NOx Treatment

by Selective Catalytic Reduction

with Catalytic Ceramic Filter Elements

September 28, 2016

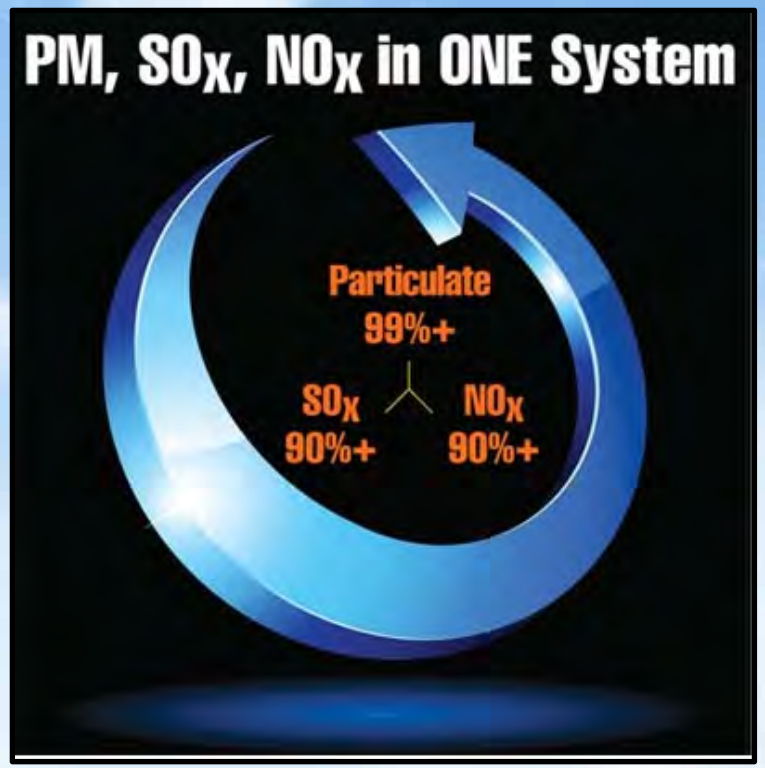
Rod Gravley

Technology Director

Tri-Mer® CORPORATION

Technology Leader *air pollution control*

Ceramic Catalyst Filters for Multi-Pollutant Control



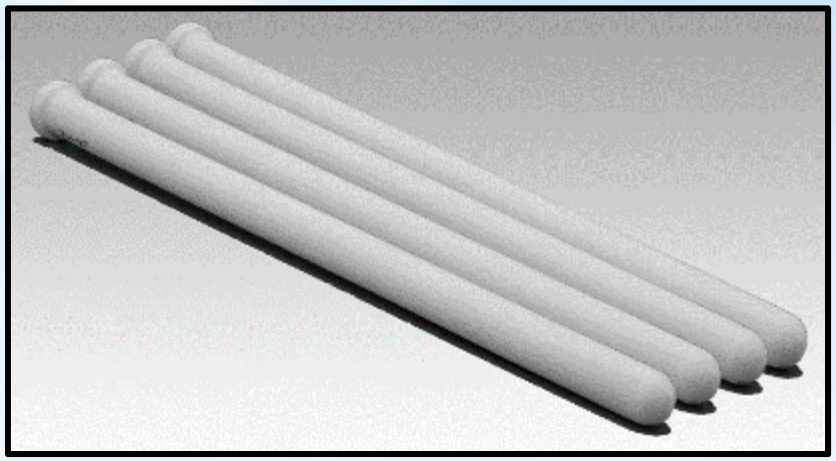
Also Treats

- CO
- VOC
- Hg
- Pb
- Se
- Other Metals
- Dioxin

Tri-Mer is the Largest Supplier of Ceramic Filter Systems in the World

Presentation Outline

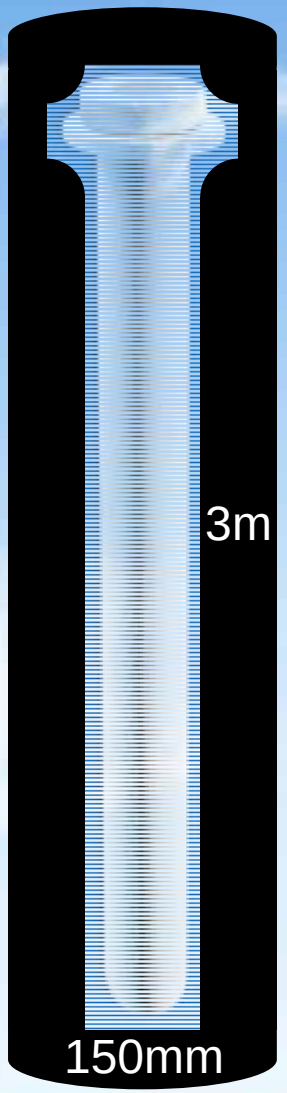
- Technology Basis (SCR)
- System Design
- NOx Control
- Multi Pollutant Performance
- Project Delivery



Technology Basis

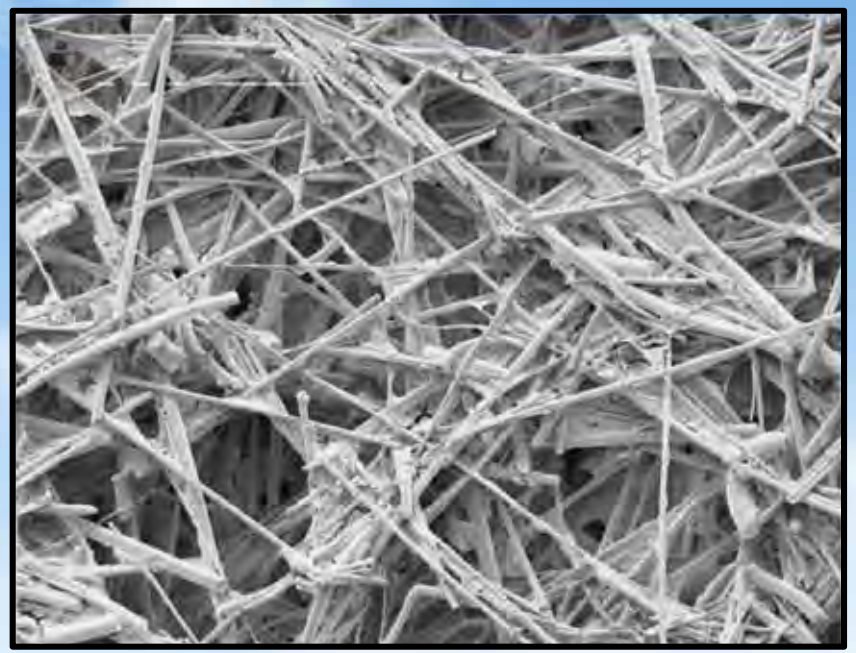
UltraCat Ceramic Filter Elements

CHARACTERISTICS OF (LOW-DENSITY) CERAMIC ELEMENTS	
Form	Monolithic rigid tube
Composition	Refractory fibers plus organic and inorganic binding agents
Porosity	About 80-90%
Density	About 0.3 - 0.4 g/cc
Support	Self supporting from integral flange
Geometry	Outer diameter up to 150 mm; Length up to 3 m



Technology Basis

UltraCat Ceramic Filter Construction



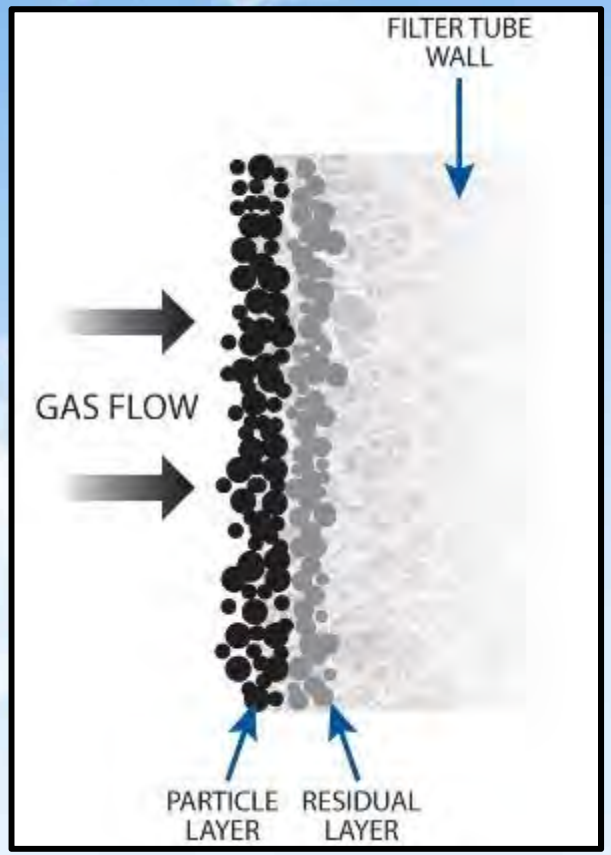
Ceramic Filter Element Outer Surface

Inner Fibers with Imbedded Catalyst

Filtration Mechanism

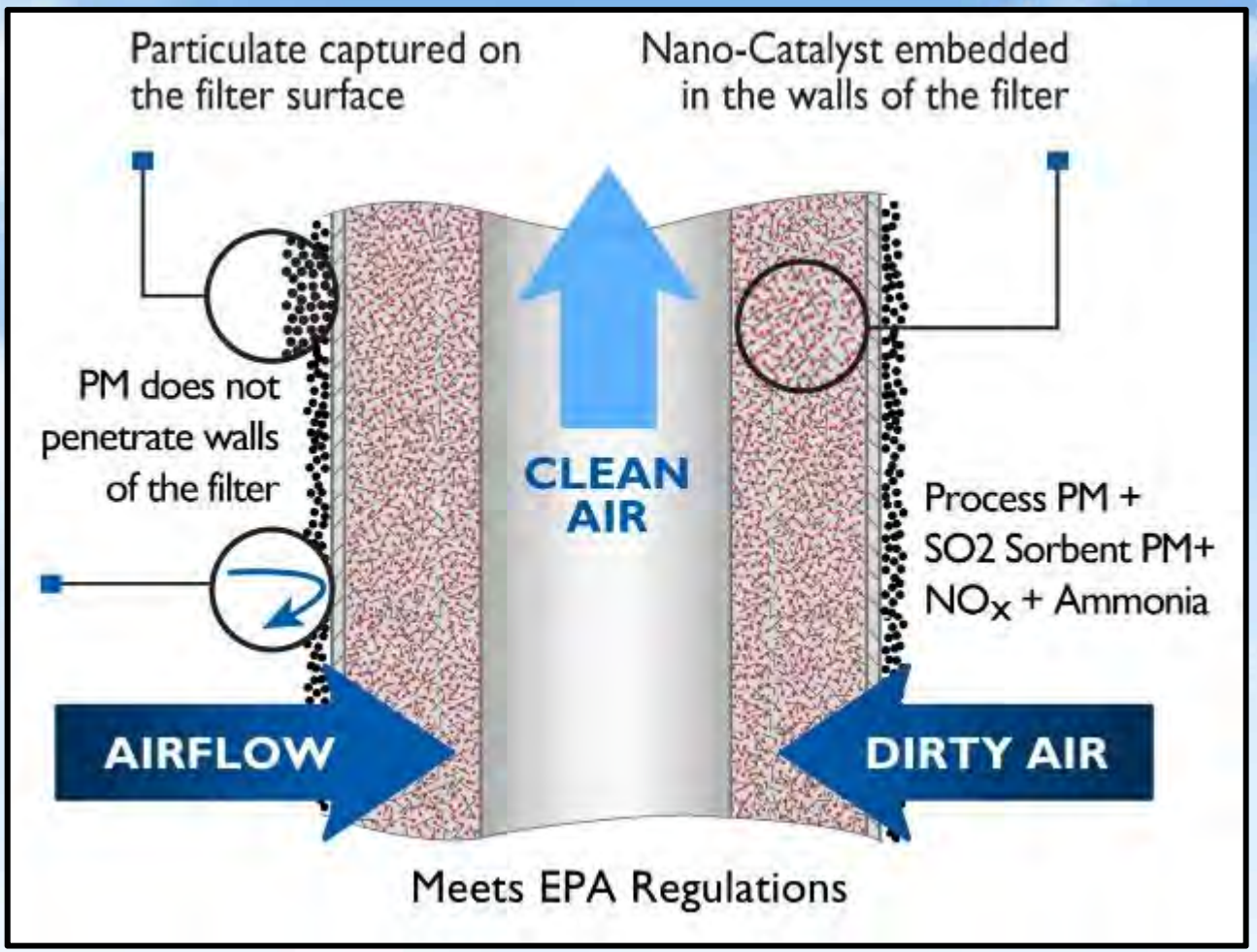
- Dust cake builds upon the residual layer, does not penetrate into filter body
- Cake is periodically removed with a reverse pulse of air, a brief low volume shockwave
- Can handle variable loading conditions
- Tube does not flex like a Fabric Filter bag,

  No mechanical wear = long filter life

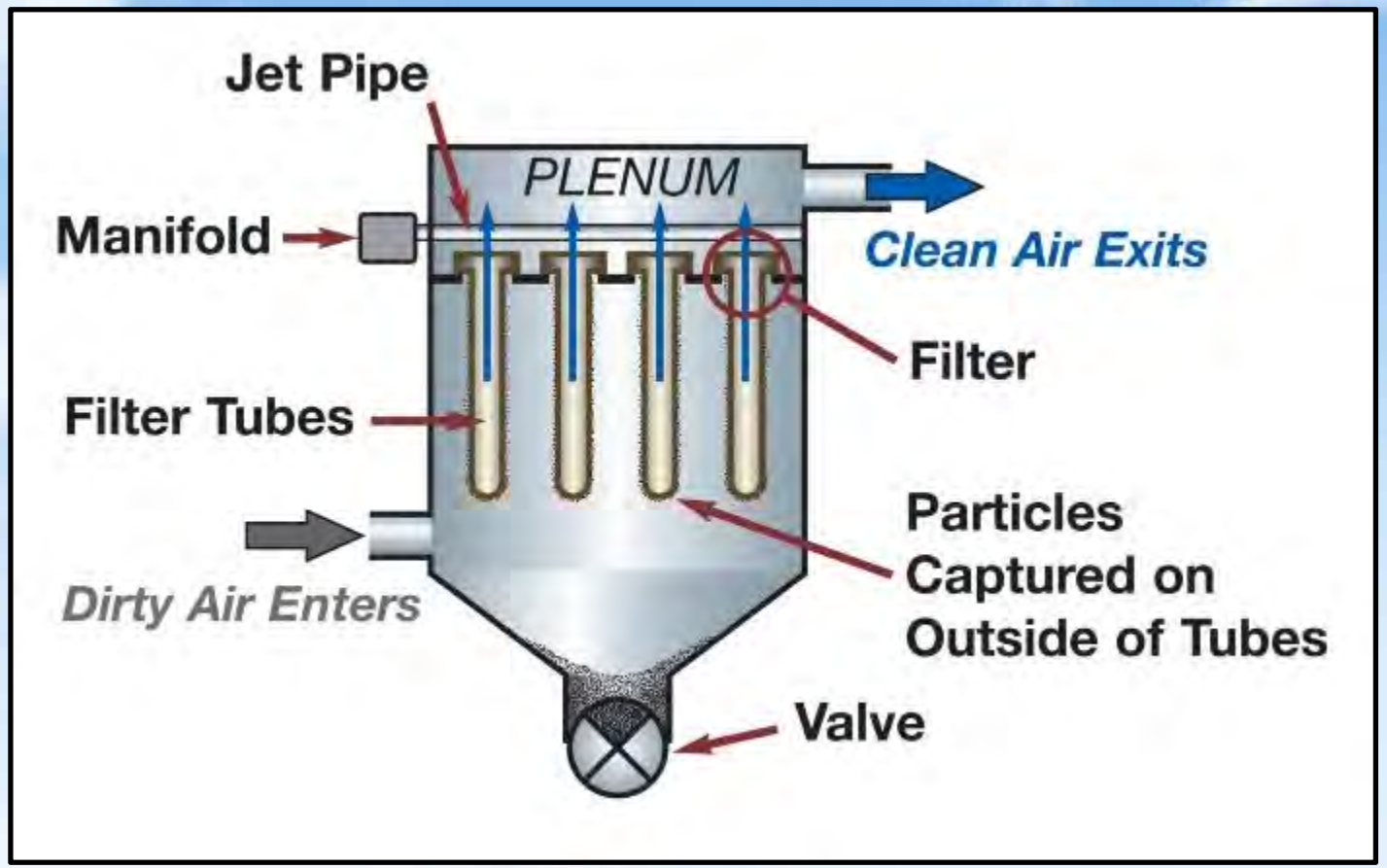


Technology Basis

Protection from Catalyst PM Blinding and Poisoning



Filter Elements - Basic Operations



Technology Basis

Filter Elements – Operating Temperatures

PM + Acids + NO_x

280 → 750 °F

Low temp applications might require second stage of catalyst

PM + Acids

200 → 1200 °F

PM only

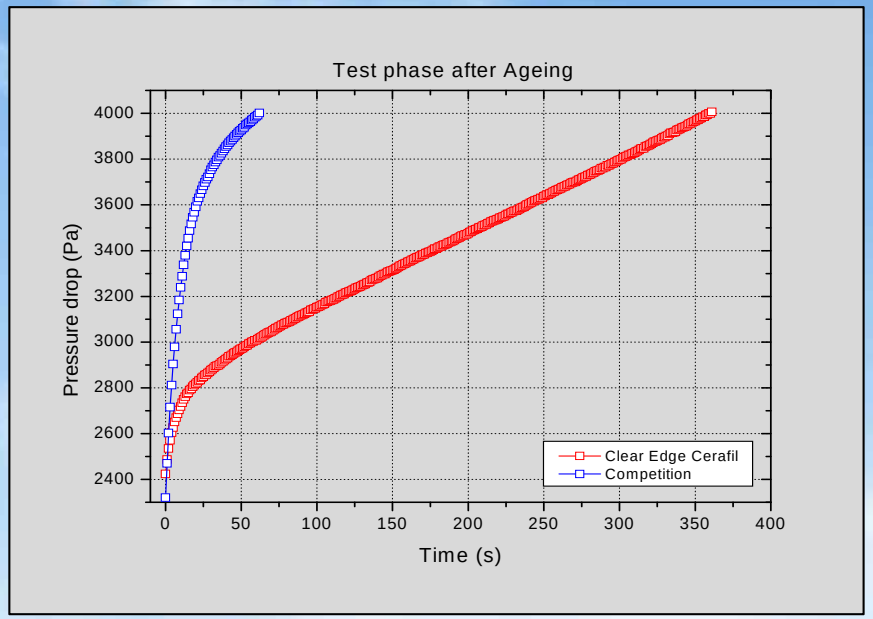
200 → 1,650 °F

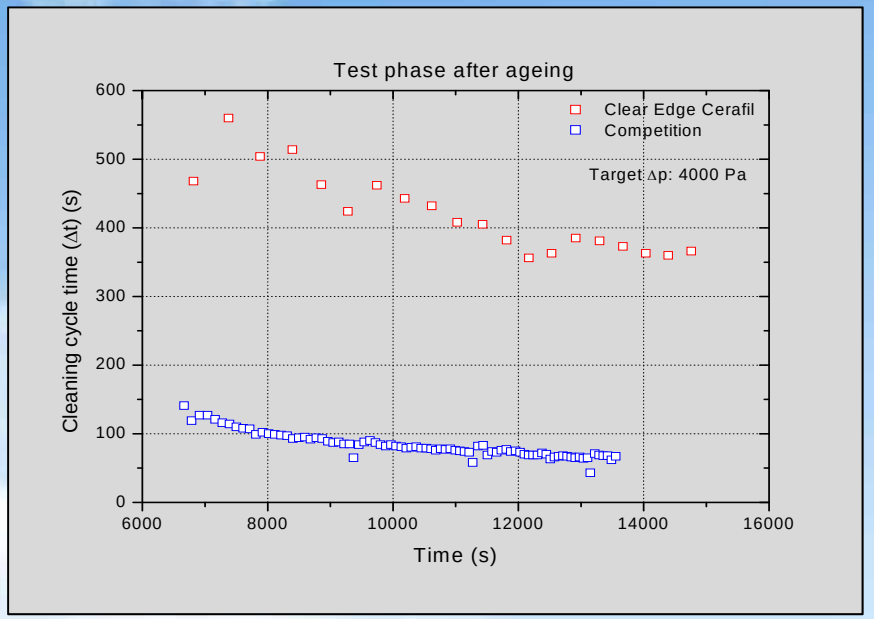
200 °F Temperature Scale 1,650 °F

Acids Include: SO_2, HCl, HF, SO_3

Technology Basis

UltraCat by Clear Edge vs. Other Filter Brands





Parameter	UltraCat by Clear Edge	Others
Porosity	80% (dense outer wall)	90% (open outer wall, dense inner wall, gradient)
Filtration	Mainly on the conditioned outer surface	First dust penetration and then filtration
Dust penetration	0.63 mg	5.03 mg
Pressure drop rise	Gradual	Quick
Cleaning cycle interval	Long	Short

Pressure Drop and Filter Life

- Initial pressure drop dP approximately 4 to 6 “H2O.
- Very gradually ultrafine and condensable penetrate filter.
- Less than of 3% differential pressure increase per year.
- Performance is not affected by increase in pressure drop.
- Extra fan power is built into the system.
- Filters must be changed when the system runs out of fan.
- Filter change is not triggered by catalyst deactivation or change in PM performance.

7 – 10 years filter life

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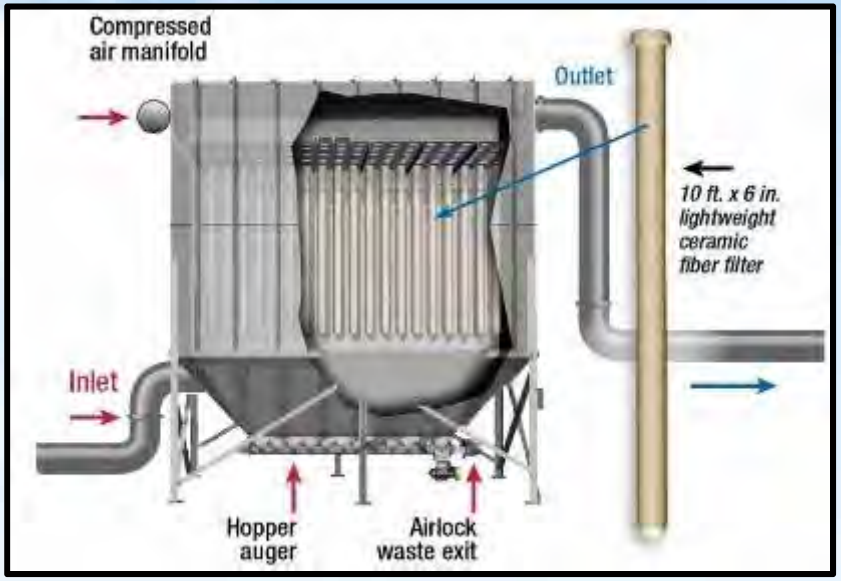
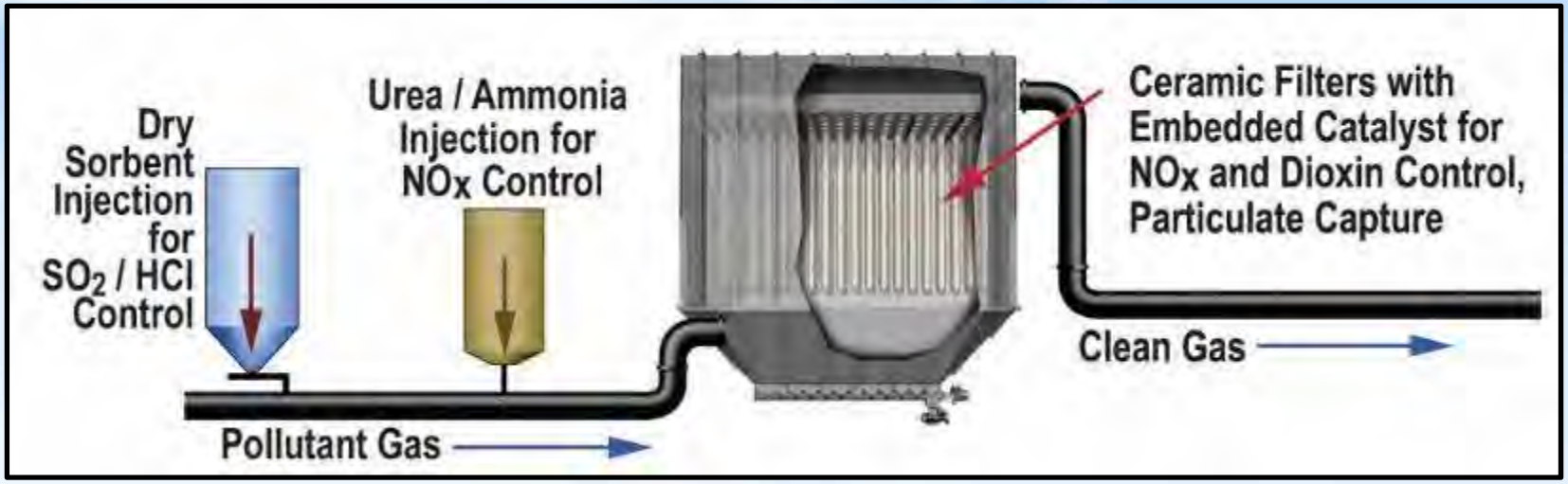


Typical System Configuration

1. If necessary, condition incoming gas to <750ºF
2. Add sorbent to control acid gases and Hg.
3. Add aqua ammonia for NOx reaction.
4. Remove solid waste.



System Design

Single Housing Configuration

1. Maximum of 500 filters per housing.
2. No limit to housings operating in parallel
3. Single Housing Height 34’
4. Single Housing Width 11’
5. Single Housing Length 11’ to 38’ depending on filter count
6. Fully Insulated
7. Indoor/Outdoor

System Design

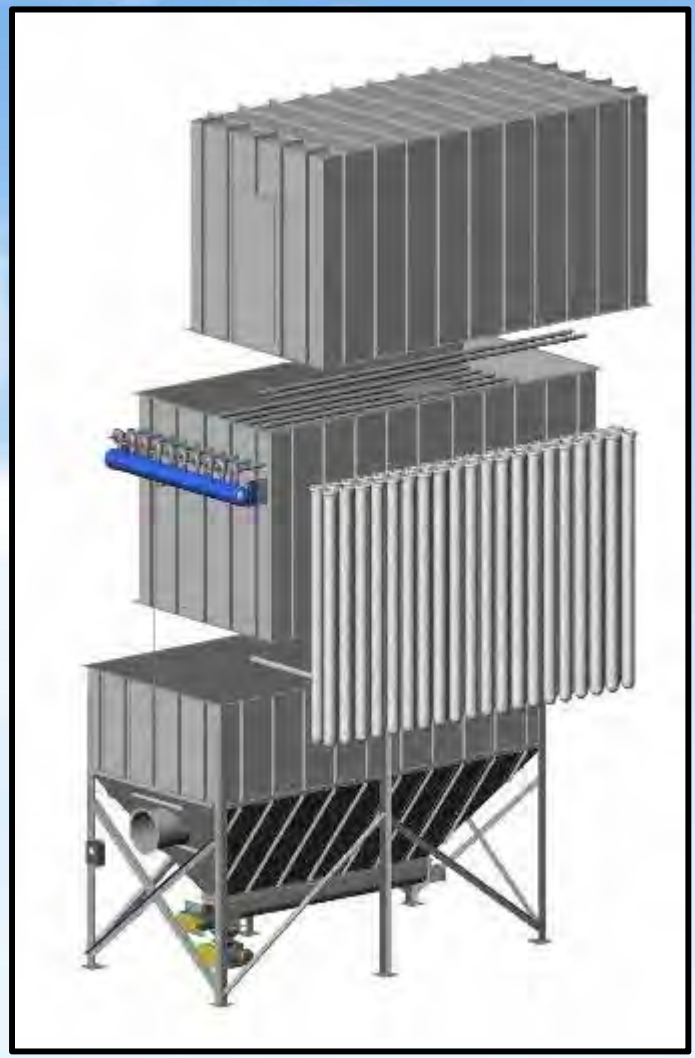
Constructed in Four Sections

1. Walk-in plenum
2. Tube Sheet
3. Hopper
4. Support Frame

Shipped in four pieces

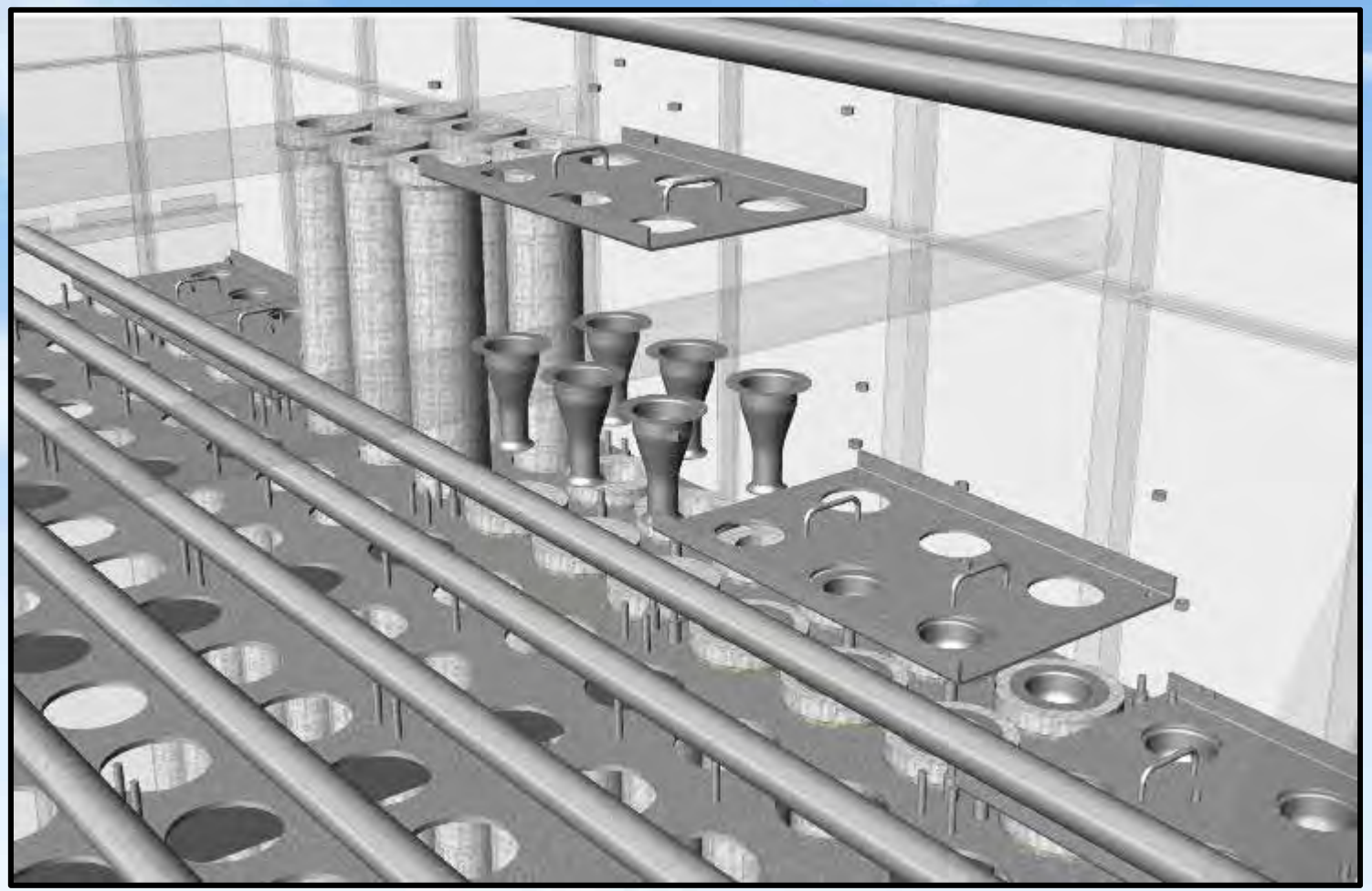
Simple installation with a crane

Filter elements installed in the field by Tri-Mer personnel.



System Design

Tube Sheet and Filter Element Hold Down Detail



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System Design

Filter Element Installation

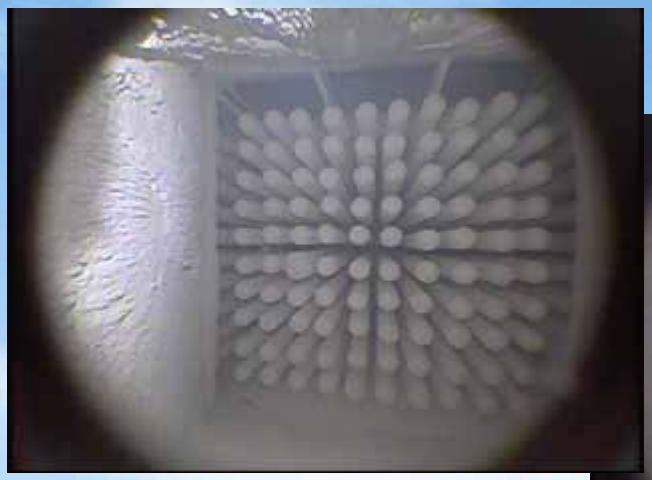
Filter Gasket, Stud, Spacer, and Hold Down Plate

Completed Assembly with Blow Tubes in Place

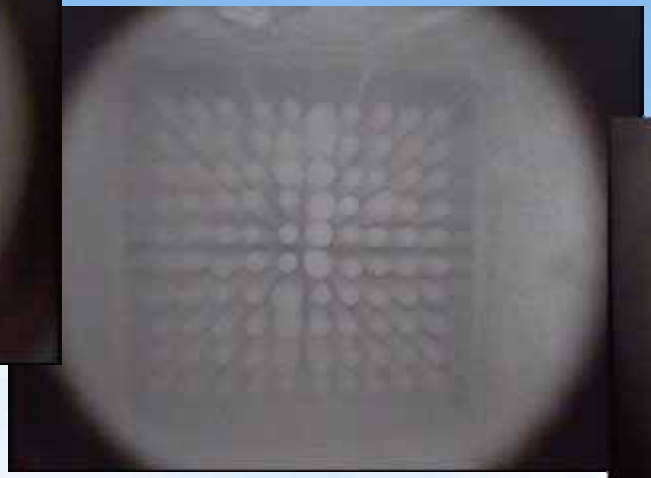
Broken Filter Element

System Design

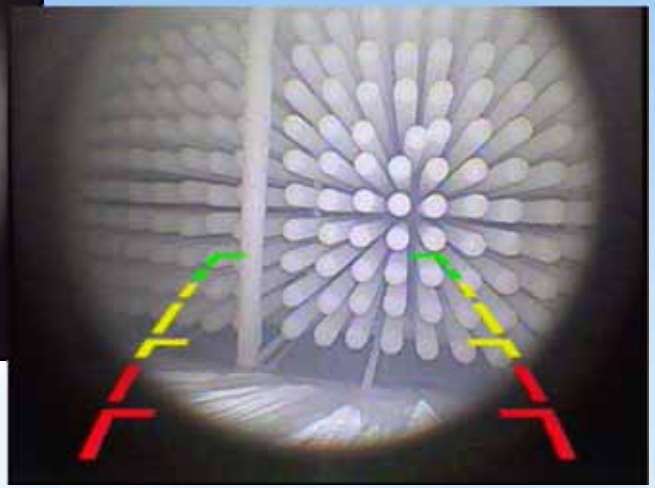
System Inspection Camera - Results



Elements Intact



Pulse Valve Inoperable



Broken Element

- Filters fail at a rate of less than 1 per 500 annually
- Changing a filter requires 4 to 6 hours, most of that is cool down time
- After service gradual heat-up is unnecessary

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System Design

Multiple Filter Housings to Match the Flow

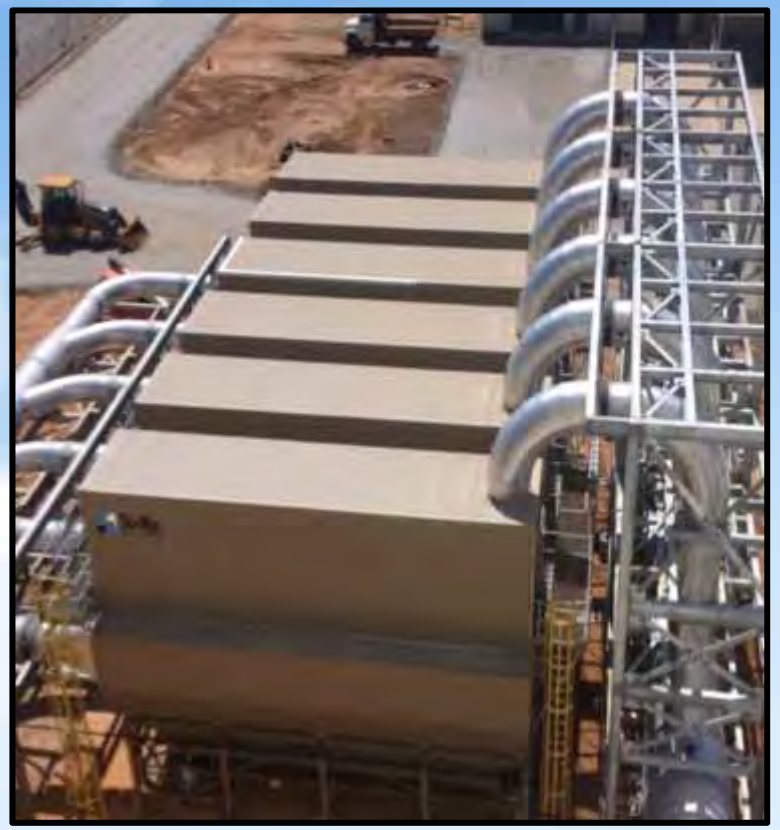
With 3 or More Housings…

- Modules are serviced individually
- Remaining modules treat 100% of the gas flow
- No loss of performance while servicing
- Minimal pressure drop increase while servicing

System Design

12 Housings – Kiln Exhaust

- Ceramic Proppants (Fracking)
- 650 F
- NO_x, SO_2, HCl, HF, and PM
- Operational Q1 2013
- Compliance Verified



System Design

Diesel Exhaust (PM, SOx, NOx)

Systems for treating diesel exhaust from ships at berth are comprised of 2 principal components.

1 Capture System

Stack adaptor and exhaust shuttle connected to stack of auxiliary engine

2 Treatment System

Catalytic ceramic filter system configured for treating PM, SO_x, NO_x

System Design

9 Housings – Glass Furnace, Tableware

- 3 Housings per Furnace, 3 Furnaces
- 600 ^{o}F
- PM, NO_x, SO_x, HCl, and Metals
- Operational Since Jan 2011
- Compliance Verified

System Design

6 Housings – Glass Furnace, Containers

- 3 Furnaces
- 600 ^{o}F
- PM, NO_x, SO_x, and Metals
- Operational Since Sept 2014
- Compliance Verified

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System Design

5 Housings – Glass Furnace, Flat Glass

- 1 Furnace
- 725 ^{o}F
- PM, NO_x, SO_x, and Metals
- Operational Since April 2015
- Compliance Verified

System Design

Experience Counts: 25 Ceramic Filter Projects – Selected List

	Project	Type	ACFM	Emissions	Comments
	Kohler Glass, WI	Glass Furnace	12,000	PM, NOx, HF	Specialty glass
	Illumina, CA	RTO Exhaust	13,500	PM, HCl, NOx	Biotech company
	U of Iowa, IA	Biomass Boiler	15,600	PM, NOx, CO	Boiler MACT
	Gallo Glass, CA	Glass Furnace	23,125	PM, SO2	First module of 6
	Military/Siemens, CA	Boiler Exhaust	24,000	PM, NOx, HCl, SO2	Boiler MACT
	3M, MN	Production	25,000	PM, NOx	Two projects
	Calgon Carbon, AZ	Reactivation Furnace	25,400	PM, SO2, HCl	First industry application
	CAEM, Port of LA	Diesel Engine Exhaust	25,900	PM, NOx	Ships at dock
	EveryWare Glass, PA	Glass Furnace	29,300	PM, NOx, SO2, Metals	EPA ruling
	Durand Glass, NJ	Glass Furnace	106,000	PM, NOx, SO2, Metals	EPA ruling
	Ardagh Glass, IL	Glass Furnace	144,000	PM, NOx, SO2, Metals	EPA ruling
	AGC Glass, KS	Glass Furnace	150,000	PM, NOx, SO2, Metals	EPA ruling
	AGC Glass, TN	Glass Furnace	165,000	PM, NOx, SO2, Metals	EPA ruling
	Guardian Glass, MI	Glass Furnace	175,000	PM, NOx, SO2, Metals	EPA ruling,
	Imerys, GA	Ceramic kiln	324,000	PM, NOx, SOx, HCl, HF	First industry application
	Confidential	Kiln Exhaust	450,000	PM	Design, industry first

System Design

Tri-Mer Catalytic Ceramic Filters - Applications

Combust / Incinerate

- Glass furnaces
- Solid fuel boilers
- Syngas cleaning
- Chemical waste
- Medical waste
- Radioactive waste
- Munitions destruct
- Petrochemical sludge
- MSW, scrap tires
- Animal waste

Chemicals & Minerals

- Alumina refining
- Calcium carbide production
- Activated carbon production
- Catalyst production
- Silica production
- Fine chemicals production
- Sulphuric acid plant

Metallurgical

- Secondary aluminium smelting
- Precious metal recovery
- Swarf drying
- Tin smelting
- Lead smelting
- Nickel refining
- Foundries
- Copper smelting
- Steel making

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- **NOx Control**
- Multi Pollutant Performance
- Project Delivery

NO_x Control

Tri-Mer System – Brief Summary

1. Dry powdered sorbent – bicarb, trona, or lime – is injected into the duct. It immediately starts to react with the SO_2, SO_3, and HCl to form solid particles that will be captured by the ceramic filter.
2. Non-hazardous 19% aqueous ammonia is atomized and sprayed into the duct. It immediately turns into a gas and mixes with NO_X. This mixing is not affected by the process PM or sorbent PM.
3. The gas stream goes into the filter housing, and the particulate from the process and sorbent is captured on the outside surface of the filters. Filters are periodically cleaned (about twice a day for many applications) with a burst of compressed air while filter housings remain on-line.
4. The NO_X and ammonia mixture react on the enormous surface area of the nano-catalysts embedded in the filter walls. The mixture is free from particulate that can blind or poison the catalyst, so the reaction can occur more efficiently and across a much wider temperature range. NO_X is broken down into harmless N_2 and water vapor. There is minimal ammonia slip.
5. Treated air exits the ceramic filter system, drawn by an induction fan to the stack.

SCR Reaction for Destroying NO_x

Selective Catalytic Reduction (SCR)

$$2NO_{gas} + 2NH_{3\ gas} + \tfrac{1}{2}O_{2\ gas} \xrightarrow{\text{CATALYST}} 2N_{2\ gas} + 3H_2O_{gas}$$

NOx is converted to the harmless basic constituents of our atmosphere, nitrogen and water vapor.

Conventional SCR Catalyst Support Systems

High Removal at >650 F

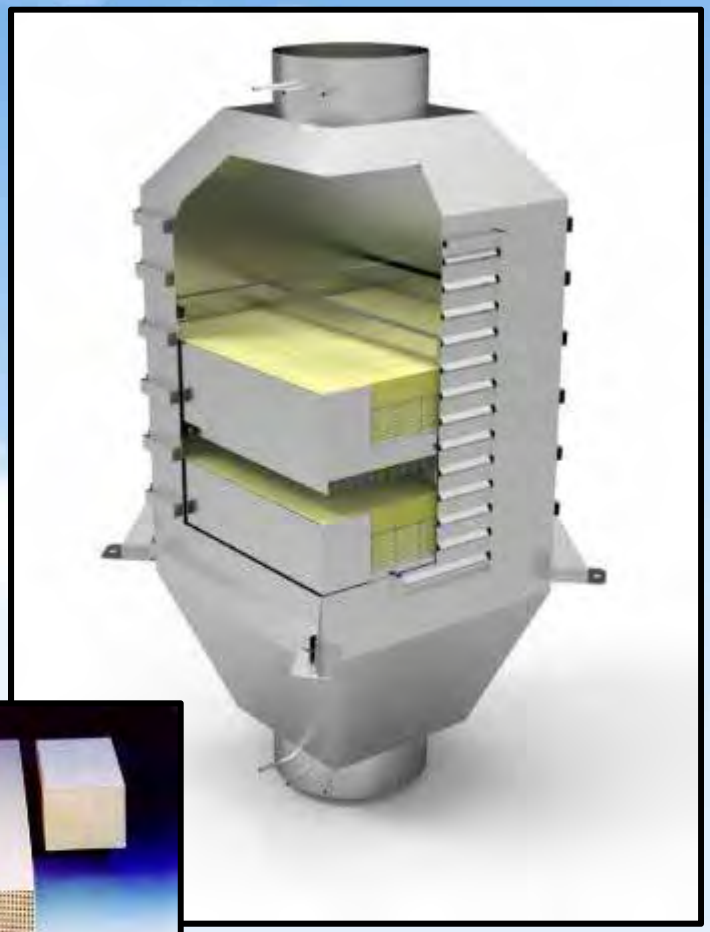
Blinding and poisoning the catalyst are the greatest drawbacks.

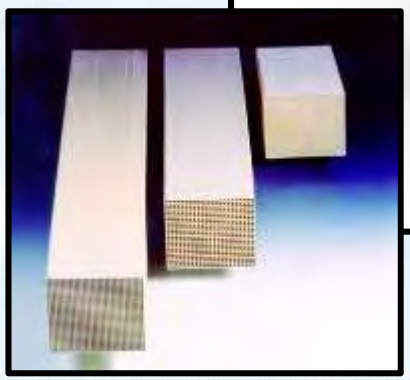
"Hot side"

Reactor placed before
any PM or other pollutant removal

"Cold side"

Reactor placed after electrostatic precipitator or fabric baghouse for PM control.





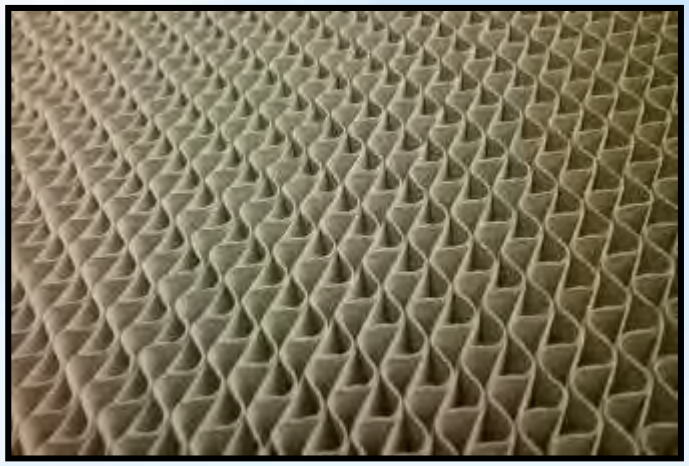
Conventional SCR Blocks and Channels

Typical SCR Block Catalysts

Typical temperature range
600 F – 1,100 F

In industrial plants the conventional catalyst types typically operate with 5-15% catalyst effectiveness in the SCR (Selective Catalytic Reduction of NOx by NH3) – Haldor Topsoe, P. Schoubye paper 2006

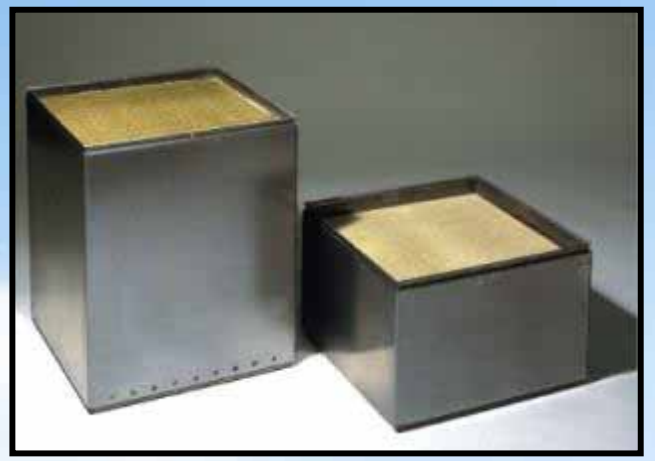
Gas Channels



Catalytic Filter Technology for NO_x

The combination of two well established technologies

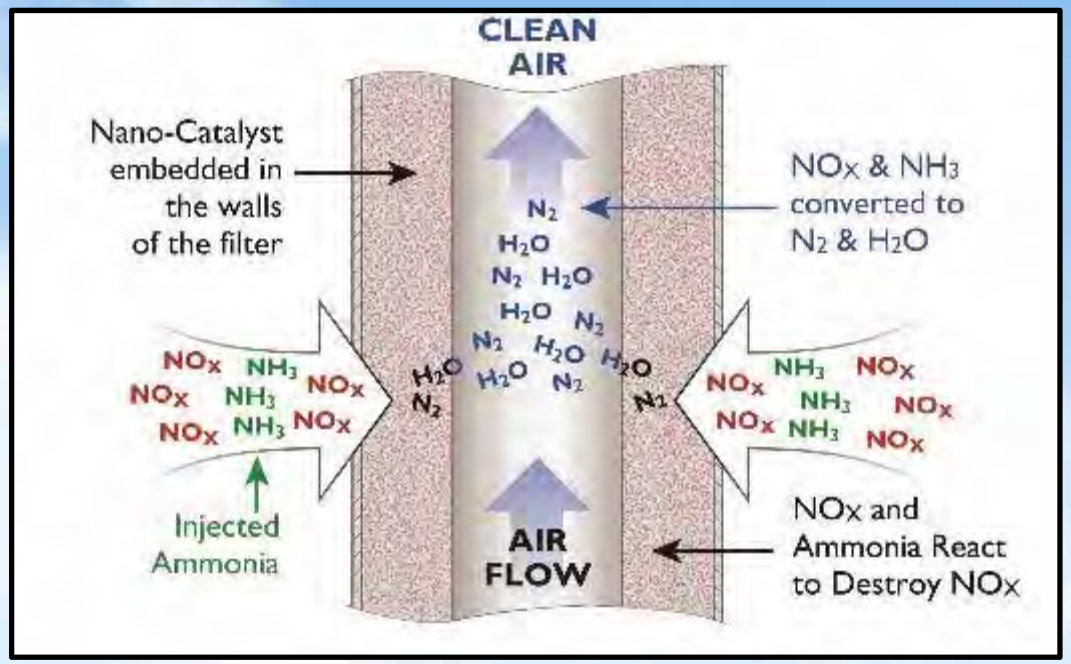
Standard filter tube
+ SCR catalyst (in micronized form Infused in filter walls)



Catalyst Utilization: 6X over Conventional SCR

Utilization is virtually 100%, compared to 15% for traditional SCR

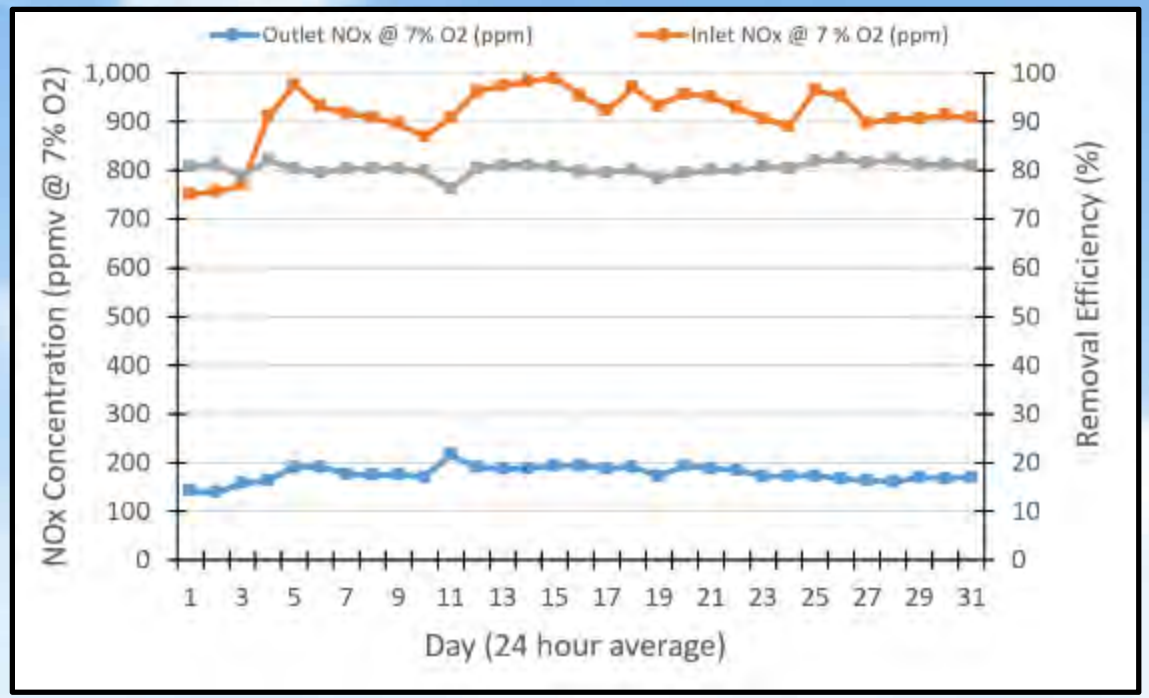
Haldor Topsoe, P. Schoubye paper 2006



- Lower temperatures achieve higher removal efficiency.
- 60-70% starting at 350 ^{o}F, and over 90% approaching 450 ^{o}F.
- Traditional block SCR usually requires 650 ^{o}F to reach 90%.

NO_x Control

Float Glass Furnace



- Compliance Requirement is 80% Reduction
- Average Reduction = 80.5%
- Ammonia Slip <5 ppmv as Measured by Insitu IR
- Precise Control Minimizes Ammonia Consumption
- Filter Operating Temp = 690F

Average Inlet NOx	[ppm]	915.2
Average Outlet NOx	[ppm]	176.6
Average NOx Percent Removal	[%]	80.5%

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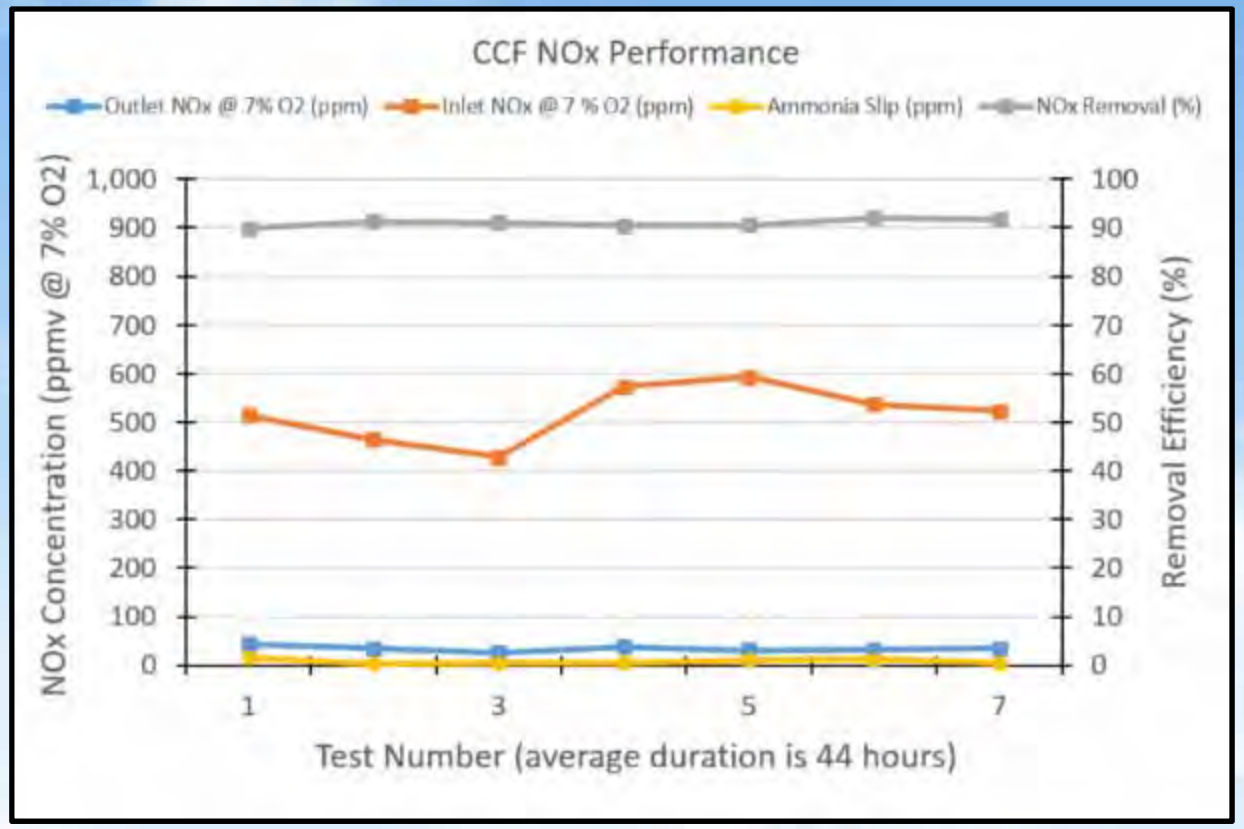
NO_x Performance

Multiple Stationary Diesel Generators



- Compliance Requirement is 90% Reduction
- Average Reduction = 91.0%
- Filter Operating Temp = 450F
- Ammonia Slip <5 ppmv as Measured by Insitu IR
- Precise Control Minimizes Ammonia Consumption

Average Inlet NOx	[ppm]	519.4
Average Outlet NOx	[ppm]	34.6
Average NOx Percent Removal	[%]	91.0%
Average Ammonia Slip	[ppm]	3.5

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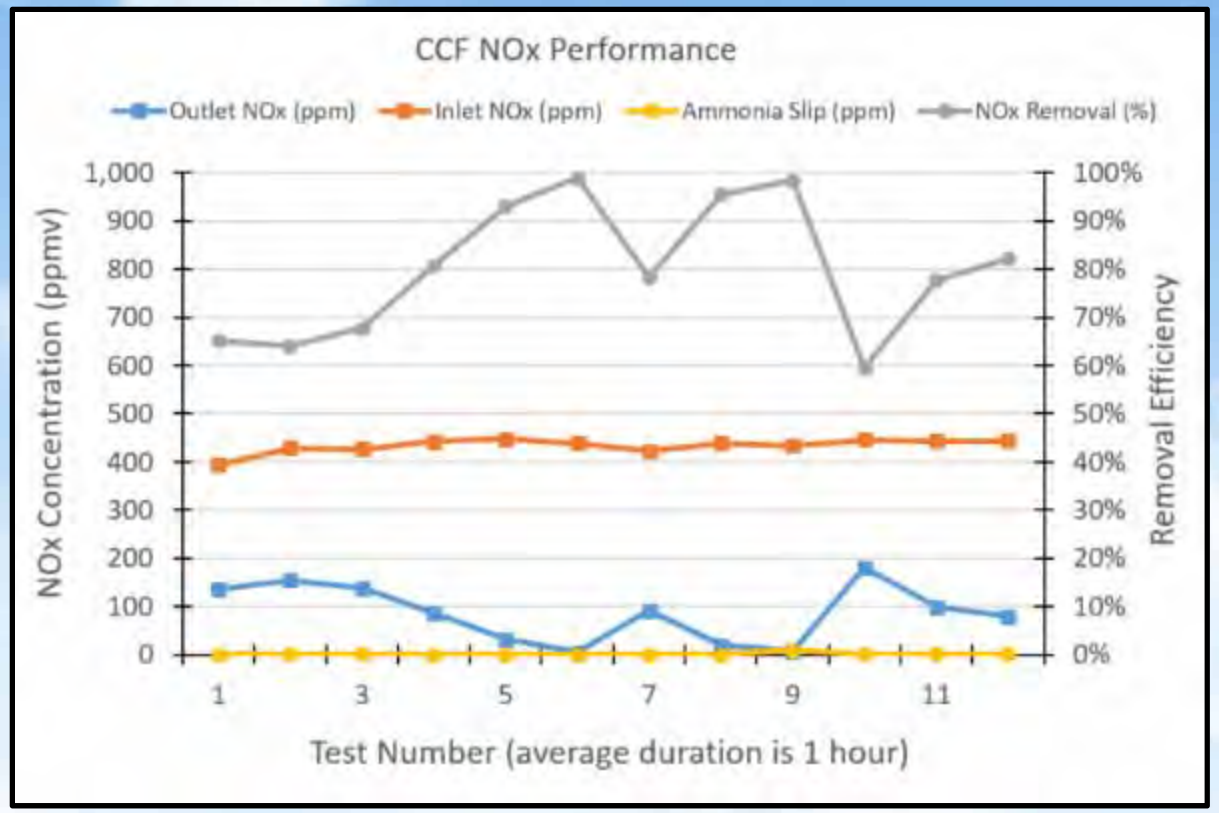
NO_x Performance
Lignite Coal



Average Inlet NOx	[ppm]	433.7
Average Outlet NOx	[ppm]	85.3
Average NOx Percent Removal	[%]	80.1%
Average Ammonia Slip	[ppm]	0.9

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Multi Pollutant Performance

Typical Ceramic Filter PM Results

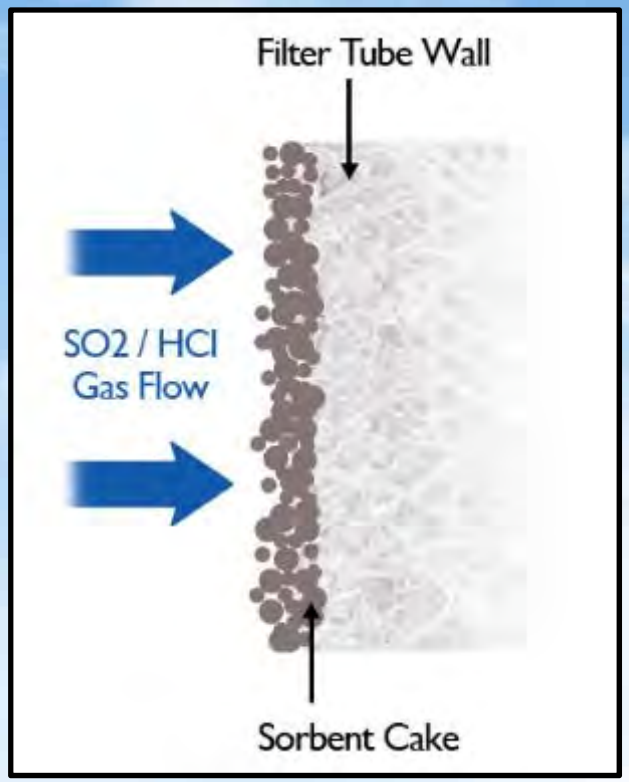
EFFICIENCY OF FIBROUS CERAMIC FILTER ELEMENTS IN VARIOUS APPLICATIONS						
PROCESS	PARTICLE SIZE	INLET PM LOADING		OUTLET PM LOADING		INFERRED EFFICIENCY
	d_{50}[1] , µm	mg/Nm^3	gr/dscf	mg/Nm^3	gr/dscf	%
Aluminum powder production	<50	550	0.24	<1	<0.0004	99.99
Nickel refining	<10	11,800	5.16	<1	<0.0004	>99.8
Smokeless fuel production	4.8	1000	0.44	1.5	0.0007	99.9
Zirconia production	1.2	8000	3.5	0.8	0.0003	99.85
Secondary aluminum	<1.0	870	0.38	0.5	0.0002	>99.99

1. Diameter of median size particle 2. 1 mg/Nm^3 equals 2288 grains/dry standard cubic foot.

Meets all EPA and state requirements across the spectrum of applications.

Multi Pollutant Performance

In-Duct Reaction PLUS Sorbent Cake on the Filter



Sorbent Injection Chemistry

$$Ca(OH)_{2\ (powder)} + SO_{2\ (gas)} + 1/2O_{2\ (gas)} \longrightarrow CaSO_{4\ (powder)} + H_2O_{\ (gas)}$$

Multi Pollutant Performance

Lhoist Sorbacal SP Surface Area

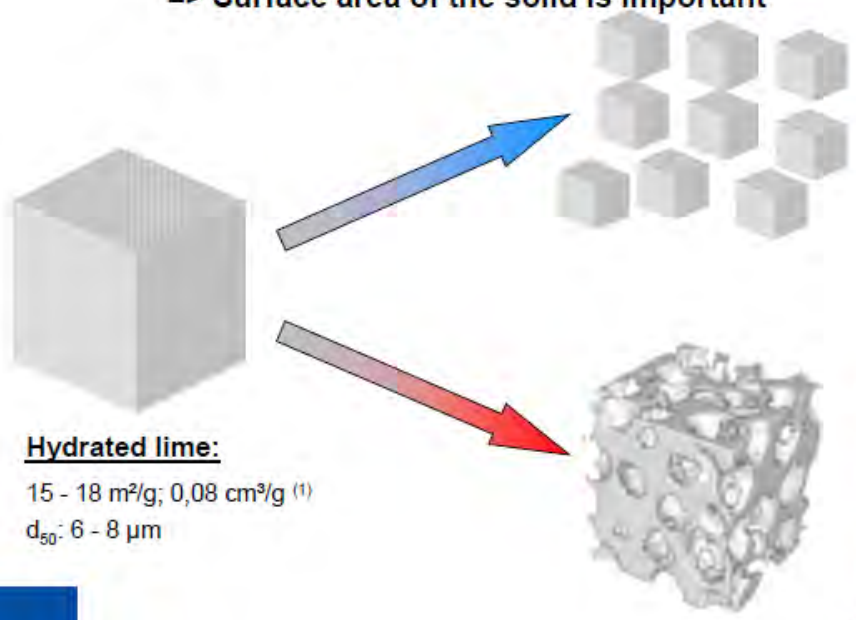
Sorbacal®

Product development highly reactive hydrate ($Ca(OH)_2$):

Reaction of $Ca(OH)_2$ and acid flue gas components:

Acid – base reaction by gas – solid contact

=> Surface area of the solid is important



Hydrated lime:

15 - 18 m²/g; 0,08 cm³/g (1)

d_{50}: 6 - 8 µm

Sorbacal® A:

35 - 38 m²/g; 0,13 cm³/g

d_{50}: **2 - 3 µm**

Sorbacal® SP:

42 - 45 m²/g; 0,25 cm³/g

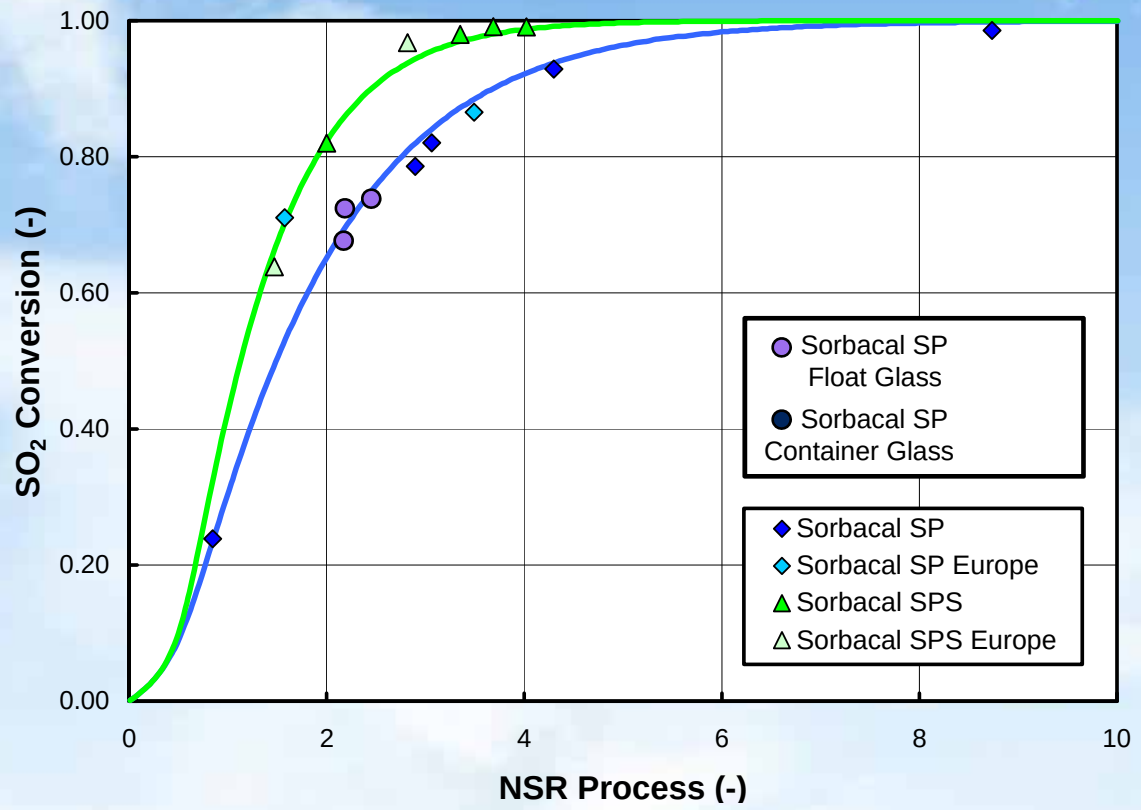
d_{50}: 6 - 8 µm

At the moment developing
(Sorbacal® SPS for > 160°C)

(1): spec. surface area/ pore volume

Multi Pollutant Performance

SO_2 Reduction on Various Glass Furnace Applications



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Project Delivery

Tri-Mer Corporation

Established 1960

12 Acre Site Near Detroit, Michigan

Tri-Mer® CORPORATION

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Project Delivery

In-House Manufacturing , U.S. based

- Air pollution control (APC) specialists
- Engineer, design, fab, and install
- Wet and dry systems
- In-house equipment fabrication
- Steel and thermo-plastic fab facilities

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Project Delivery

200,000 Sq Ft of Engineering Offices and Manufacturing

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Project Delivery

Tri-Mer Corp – Turnkey Project Execution

Tri-Mer offers turnkey systems and services:

- Pollution control system design
- Engineering (mechanical, electrical, civil, structural)
- Site work such as demolition
- Site work up-front construction
- Regulatory agency support
- Controls and integration
- Continuous Emission Monitors
- In-house equipment fabrication
- Installation and start-up
- Aftermarket support services

Thank You

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