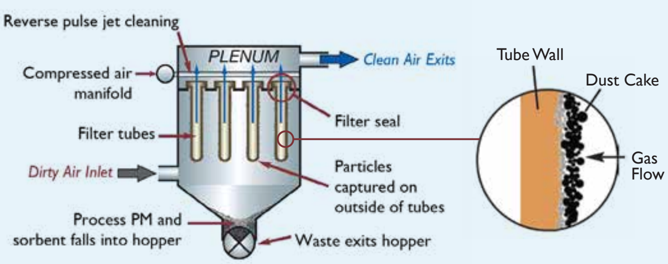
Boilers, Cement, Glass, Incinerators, Stationary Diesel

CERAMIC CATALYST Filter Systems

Controls PM, S02, HCI, Hg, NOx, Dioxins, Cement O-HAPs

Operation and Maintenance

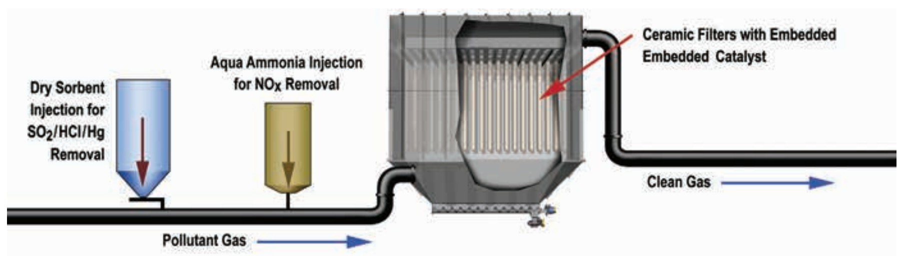
Tri-Mer's Ceramic Catalyst Filter System uses a baghouse configuration with a reverse pulse-jet cleaning action. The filters are back-flushed with air or inert gas. The design has been engineered for easy filter installation and maintenance. Filter tubes are manufactured in various sizes, the largest of which is 10' long and 6" in diameter, including an integral mounting flange. Filter life averages 5 to 10 years on most applications.



Reverse pulse-jet cleaning mechanism for the filter tubes.
Filter tube wall is 3/4" thick with catalyst embedded inside.

Initial system cost is lower than competing options, with much better performance and flexibility. Pressure drop is 4" w.g. – lower than the total energy usage of multi-step systems.

Modular systems to treat any flow volume



Controls PM, S02, HCI, Hg, NOx, Dioxins, Cement O-HAPs

Tri-Mer's Ceramic Catalyst Filter System is the Low Cost Solution

Tri-Mer Corporation, a technology leader in air pollution control, provides turnkey engineering, manufacturing, installation, and service of its ceramic catalytic catalyst filter systems.

Tri-Mer Corporation
Factory and Headquarters
1400 Monroe St., Owosso, MI 48867

Primary Applications

- Boiler MACT compliance for coal, biomass, wood
- Cement NESHAP Organic HAPs
- Glass furnaces
- CISWI Incinerator MACT
- Stationary diesel for ships at dock
- Metal smelting, mineral processing
- Chemical production

More Applications

Air Pollution Control
- Medical waste
- Soil cleaning
- Foundry processes
- Energy production
- Fire testing
- Many specialized high temp applications

Product Collection/Recovery
- Titanium dioxide production
- Fumed silica production
- Catalyst manufacturing
- Platinum smelting
- Metal powder production
- Activated carbon production

Tri-Mer® CORPORATION Technology Leader *multi-pollutant control*

www.tri-mer.com

Appendix D

GEA Brochure

Hot gas filtration with ceramic candles

A multifunctional filter for the simultaneous removal of particulate, acid gases and NOx from flue gases

engineering for
a better world

gea.com

Discover the benefits of ceramic candle filters

GEA high temperature filters with ceramic elements remove particulates and are now available as BisCat ceramic filters with an embedded catalyst matrix allowing removal of NOx, dioxins, mercury and VOC. The filter elements are chemically inert and corrosion-resistant.

Emission control advantages

Ceramic filter elements show very low dust emissions < 2 mg/Nm³ and are thermally stable up to high operating temperatures. No cooling of flue gases is required and no thermal heat energy is wasted.

Filter elements are cleaned online during operation by means of separate, compressed air jet pulses. The filter elements are placed in a single or multi-compartment housing to handle large volumetric flow rates. This construction technique allows for maintenance of a single module while others continue to operate, without interruption of the process itself.

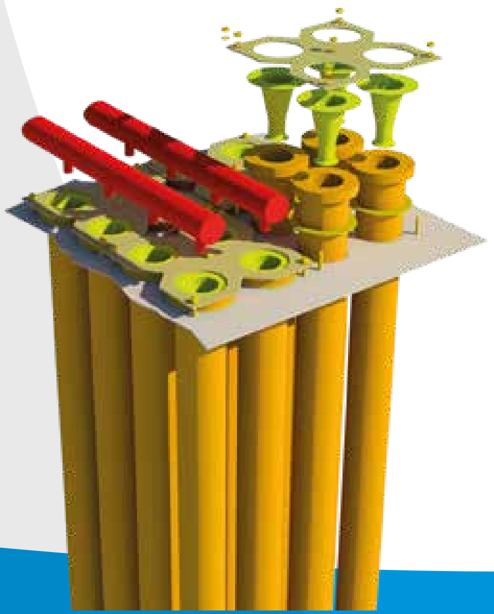
The injection of lime-based reagents allows for control of inorganic gaseous emissions like HF, HCl, SOx. The rigid candle structure enables surface filtration and forms a first layer of reactive dust for absorption processes.

BisCat ceramic catalyst filters

In addition to treating particulate and acid gases, the BisCat ceramic catalyst filters is enriched with a catalyst providing effective NOx removal by using upfront ammonia injection and replace a conventional selective catalyst reactor (SCR).

The BisCat filter solution is combining three process steps in one unit for advanced emission control:

- Dedusting
- Removal of acid components
- Reducing THC and NOx



Details of BisCat installation

CERAMIC FILTERS

- Low dust emissions
- High operating temperatures
- Excellent gas permeability
- Lightweight construction
- Long service lifetime

BISCAT

- Effective NOx removal
- Low differential pressure
- Single emission control unit
- Multi-pollutant performance

APPLICATIONS

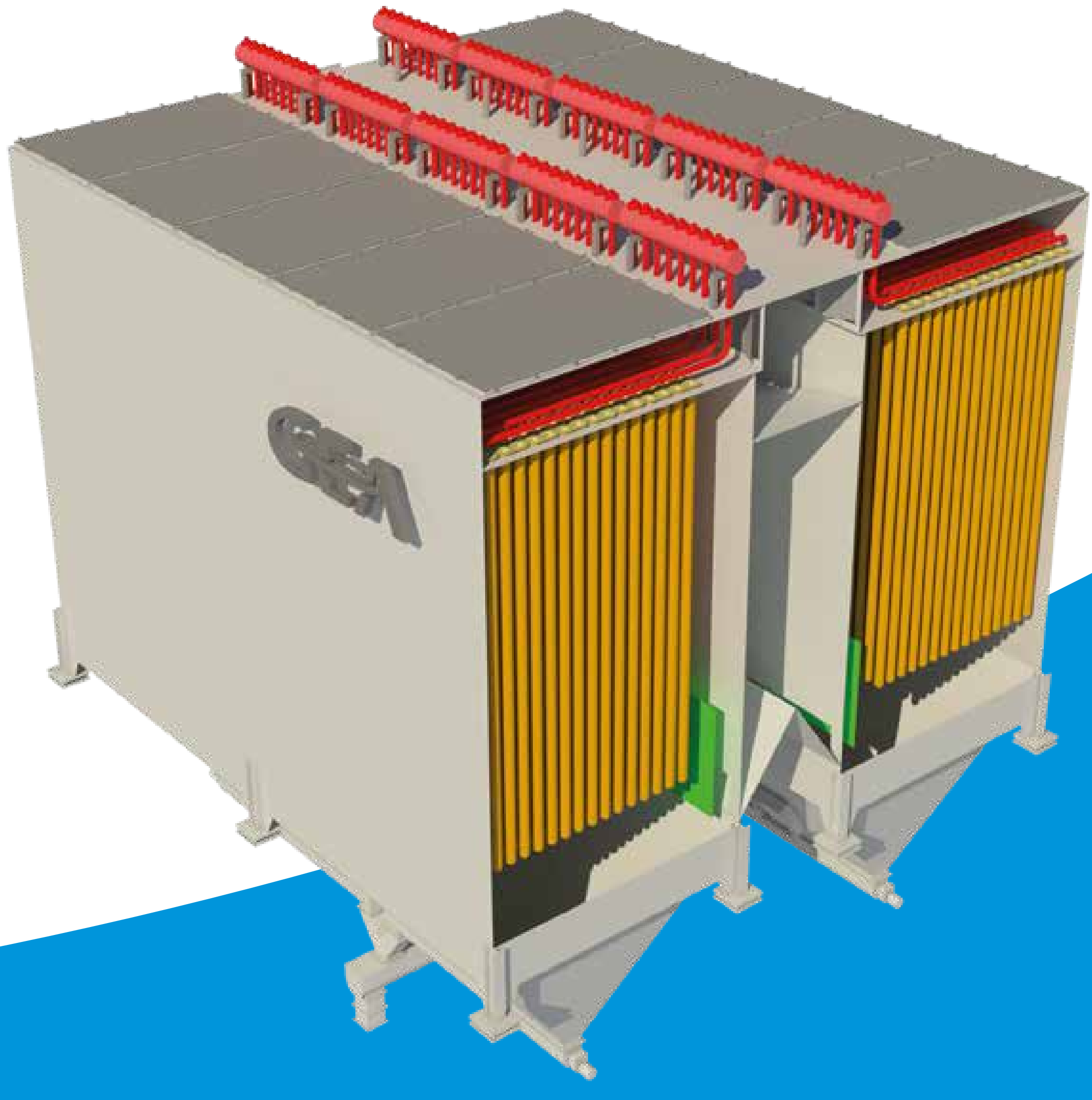
- Glass furnaces
- Cement kilns and coolers
- Incinerators
- Refineries
- Roasters

Special features of ceramic candle filters with pulse jet technology

- Low differential pressure
- Dust monitoring system (Broken Bag Detector) allows for safe operation with almost zero dust emission
- Low a/c ratio allows n-1 operation for longer periods
- Baffle plates protect candles from direct gas flow intake in raw gas compartment
- Clean gas dampers are designed for low differential pressure
- Candle installation period is short, due to easy and fast candle piece assembly
- Penthouse equipped with lifting devices to handle candles and clean gas compartment covers

The special GEA design allows for candle length of up to six meters. A downholder plate holds four candles in place to a common tubesheet. The intake nozzle protects candles from excessive abrasion by means of compressed air and the sealing between candle and head plate prevents from bypass gas.

Standard reverse pulse jet methods, commonly used in fabric filter baghouses, are used for ceramic filter cleaning. A pulse of compressed air is sent down in the center of the filter elements and cleans the accumulated dust from the outer surface of the tubes. The particulate falls into a lower hopper and is removed through an airlock device. Filters are cleaned on-line, with no need to isolate individual housings or sections.



BisCat system

engineering for
a better world

We live our values.

Excellence • Passion • Integrity • Responsibility • GEA-versity

GEA is a global technology company with multi-billion euro sales operations in more than 50 countries. Founded in 1881 the company is one of the largest providers of innovative equipment and process technology. GEA is listed in the STOXX® Europe 600 Index. In addition, the company is included in selected MSCI Global Sustainability Indexes.

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45136 Essen, Germany

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gea.com/contact
gea.com

Appendix E

Haldor Topsoe Brochure

TopFrax™ catalytic filters

Remove gas emissions and dust in one single process

Breakthrough catalytic filters trap dust, while removing NOx, dioxins, CO and VOCs

www.topsoe.com

HALDOR TOPSØE

Are regulators putting the **squeeze** on your business?

Topsoe's new TopFrax™ catalytic filter makes compliance a whole lot more affordable

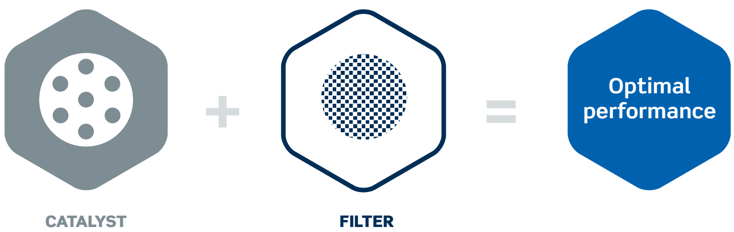
Authorities in many countries are tightening emissions standards by reducing particle permissible levels and adding new gases to the list of regulated components. Compliance is costly, requiring substantial investments in new abatement technologies.

At Topsoe, we hear producers calling not just for new technologies, but for innovation that makes compliance affordable. That's what our TopFrax™ catalytic filter is all about.

Trap dust and remove pollutants
TopFrax™ are patent-pending catalyst-coated filters designed to treat off-gases in high-dust environments found in a wide range of industries and activities, including:

- Glass production
- Cement production
- Waste incineration
- Bio-mass boilers
- Steel production

Built on decades of leadership in filtration and catalysis, these breakthrough solutions can transform the economics of meeting regulatory emissions.



The fact that we both master catalysts and process technology gives us the "big picture" view it takes to ensure optimal performance

Remove gas emissions and dust **in one single process**

Upgrading is easy and affordable, if you use a candle system

Topsoe's catalytic filter is designed to give any facility the option of treating off-gases along with trapping dust. TopFrax™ is a catalytic ceramic candle solution that provides high removal performance efficiency at both high and low operating temperatures and with the resistance of sparks contained in off-gases.

TopFrax™ catalytic filter candle
The TopFrax™ catalytic filter candle consists of a high-temperature-resistant ceramic filter impregnated with carefully selected catalytic compounds. Benefits include:

- Simultaneous dust and multiple gaseous compounds removal in a single step
- No need for costly, space-demanding tail-end gas removal equipment
- Reinforced at flanges and bottom to enhance mechanical durability
- Catalytic ceramic filter accommodates temperatures as high as 400°C (752°F)
- No contact between catalyst and potentially harmful particles
- Exceptional resistance to catalyst poisoning
- Effective down to 180°C (356°F) operation
- Easy to install and handle

TopFrax™ ceramic catalytic filter

A broad spectrum of **regulated pollutants**

While the filters trap dust, the catalyst removes NOx, dioxins, CO and VOC

Dust
TopFrax™ effectively blocks particulates and dust particles at the filter surface the same way conventional filters do, ensuring full compliance with stringent emission standards.

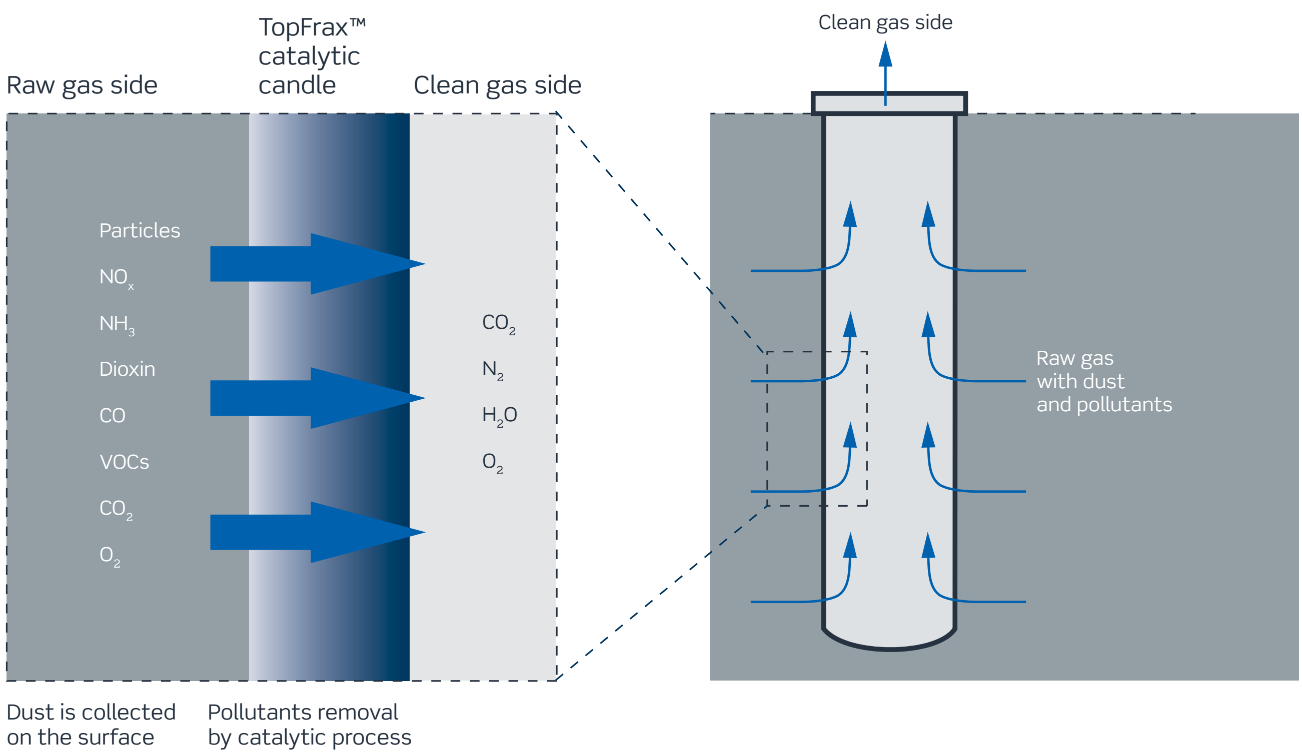
TopFrax™ candles are made from either refractory ceramics or fibers with low bio-persistance. Both products trap dust emissions (below $PM_{2.5}$) down to 1 mg/Nm³.

NOx
TopFrax™ uses selective catalytic reduction (SCR) to remove NOx from off-gases, by utilizing ammonia to convert to harmless nitrogen and water

Dioxins
TopFrax™ also ensures compliance with limits on dioxins and furans, by treating more than 99% of these by converting them into harmless compounds and reducing their concentrations to below 0.1 ng/Nm³, TEQ.

CO and VOCs
The catalytic sites on TopFrax™ candles also oxidize CO and volatile organic compounds into harmless CO_2 and H_2O.

The TopFrax™ oxidation version ensures optimal combustion of VOCs with no additional emission of CO.



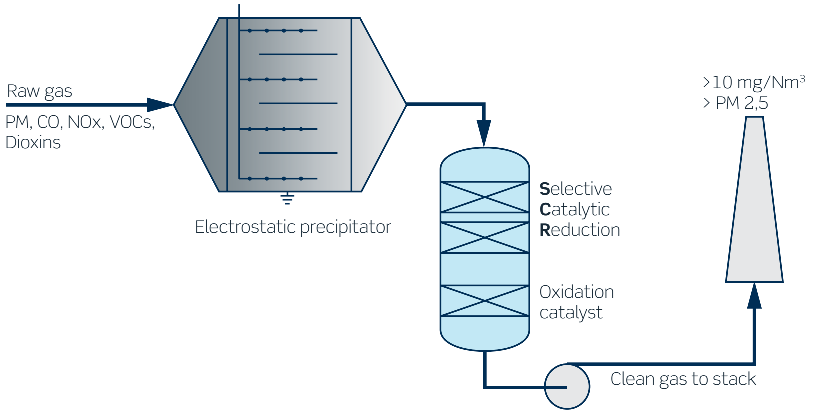
Cut technology costs

The Topsoe catalytic filter solution TopFrax™ can help you reduce capital expenditures compared to competing solutions relying on separate DeNOx and oxidation technologies

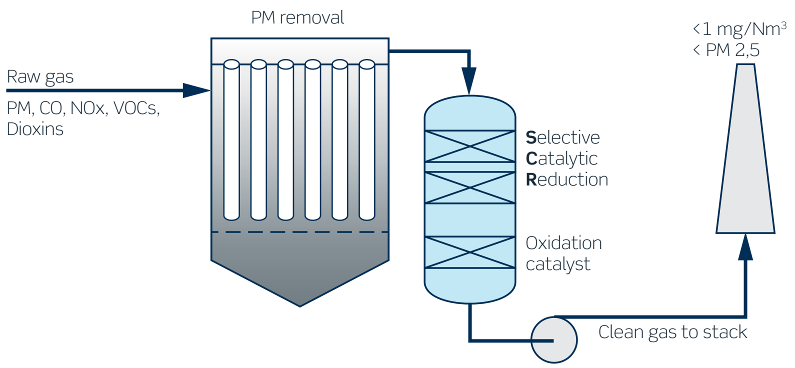
Filtration unit and tail end removal of NOx and VOC

Traditional solution based on separated technologies

Non-catalytic filters



Non-catalytic filters

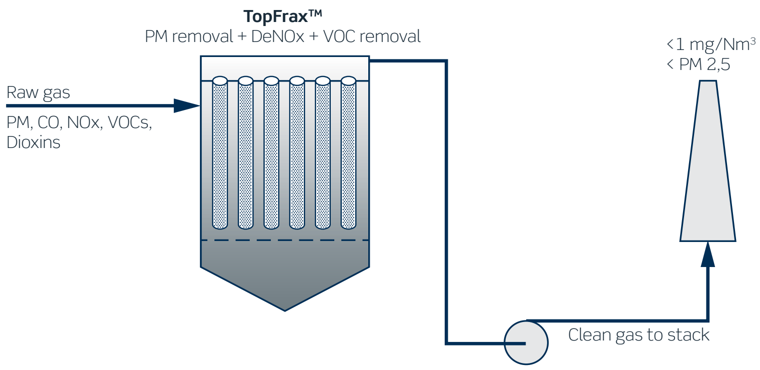


Catalytic filtration - integrated solution

Catalytic filter solution:

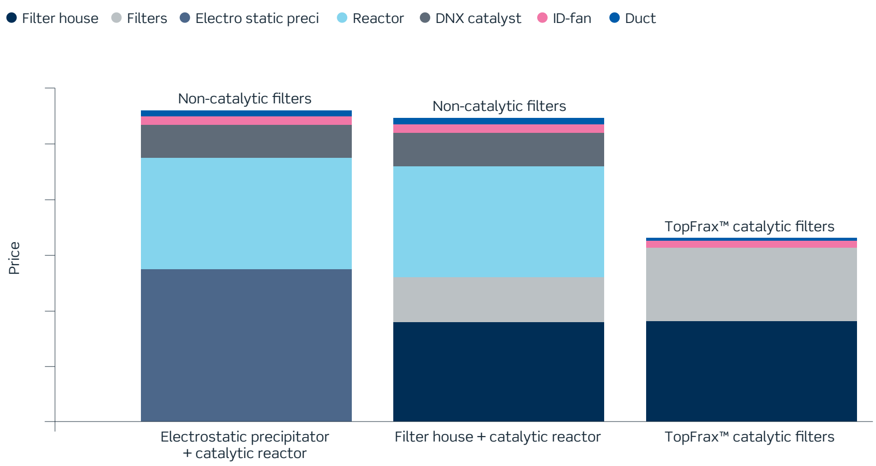
- Lower CAPEX
- Less foot print
- Lower pressure drop
- Less maintenance
- Lower cost of ownership

TopFrax™ catalytic filters



Comparison of lump sum investment

CAPEX savings from installing catalytic filters.



Related technologies

Discover the full range of Topsoe catalysts and technologies for optimizing performance

Optimized performance often means ensuring that multiple technologies and components are tuned to each other. If you're not already using them, please consider these related offerings from Topsoe.

VOC

VOC removal
Regulatory pressure on VOC emissions has never been greater, and we can help you meet the challenge by removing VOCs from off-gases via low-temperature catalytic processes. Our solutions deliver reduction efficiencies exceeding 99%, without creating any secondary pollutants. Our catalysts remove VOCs from air and waste gas streams in an energy-efficient and environmentally friendly manner.

S

Sulfur removal
As emission regulations continue to get tighter around the world, optimal handling of sulfurous gases is becoming increasingly important. In addition to meeting regulatory requirements, we make sure our solutions also make financial sense. Due to their high availability, energy efficiency and flexibility, our sulfur removal systems deliver market-leading performance. They can even be used to convert otherwise costly waste into valuable commercial-grade sulfuric acid.

Why partner with **Haldor Topsoe**

The Topsoe advantage lies not just in individual solutions, but in how our solutions work together

When you partner with Haldor Topsoe, you partner not only with the world's experts in catalysis, surface science and emissions management. You also partner with a company that takes a uniquely holistic approach to your plant and your business.

When we look at your plant, we look at the big picture – and then apply the full breadth of our expertise to deliver a thoroughly tailored solution, where individual components work together to ensure environmental compliance at the lowest possible cost.

Haldor Topsoe is a world leader in catalysis and surface science, committed to helping our customers achieve optimal performance. We enable companies to get the most out of their processes and products, using the least possible energy and resources, in the most responsible way. We are headquartered in Denmark and do project development, R&D, engineering, production, and sales & service across the globe.

Get in touch today
www.topsoe.com/topfrax

Haldor Topsoe A/S, cvr 41853816 | CCM | 0224.2017/Rev.1

HALDOR TOPSØE

CataFlex™ catalytic filter bags

Remove pollutants and **trap** dust in one **single** step

Breakthrough catalytic filter bags trap dust, while removing dioxins, NOx and NH_3

www.topsoe.com

HALDOR TOPSØE

Are regulators putting the **squeeze** on your business?

Topsoe's CataFlex™ catalytic filter bags make compliance a whole lot more affordable

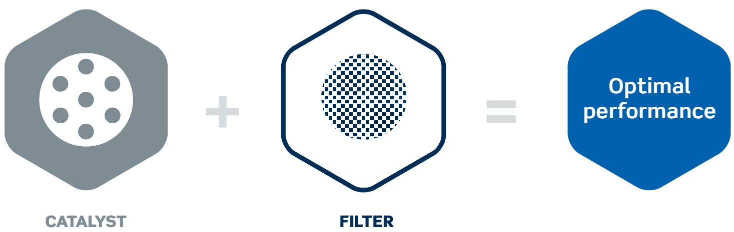
Authorities in many countries are tightening emissions standards by reducing permissible levels and adding new gases and particles to the list of regulated components. Compliance is costly, requiring substantial investments in new abatement technologies.

At Topsoe, we hear producers calling not just for new technologies, but for innovation that makes compliance affordable. That's what our CataFlex™ catalytic filter bags are all about.

Trap dust and remove pollutants
CataFlex™ are catalyst-coated filter bags designed to treat off-gases in high-dust environments found in a wide range of industries and activities, including:

- Waste incineration
- Biomass boilers
- Power plants
- Cement production
- Glass production
- Steel production

Built on decades of leadership in filtration and catalysis, these breakthrough solutions can transform the economics of meeting regulatory emissions.



The fact that we both master catalysts and process technology gives us the "big picture" view it takes to ensure optimal performance

Single step **removal** of dioxins, NOx and NH_3

Upgrading is easy and affordable

Topsoe's catalytic filter systems are designed to give any facility the option of treating off-gases along with trapping dust. CataFlex™ is the ideal choice for facilities already using a filter bag solution.

Designed for use in most industries that require flue gas cleaning, the CataFlex™ catalytic filter bag consists of a catalytic fabric layer installed inside a standard filter bag. Both the catalyst formula and the fabric material for the catalytic inner layer and the dust filtration layer are optimized according to the process requirements.

Benefits include:

- Removes dust and multiple gaseous compounds in a single step
- No need for costly, space-demanding tail-end SCR equipment
- Low pressure drop means no need for costly new ID fans or compressed air
- Accommodates operating temperatures up to 260°C (500°F)
- Bags can be inserted into existing filter houses for an affordable drop-in upgrade
- Life time and pressure drop is comparable to conventional fabric filters
- No contact between catalyst and potentially harmful particles
- Exceptional resistance to catalyst poisoning
- Length up to 10 m (32 ft)
- Longer outer bag lifetime

CataFlex™ catalytic filter bag

A broad spectrum of **regulated pollutants**

While the filters trap dust, the catalyst removes dioxins, NOx and NH_3

SEM image of CataFlex™

Outer layer

Dust
CataFlex™ effectively block particulates and dust particles on the outer layer which consist of a traditional dust filter bag, ensuring full compliance with the stringent emission standards.

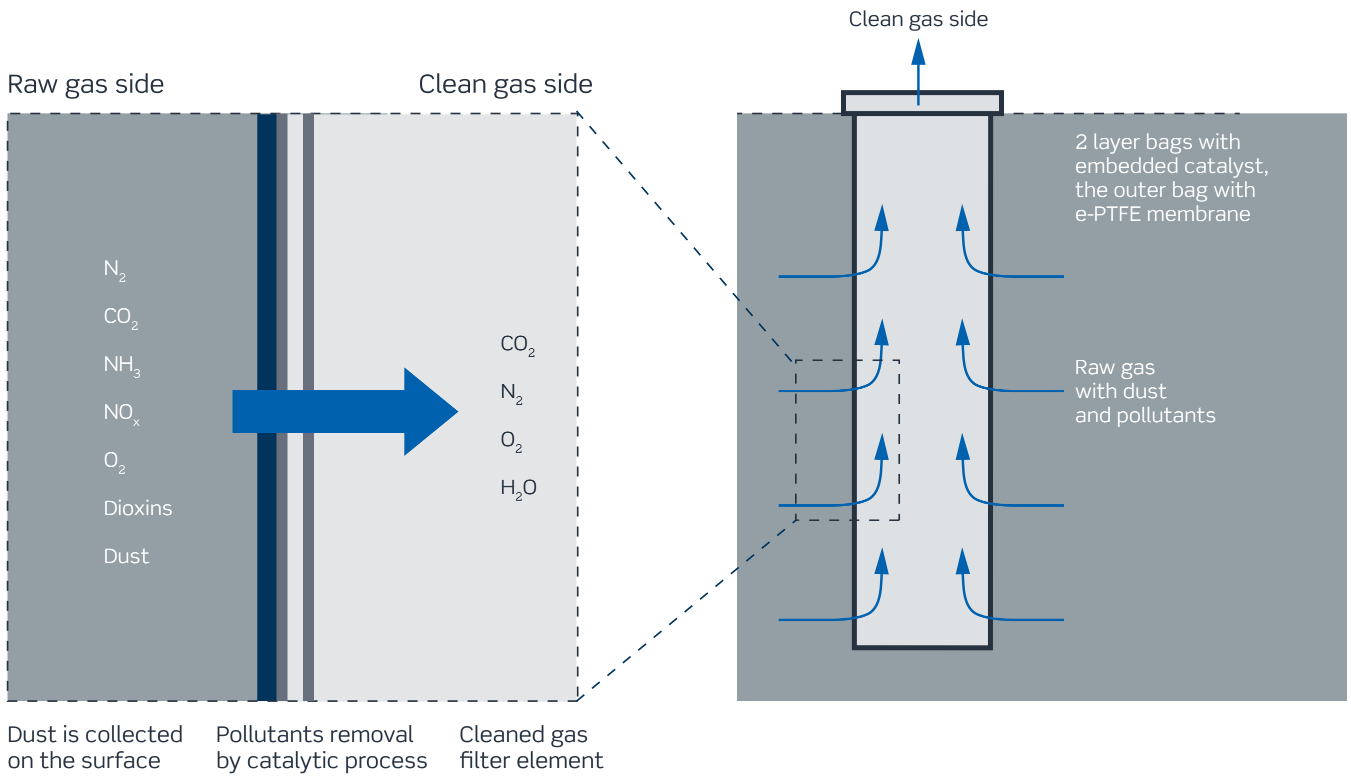
The outer layer of a CataFlex™ filter bag is a conventional filter bag which can be made by different fabrics and with and without PTFE membrane. CataFlex™ reduces dust emissions to below 1 mg/Nm³.

Inner layer

Dioxins destruction
CataFlex™ ensure compliance with limits on dioxins and furans - destruction more than 99% of these by converting them into harmless compounds and reducing their concentrations to below 0.1 ng-TEQ/Nm³.

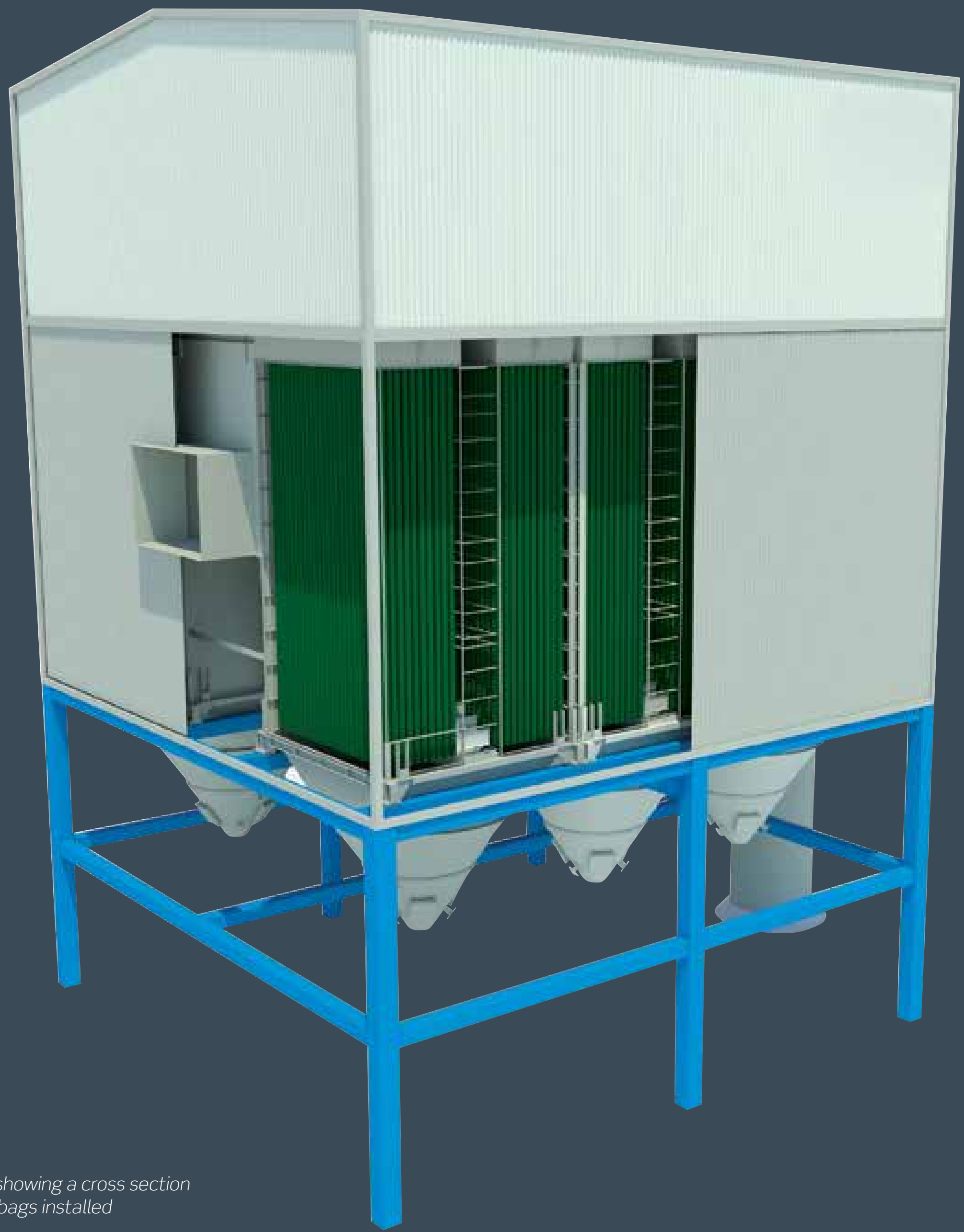
NOx
CataFlex™ use selective catalytic reduction (SCR) to remove NOx from off-gas, either by utilizing ammonia contained in the off-gas or via ammonia injection. The NOx is converted to harmless nitrogen and water.

NH_3
CataFlex™ eliminates any NH_3 slip from upstream selective non-catalytic reduction (SNCR) of NOx. This complies with NH_3 regulations and makes SNCR control easier.



Cut equipment **costs**

The Topsoe catalytic filter bag solution can help you reduce capital expenditures by up to 80% compared to competing solutions relying on separate dust removal and SCR technology.

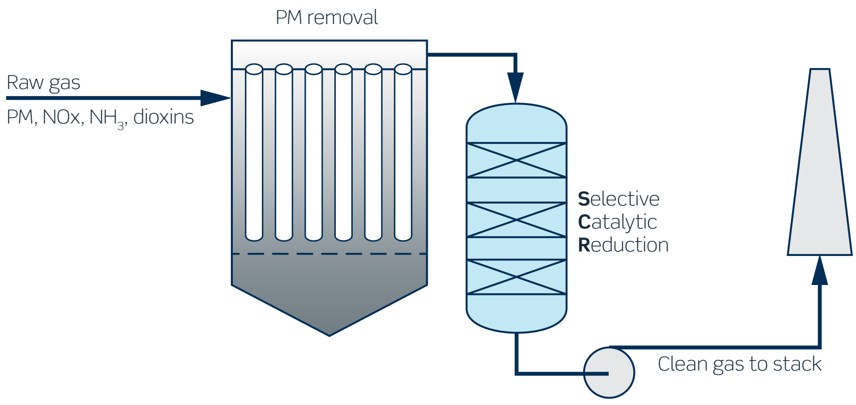


Typical fabric filter showing a cross section with catalytic filter bags installed

Filtration unit and tail end removal of NOx and NH_3

Traditional solution based on separated technologies

Non-catalytic filters

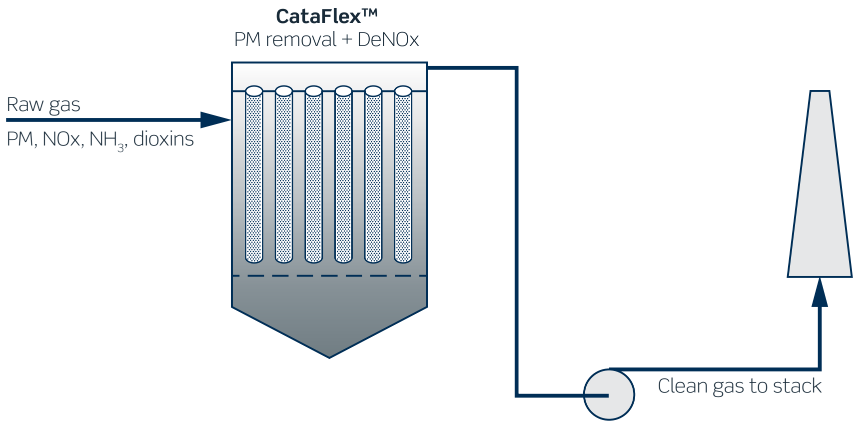


Catalytic filtration - integrated solution

Catalytic filter bag solution:

- Lower cost of ownership
- Less foot print
- Lower pressure drop
- Less maintenance

Catalytic filters



Related technologies

Discover the full range of Topsoe catalysts and technologies for optimizing performance

Optimized performance often means ensuring that multiple technologies and components are tuned to each other. If you're not already using them, please consider these related offerings from Topsoe.

S

Sulfur removal
As emission regulations continue to get tighter around the world, optimal handling of sulfurous gases is becoming increasingly important. In addition to meeting regulatory requirements, we make sure our solutions also make financial sense. Due to their high availability, energy efficiency and flexibility, our sulfur removal systems deliver market-leading performance. They can even be used to convert otherwise costly waste into valuable commercial-grade sulfuric acid.

VOC

VOC removal
Regulatory pressure on VOC emissions has never been greater, and we can help you meet the challenge by removing VOCs from off-gases via low-temperature catalytic processes. Our solutions deliver reduction efficiencies exceeding 99%, without creating any secondary pollutants. Our catalysts remove VOCs from air and waste gas streams in an energy-efficient and environmentally friendly manner.

Why partner with **Haldor Topsoe**

The Topsoe advantage lies not just in individual solutions, but in how our solutions work together

When you partner with Haldor Topsoe, you partner not only with the world's experts in catalysis, surface science and emissions management. You also partner with a company that takes a uniquely holistic approach to your plant and your business.

When we look at your plant, we look at the big picture – and then apply the full breadth of our expertise to deliver a thoroughly tailored solution, where individual components work together to maximize your plant's performance and your business success.

Haldor Topsoe is a world leader in catalysis and surface science. We are committed to helping our customers achieve optimal performance. We enable our customers to get the most out of their processes and products, using the least possible energy and resources, in the most responsible way. This focus on our customers' performance, backed by our reputation for reliability, makes sure we add the most value to our customers and the world.

Get in touch today
www.topsoe.com/Cataflex

Haldor Topsoe A/S, cvr 41853816 I GMC I 0268.2019/Rev.1

HALDOR TOPSØE

Appendix F

Tri-Mer Proposal

TECHNICAL FEASIBILITY ASSESSMENT

APPLICABILITY OF CERAMIC FILTERS FOR CEMENT PLANT POLLUTION CONTROL

REFERENCE NUMBER: **P-22.518**

REVISION: 0

PREPARED FOR WINGRA ENGINEERING

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DOCUMENT ISSUED:
SEPTEMBER 21, 2021

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INTRODUCTION

In response to your recent request, we are pleased to provide Wingra Engineering with our initial assessment relating to the applicability of Ceramic Filter Technology at both the Holcim, Florence Site in Colorado, and the GCC, Pueblo Site in Colorado for multi-pollutant control.

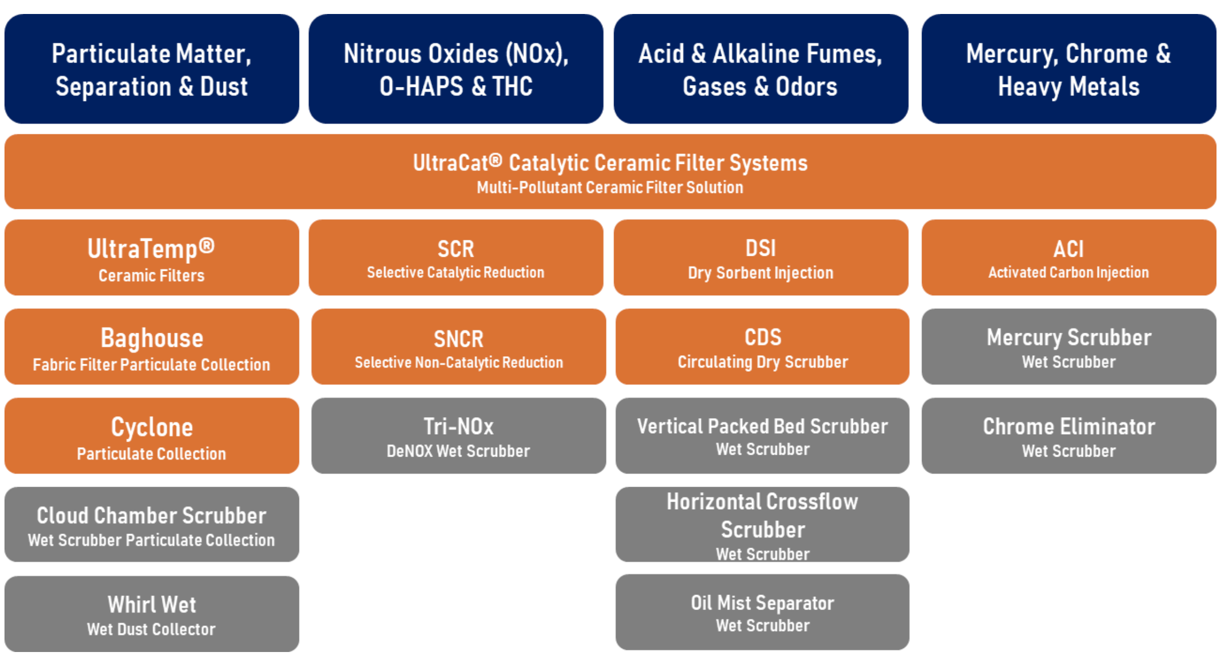
Ceramic Filter Technology has been utilized as a premier solution for Air Pollution Control (APC) for a number of decades, with Tri-Mer having installed over 75% of the ceramic filter systems operating across North America today. The technology has been enhanced considerably since the first US installation in the 2000's, with significant advancements in both the filter technology, and the overall multi-pollutant solution installed.

Across North America, while the technology has predominately been installed in the glass industry, it has wide applicability to a wide range of other industries. Specifically in respect to the cement industry, ceramic filter technology has been installed for the purposes of multi-pollutant reduction into a number of cement plants both in Europe and Asia, while there is also a major cement installation in the US.

Based on the initial information received, we expect that Tri-Mer's ceramic filter technology can be installed to both sites to fully achieve the requirements set forth in respect to both taking on the inlet conditions and operational requirements of both sites, while also meeting the legislative requirements for PM, NOx and SOx removal. Importantly, following our initial assessment, we fully expect Tri-Mer's proprietary ceramic filter technology – UltraCat® Catalytic Ceramic Filter Solution (UCF) - can be a cost-effective solution available to these plants.

OUR TECHNOLOGIES

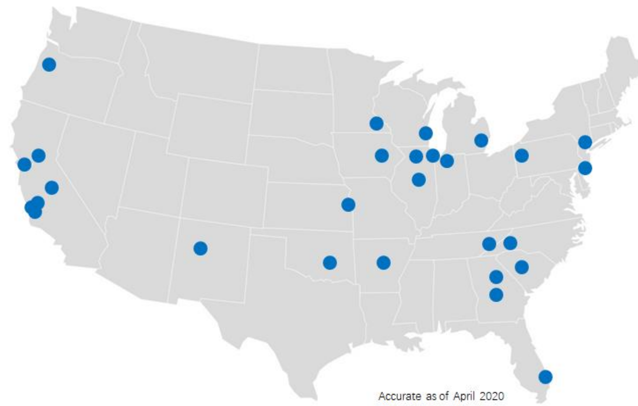
For over 60 years, TMC has developed an enviable reputation in the field of air pollution control. The business performed over 6,000 global installations, providing a wide range of technologies and solutions, to clients across most major industries. TMC has developed a large number of technologies in-house, and works with proven partners to allow for expanded scope where required.



Based in Owosso, Michigan, TMC is a full solution integrator, providing solutions that support our clients reduce almost all major air pollutants. The company headquarters include over 200,000 sq. ft. of state-of-the-art steel fabrication and manufacturing facilities. While our wide range of technologies and solutions provide the strong foundation for the business, it is our dedication to exceed your needs through full and flexible lifecycle services, that help to set us apart.

OUR EXPERIENCE

TMC is the global leader in designing and delivering high-efficiency ceramic filter technology. Through our proprietary UltraCat® Ceramic Filter systems, we have installed over 50,000 ceramic filters across over 40 installations in North America alone. The technology is proven to operate on all pre- and post-combustion processes, mitigating pollutants such as PM, SO_2, SO_3, HCl, O-HAPS, VOC, HF, and NO_x to higher removal rates than industry standard within a single system, while heavy metals, mercury, dioxins, and VOC O-HAPS can also be removed.



DESIGN PARAMETERS

To provide a basis to this assessment, our proposed solution has been evaluated based on the design and process details as outlined below:

Facility		Holcim Florence Portland Cement Plant Florence, Colorado Preheater/Precalciner Kiln	GCC Pueblo Pueblo Cement Plant Pueblo, Colorado Preheater/Precalciner Kiln
AIRS Point		111	039
Fuels		Coal, NG, TDF, Pet Coke	Coal, NG, TDF
Capacity	tons per day	5,950	3,750
Current Control for PM		Baghouse	Baghouse
Current Control for SO_2		Inherent & Wet Scrubbing	Inherent Scrubbing
Current Control for NOx		SNCR	SNCR
Exhaust Flow Rate (acfm)	acfm	827,731	306,708
Exhaust Temperature (°F)	°F	166	377
Exhaust Moisture (%)	vol.%	13.9	8.2
PM10 (Filterable)	(lbs/hr)	61,979.2	39,062.5
PM10 (Condensable)	(lbs/hr)	0.0	10,473.7
PM_{10} (Total)	(lbs/hr)	61,979.2	49,536.2
SO_2	(lbs/hr)	164.6	215.4
NOx	(lbs/hr)	1,041.3	656.3

DESIGN ASSUMPTIONS

Without gaining full access to full details regarding the operation and design of the existing systems in place at Holcim, Florence and GCC, Rio Grande, we have made the following assumptions, exclusions and clarifications within our overall assessment. Tri-Mer has the full capability to investigate, design and supply many of these elements within a full turnkey solution:

- Both cement plants use water quench system for adjustment of the flue gas temperature at baghouse inlet
- Adjustments to decreasing quench efficiency can be easily made in order to increase the flue gas temperature to about 550°F for 90% NOx removal efficiency. Tri-Mer is presently investigating capabilities to operate its UCF filters at lower temperature
- Existing baghouse is designed for 12' bag filters.
- Existing baghouse is designed for a face velocity at filter (air-to-cloth ratio) of 0.8 m/min (about 2.7 fpm)
- Typical operation temperature for the existing baghouse is limited to 425°F
- Existing infrastructure for online filter cleaning consists of pulse jet system and can be used for the cleaning of the UCF® filters, e.g. without any modifications to jet tubes, solenoid valves, tank volumes, available pressure and compressed air class 2 quality requirements.
- Existing ID-fans will be capable to handle additional volumetric flow and pressure drop requirements

OUR SOLUTION

With our extensive range of air pollution control technologies, our approach is always to identify the best technical fit for the specific project. As each project, client and site is unique, we ascertain the most appropriate technology and applicability of these technologies. For this assessment, we have evaluated ceramic filter technology only, and looked into the most economical option for the two sites.

Traditionally, ceramic filter technology is installed within its own filter housing (either UCF or UTF), both for brownfield and greenfield projects. More recently, where a baghouse is already installed and its design meets the flow and particulate requirements, we can utilize the existing baghouse and replace the existing filter bags with ceramic filters. This concept has been achieved outside of the US, while Tri-Mer has undertaken extensive design and capability assessments on other cement plants to ensure its applicability. Therefore, for both sites, our proposed Bag-to-Ceramic Filter Retrofit solution would include:

- Structural analysis of the existing baghouse with recommendations for structural improvement
- Engineering package and design of upgraded internals for the replacement of bag- with catalytically activated ceramic filters
- Engineering package with analysis of existing ID-fan capacity and if required, booster fan upgrade recommendations
- Upgrade equipment, both internal replacements and structural modifications
- Catalytically activated UCF replacement filters
- Aqua ammonia storage, dosing and injection system, utilizing a 30,000-gal tank for 7+ days holding capacity at GCC Rio Grande and a 4+ days holding capacity at Holcim Florence
- Mechanical and electrical installation
- Site supervision

EXPECTED SYSTEM PERFORMANCE

Tri-Mer's UltraCat® Catalytic Ceramic Filter Systems are proven to deliver some of the highest levels of pollutant reduction available from commercially proven technology. Based on the initial process information provided, we expect our solution to deliver the following:

Targeted Pollutant	Expected Performance[1]	Test Method
PM10	>99.9%	US EPA Test Method 5
PM2.5	>99.9%	US EPA Test Method 201A or 202
NOx	>90%	US EPA Test Method 7E
SOx	>90%	US EPA Test Method 8A
Ammonia Slip	<10ppm	US EPA Test Method CTM 027

Note: 1 Based on a 30 day rolling average

When considering both NOx and SOx, Tri-Mer have the capability to provide higher levels of performance should it be required through the additional of supplementary technology and solutions.

ESTIMATED COSTS

Utilizing the existing information provided, and aligned with our extensive experience in providing ceramic filter systems, we fully expect that our Bag-to-Ceramic Filter Retrofit would be one of the most cost-effective solutions to providing some of the highest levels of pollutant reduction available

	Holcim, Florence	GCC, Pueblo
Estimated Upfront Capital Investment Cost (US $)	$31,250,800	$8,999,200
Estimated Cost per ton NOx removed per annum[1] *(CapEx + 20 Year OpEx / ton NOx removed per year)*	$1,576/ton of NOx removed per annum	$800/ton of NOx removed per annum
Estimated Lifetime Cost[2] *CapEx + 20 Year OpEx*	USD $129,250,800	USD $41,399,200
Estimated Lifetime Cost per annum[2] *(CapEx + 20 Year OpEx / 20 years)*	USD $6,462,540 per annum	USD $2,069,960 per annum

Note: [1] *the following base cost assumed: Power: US$44/MWh; Aqua ammonia (19 wt.%): US$1,200/ton; Maintenance: US$270,000/yr; Replacement Filters: Once every 10 years.*
[2] *Lifetime cost does not include any assumption to calculate NPV*

The estimated costs shown in the table below are preliminary, and we would require additional information to better ascertain the exact costs for each facility.

ADDED BENEFITS

In addition to the estimated costs, both capital and 20-year lifetime costs, the ceramic filter technology will provide a wide range of benefits to both facilities in comparison to utilizing the existing baghouse (with filter bags) and the installation of a new SCR:

1. **Minimal Footprint**

   Unlike a requirement to add an SCR, our proposed solution to retrofit the existing baghouse, will not require significant footprint to ensure that the site meets increased NOx mitigation. The only footprint that will be required would be for the ammonia storage and transport system to deliver the targeted levels of NOx, SOx and PM,

2. **Reduced Onsite Installation Labor**

   In alignment with the minimal footprint requirement, the proposed retrofit would significantly reduce the requirement for civil, mechanical installation, and electrical installation, reducing both the cost, complexity and the time taken to install the solution.

3. **Minimal Catalyst Plugging**

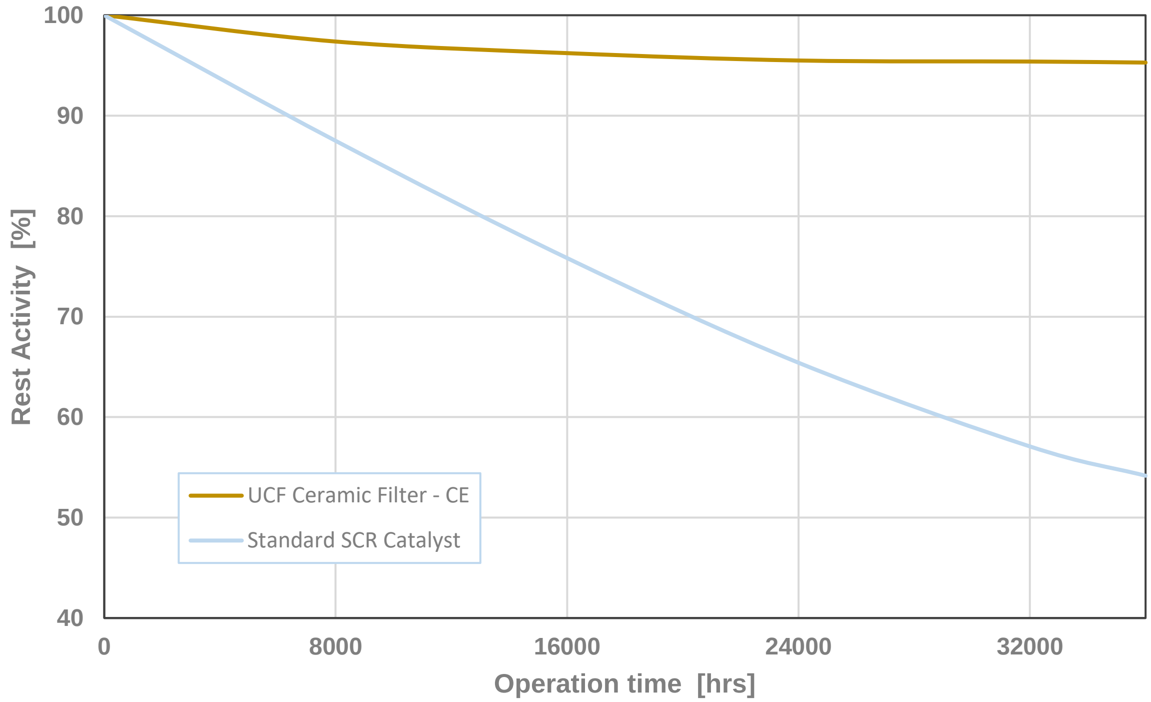
   The SCR DeNOx catalyst is finely distributed throughout the filter wall. Since the ceramic material of the filter is rigid, the filter does not inflate or otherwise change shape or form during jet pulse cleaning, unlike bag filters do. As a consequence, UCF filters always will maintain a residual filter cake as a barrier for any dust constituents, preventing active sites and pore system from being coated and plugged.

4. **Reduced Ammonia Slip**

   Field testing of ammonia slip in service with regenerative glass furnace, e.g. periodical flow reversal, typically show very low ammonia slip well below 10 ppm and even allow the use of ammonia slip monitoring for reliable filter breakage detection.

5. **Negligible Catalyst Deactivation**

   As noted in #3, unlike the catalyst provided within an SCR, the nano-catalyst embedded within the ceramic filter is protected by the ceramic filter and its filter cake. This will ensure that the catalyst is not poisoned and therefore deactivated in the same way as the SCR. Our experience estimates that a SCR catalyst would need to be replaced every 2-3 years, whereas a ceramic filter has no deactivation of the catalyst in a continuous operation for 10 years+.



6. **Temperature Consistency**
As the existing Baghouse and proposed SCR require different operating temperatures, the installation of an SCR would require significant reheat, driving higher costs and CO2 as a result of this activity. The proposed ceramic filter technology has an optimal operating temperature range at about 550°F.

7. **Continuous Operation**
Tri-Mer's ceramic filter technology is designed to allow for continuous operation with a capability to provide full redundancy. This will ensure that both cement plants will be able to operate for as long as required, without downtime or bypass associated with the SCR downstream of the Baghouse.

8. **Mitigation of SO_2 to SO_3 Conversion**
While the UCF filter can excel a 90% NOx conversion at 550°F, SO2 to SO3 conversion at this temperature is expected to be minor.

9. **Experience**
While the ceramic filter technology may be a relatively new concept to S-based cement plants, ceramic filters are used in a number of cement plants around the world. Tri-Mer work with the leading suppliers of ceramic filters who have the experience and knowledge of cement plant operation. Our knowledge about system design, together with their capabilities in filter technoligy, will ensure that our solution can meet the needs of these projects.

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