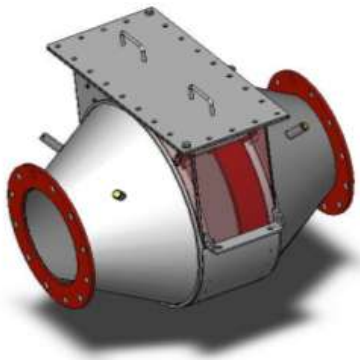
Strategic Partners Exline, Incorporated & DCL International Inc.

Engineered Solutions for Exhaust Emissions



Global Leader in Emissions Control Solutions

Overview

1. DCL International
2. Regulations
3. Catalyst Basics
4. Catalyst Types & Functionality
5. Catalyst Manufacturing
6. Sizing, Selection & Design Aspects
7. DCL Products
8. Installation, Operation & Maintenance
9. Catalyst Cleaning
10. Failure Modes
11. Trouble Shooting

Our Mission

Preserving and Improving The Quality of the Air We breathe

Global Leader in Emissions Control Solutions

Who Are We?

- **Established:** 1986
- **Business:** Catalytic emission control for industrial engines
- **Market:** Worldwide (50% NA, 35% Europe, 15% Asia)
- **Workforce:** >100 employees
- **Facility:** 120,000 sq. ft. (3 locations)
- **Quality System:** ISO 9001 registered research, design and manufacturing

Markets Served

- Global Sales: 50% N. America, 35% Western Europe, 15% Asia
- Main Focus: Off-road industrial equipment emission controls

Mobile

- Construction Equipment
- Material Handling
- Underground Mining

Stationary

- Gas Compression
- Co-Generation
- Power Generation
- Refrigeration

Vertical Integration

Canning / housing fabrication

Catalytic coating technologies

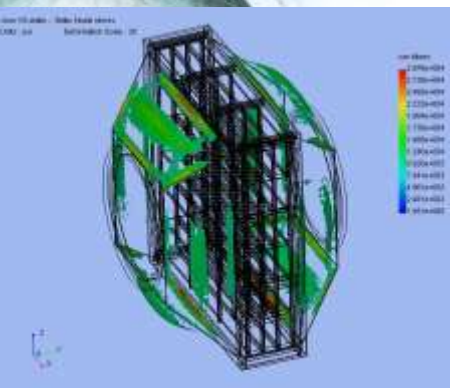
Substrate making

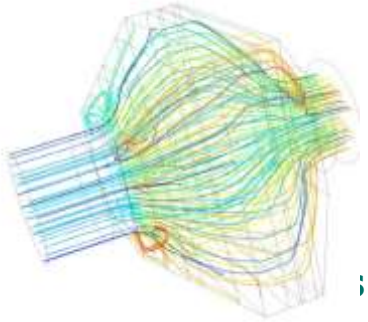
Raw Materials

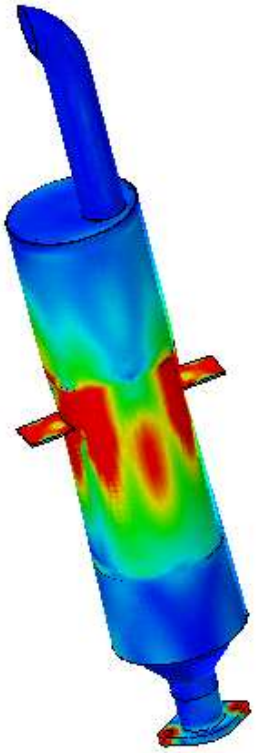
Engineering
R&D
Sales & marketing

Engineering

- Solid modelling of designs
- Finite element analysis for thermal and mechanical stress/strain problems
- Computational fluid dynamic analysis for flow fields and pressures
- Design techniques for acoustics design
- Emissions modelling techniques for catalyst design
- Engine test cells for design validation







Research & Development

Focus of Work

- Improve product performance
- Adjust PGM ratios to account for market conditions
- Reduce product cost

Model Gas Reactor

Chemistry Lab

Engine Test Cells

Emissions Measurement Equipment

EPA Definitions

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Major vs. Area Source

- Major source: is a site with the potential to emit a single HAP at a rate of 10 tons/year or a combination of HAP's at a rate of 25 tons/year
- Area Source: means any stationary source of HAP that is not a major source as defined above

CI vs. SI Engines

- Compression Ignition: means relating to a type of stationary internal combustion engine that is not a spark ignited engine
- Spark Ignited: Either a gasoline fueled engine; or any other type of engine using a spark plug (or other sparking device)…Dual fuel engines in which a liquid fuel (typically diesel fuel) is used for CI and gaseous fuel (typically natural gas) is used as the primary fuel at an annual average ratio of less than 2 parts diesel to 100 parts total fuel on an energy equivalent basis are spark ignition engines.

Emergency vs. Non-Emergency

- Emergency engines: engines that operate less than 100 hours per year and may also operate the engine as part of an emergency demand response (DR) program for a maximum of 15 hours per year when regional transmission organization has determined there are emergency conditions that could lead to a potential electrical blackout or grid failure
- Non-emergency engines: engines that operate >100 hours per year or used in peak shaving programs or to generate income for a facility to supply power to an electric grid or otherwise supply power as part of a financial arrangement with another entity with the exception of emergency DR where financial arrangements are limited to emergency power

EPA Regulations

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Major Regulations

NSPS – In place

-New equipment, either certified by manufacturer (CI & SI) or aftermarket

NESHAP – CI Rule Signed Feb 2010

-SI August 2010

-Existing equipment

NSPS – All New Engines

- New Source Performance Standards – SI
- CI Engines follow EPA Tier system

Engine Type	Maximum Engine Power	Manufacture Date	Emission Standards[a]					
			g / bhp-hr			ppmv (at 15% O_2)		
			NOx	CO	VOC	NOx	CO	VOC
Non-Emergency Engines	100 ≤ hp < 500	7/1/2008	2.0	4.0	1.0	160	540	86
		1/1/2011	1.0	2.0	0.7	82	270	60
Non-Emergency, Lean Burn Engines	500 ≤ hp < 1,350	1/1/2008	2.0	4.0	1.0	160	540	86
		7/1/2010	1.0	2.0	0.7	82	270	60
Non-Emergency Engines[c]	hp ≥ 500	7/1/2007	2.0	4.0	1.0	160	540	86
		7/1/2010	1.0	2.0	0.7	82	270	60
Emergency	25 < hp < 130	1/1/2009	10[b]	387	N/A	N/A	N/A	N/A
	hp ≥ 130		2.0	4.0	1.0	160	540	86

[a] Operators of non-certified engines may choose to comply with g/bhp-hr or ppmv limits

[b] Emergency engine standards (25 < hp < 130) are in terms of NOx + HC

NESHAP - CI

Engine Class	Rule
Non Emergency **100≤300 hp**	**Area Source - Best Practices** **Major Source -** 230 ppmvd CO at 15% O2
Non Emergency **300 ≤500 hp**	**49 ppmvd CO *or*** **70% CO reduction**
Non Emergency **> 500 hp**	**23 ppmvd CO *or*** **70% CO reduction**
Emergency	**Manufacturers Best Practices – No Test Required**

Compliance By May 3, 2013

NESHAP – SI Major Source

Engine Class	Rule
2SLB Non-Emergency 100 ≤ 500 hp	225 ppmvd CO at 15% O_2
4SLB Non-Emergency 100 ≤ 500 hp	47 ppmvd CO at 15% O_2
4SRB Non-Emergency 100 ≤ 500 hp	10.3 ppmvd formaldehyde at 15% O_2
Landfill/Digester Gas Non-Emergency 100 ≤ 500 hp	177 ppmvd CO at 15% O_2

Compliance By October 19, 2013

NESHAP – SI
Area Source

Engine Class	Rule
4SLB Non-Emergency > 500 hp that operate more than 24 hours per year	47 ppmvd CO at 15% O_2 or 93% CO reduction
4SRB Non-Emergency > 500 hp that operate more than 24 hours per year	2.7 ppmvd formaldehyde at 15% O_2 or 76% formaldehyde reduction

Compliance By October 19, 2013

NESHAP - Requirements

Engine Class	Operating Requirement
All Engines Equipped w/ Oxidation Catalysts	-BP cannot rise by >2" w.c. from baseline -T maintained between 450-1350 F
Non Emergency & Emergency < 100 hp	Manufacturers Best Practices
Non Emergency 100 hp ≤ hp ≤ 500 hp	Initial Performance Test Required
Non Emergency > 500 hp	-Initial Performance Test Required -Performance Test Required – every 3 years or 8760 hrs whichever comes first -Continuously monitor T across catalyst -Check BP drop monthly

Start-up, Shutdown & Malfunction (SSM)

- Startup, shutdown & malfunction; the rule relaxed startup regs & now allow a maximum of 30 min for startup & operators must minimize engine idling during startup
- EPA believes that any emissions during a malfunction and shutdown would be of short duration compared to the emission averaged during overall testing time (three one hour runs) and that engine should still be able to comply

Catalyst Basics

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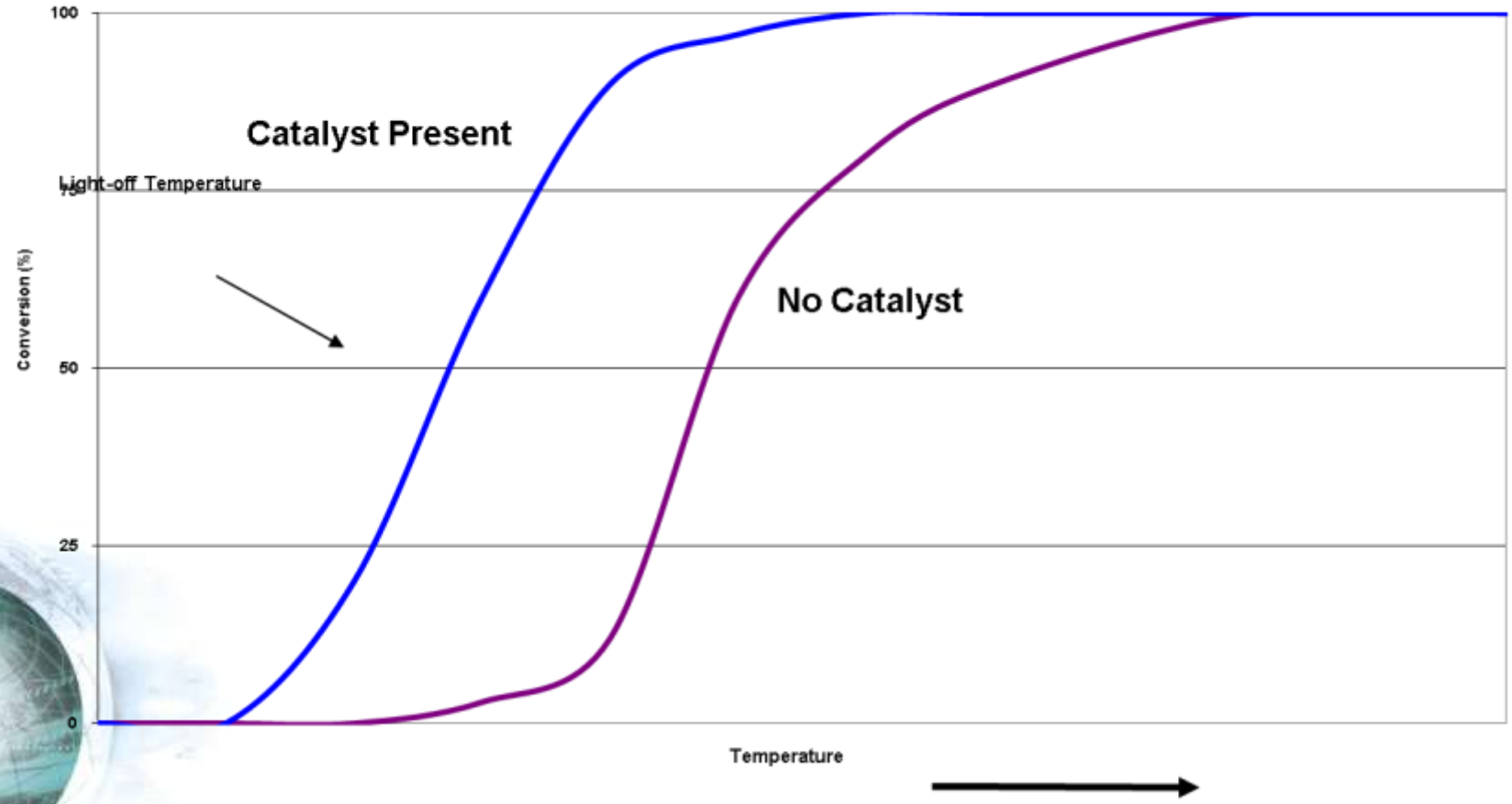
Catalyst Basics

Q. What is a catalyst?

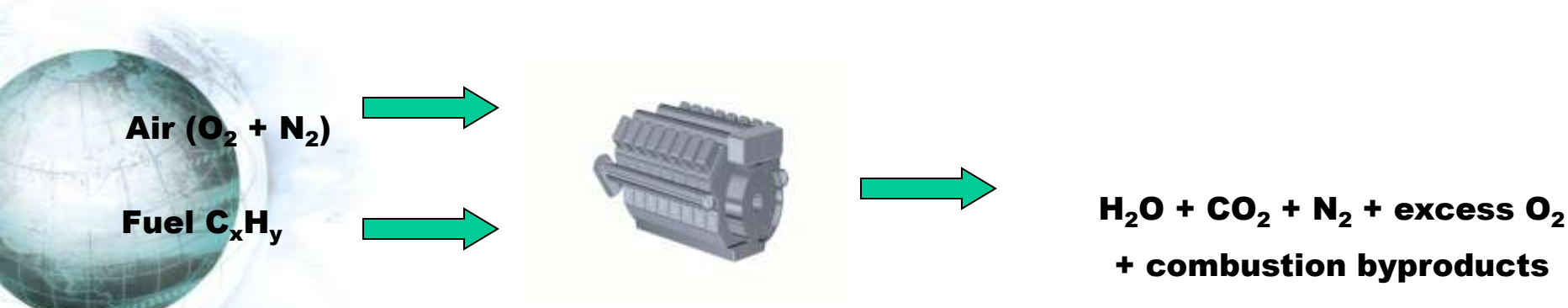
A. A material that alters the rate of reaction (lowers the required energy) and gives the desired products without being consumed in the reaction.

Catalyst Basics



Engine Exhaust

- Combustion by-products
- NO_x (oxides of nitrogen)
- CO (carbon monoxide)
- HC (hydrocarbons)
- SO_x (oxides of sulfur)
- CHO (aldehydes)
- PM_{10} (particulate matter 10 microns and smaller)
- HAPs, etc.



Pollutants of Concern

NOx	Oxides of Nitrogen, formed as bi-products of combustion that can be lethal in small concentrations and contribute to the formation of smog.
CO	Carbon Monoxide, formed as a bi-product of combustion, is poisonous and contributes to the formation of smog.
HC	Hydrocarbons, bi-products of combustion as well as unburnt fuel that can be carcinogenic and also contribute to the formation of smog. HCs can be broken into subcategories of THC (total HC), VOC (Volatile Organic Carbon), NMHC (Non-Methane HC), NMNEHC (Non-Methane Non-Ethane HC) and HAPs (Hazardous Air Pollutants) .
PM	Particulate Matter, carbon particles formed by the combustion of diesel fuel that can be carcinogenic and cause lung disease. Usually classified by particle size (less than 10 microns PM_{10} and less than 2.5 microns $PM_{2.5}$)

Catalyst Types & Functionality

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Catalyst Types

- Many types of catalysts used in many different industrial processes; oxidation vs. NSCR
- Catalysts for internal combustion engines are precious metal based; Platinum, Palladium and Rhodium
- Different types of engines, burning different types of fuel require different combinations of metals depending on which pollutants are needed to be destroyed.

Engine Types

Rich Burn	Natural Gas, Propane or Gasoline spark ignited engines that are set operate with < 0.5% oxygen in the exhaust. Also referred to as Stoichiometric engines. General trends include medium NOx production and high exhaust temperatures.
Lean Burn	Natural Gas, Propane or Gasoline spark ignited engines that typically operate with > 5% oxygen in the exhaust. General trends include low NOx production, high VOC production and medium to low exhaust temperatures.
Diesel	Diesel engines typically operate with >5% oxygen in the exhaust. NOx formation varies depending on the age and condition of the engine. PM, and CO/VOC are also produced to varying degrees depending on the age and condition of the engine

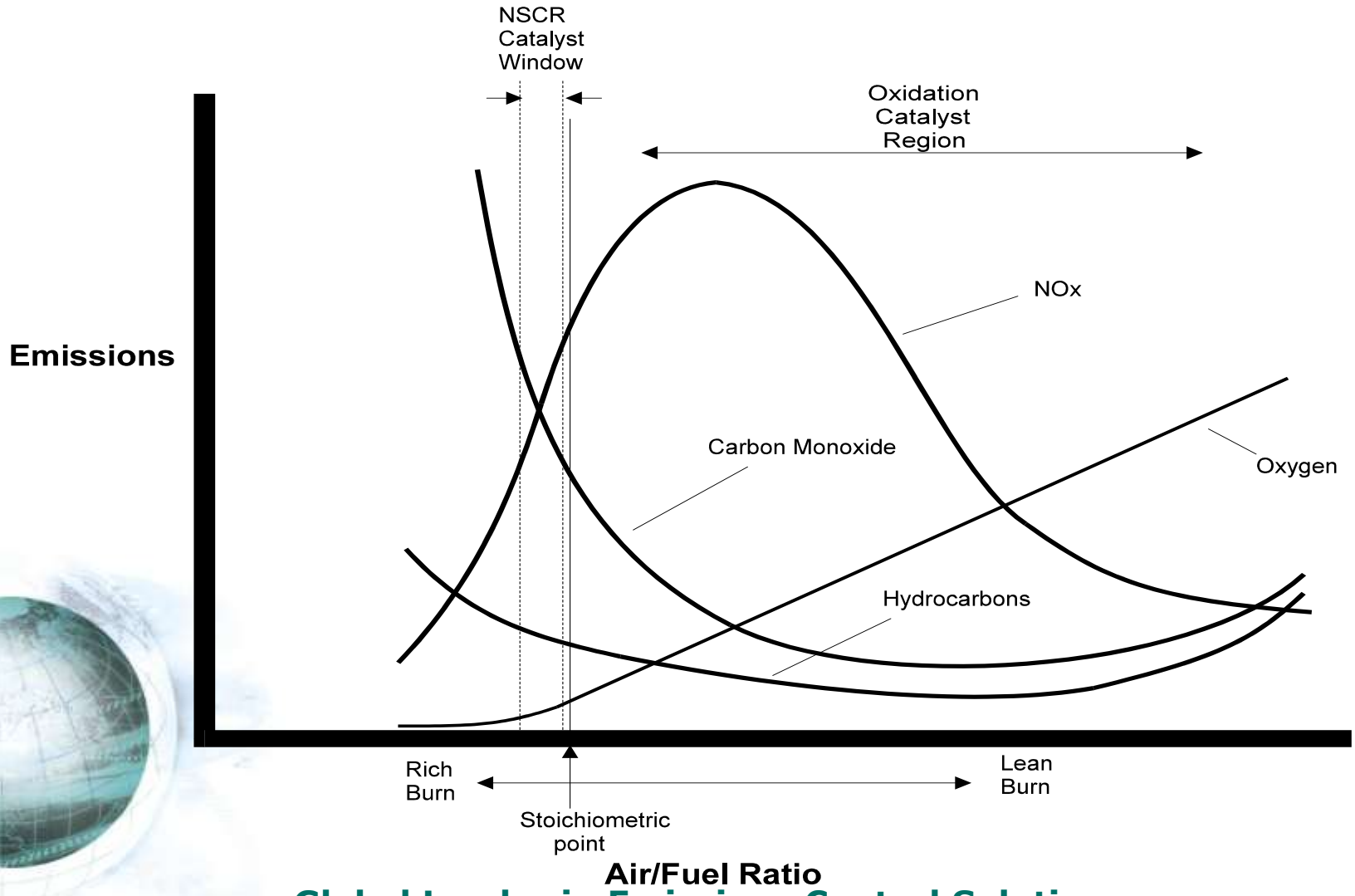
NSCR Catalysts (3-Way)

- Used on rich burn engines
- Removes NOx, CO and HC simultaneously
- Small % of O_2 in the exhaust required (0.2-0.5%)
- Requires an Air Fuel Ratio Controller

$$CO + O_2 \Rightarrow CO_2$$
$$CO + NO \Rightarrow \tfrac{1}{2} N_2 + CO_2$$
$$C_xH_y + NO \Rightarrow N_2 + H_2O + CO_2$$
$$C_xH_y + O_2 \Rightarrow CO_2 + H_2O$$

Engine Exhaust Trends

Emission Trends for Spark Ignited Engines



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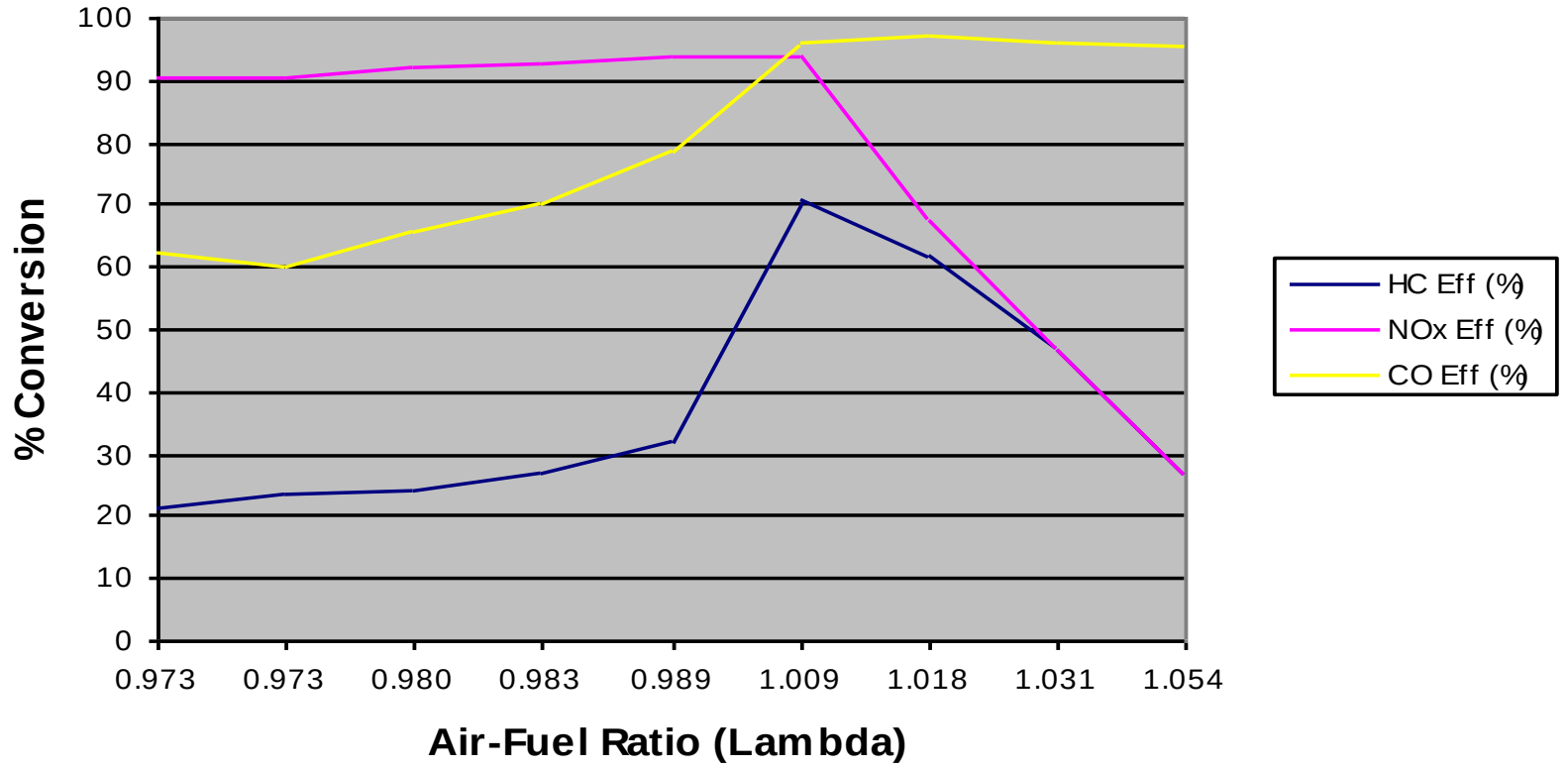
NSCR Conversion

Lambda Sweep (Lab Trial)



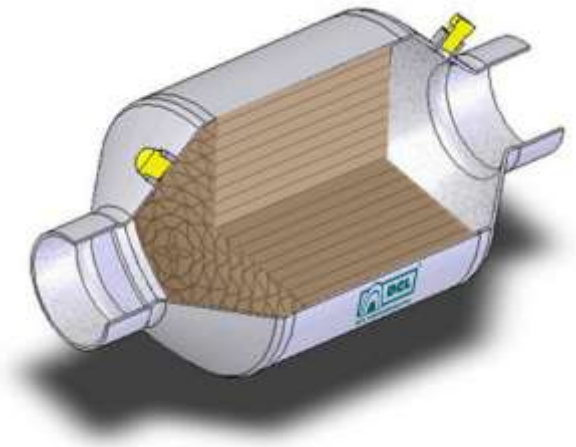
Oxidation Catalysts

- Used on lean combustion engines
- Sufficient oxygen in the exhaust is required to oxidize CO, NMHC and formaldehyde
- No effect on total NOx levels in the exhaust
- Used on LB & Diesel

$$CO + O_2 \Rightarrow CO_2$$

$$C_xH_yO + O_2 \Rightarrow CO_2 + H_2O$$

$$C_xH_y + O_2 \Rightarrow CO_2 + H_2O$$



After-Treatment Options

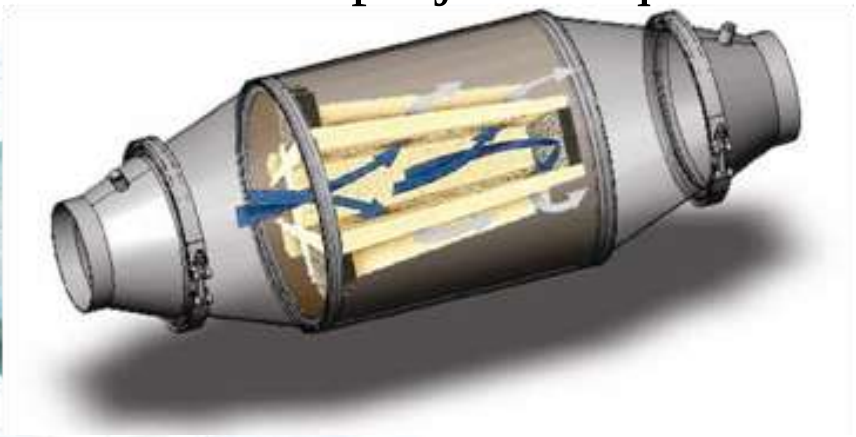
Engine Type	NOx	CO	VOC	PM
SI RB	NSCR + AFRC	NSCR + AFRC	NSCR + AFRC	N/A
SI LB	SCR*	Oxycat	Oxycat	N/A
Diesel	SCR*	Oxycat	Oxycat	DPF/FTF**

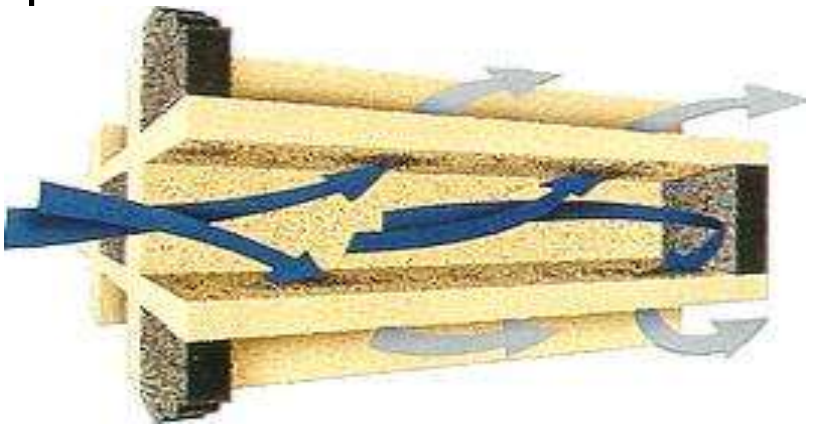
* -SCR can be combined with Oxycat

** -DPF/FTF will also remove CO & VOC

Diesel Particulate Filters (DPF)

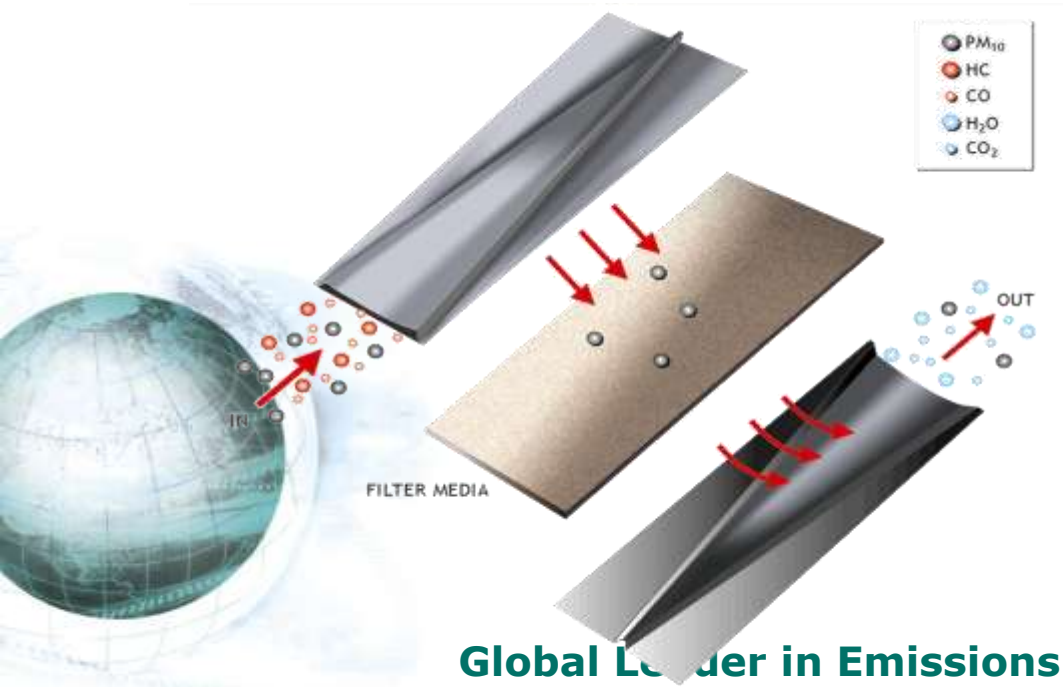
- Ceramic type substrate construction; cordierite/silicon carbide that is catalytically coated (regeneration, CO/HC removal)
- Alternating open and closed channels
- Requires minimum exhaust temperature for a certain percentage of operating hours
- Always sold with a BP monitoring device
- Some projects require Verified products

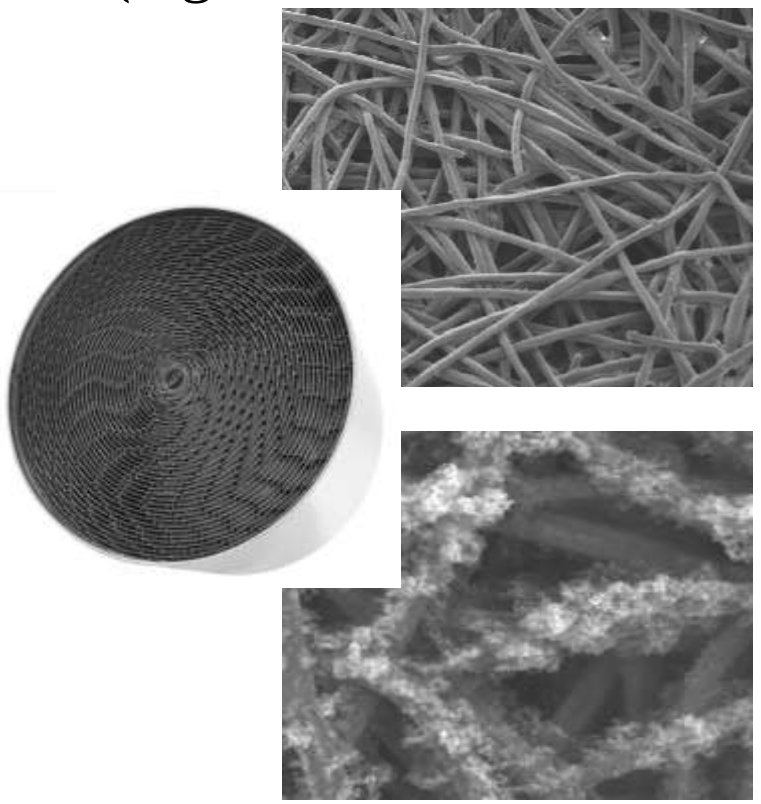




Flow Through Filters (FTF)

- Corrugated steel combined with a metallic fleece layer sandwiched between
- Non-blocking, and catalytically coated (regeneration, CO/HC removal)
- > 50% PM removal





Catalyst Manufacturing

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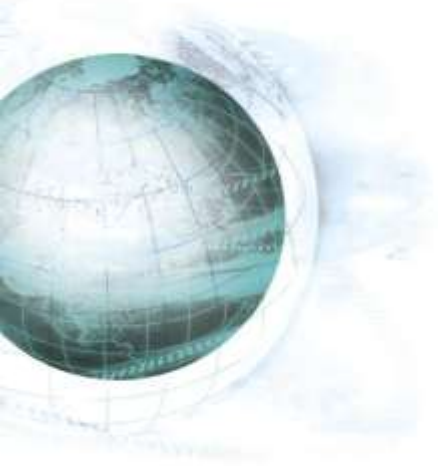
Steps in Manufacturing

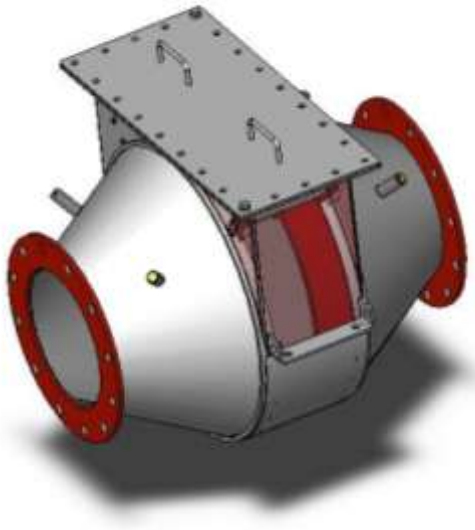
- Fabrication of a support structure
- Application of a coating to the support structure
- Impregnation of the coating with precious metals
- Packaging and assembly of the catalyst



Terminology

Catalyst Element (when coated)

Substrate (when un-coated)



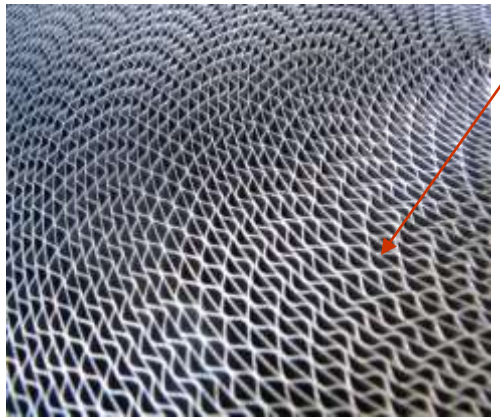
Catalytic Converter

(which can contain 1 or more elements)

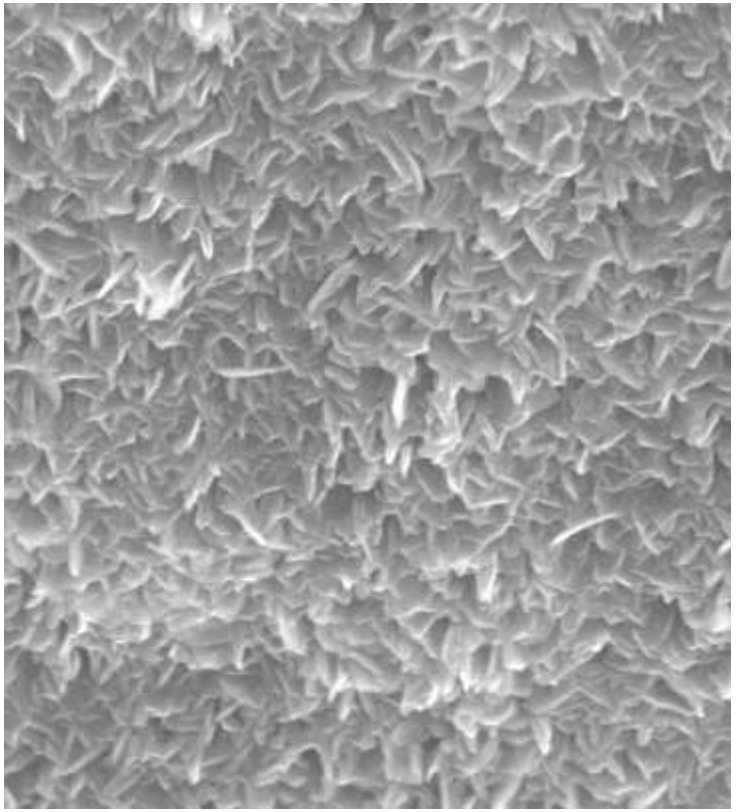
Various other terms are used in the industry, which can lead to confusion. For example, “catalyst” can refer to the complete catalytic converter, the catalyst element, or the precious metal material.

Substrates

- Specialty steel foil is rolled and corrugated into the desired shape (substrate)
- Frame added to encase and protect the part
- Uncoated substrate is oxidized in an oven to improve the adhesion properties.
- Brazed and non-brazed metal substrates available

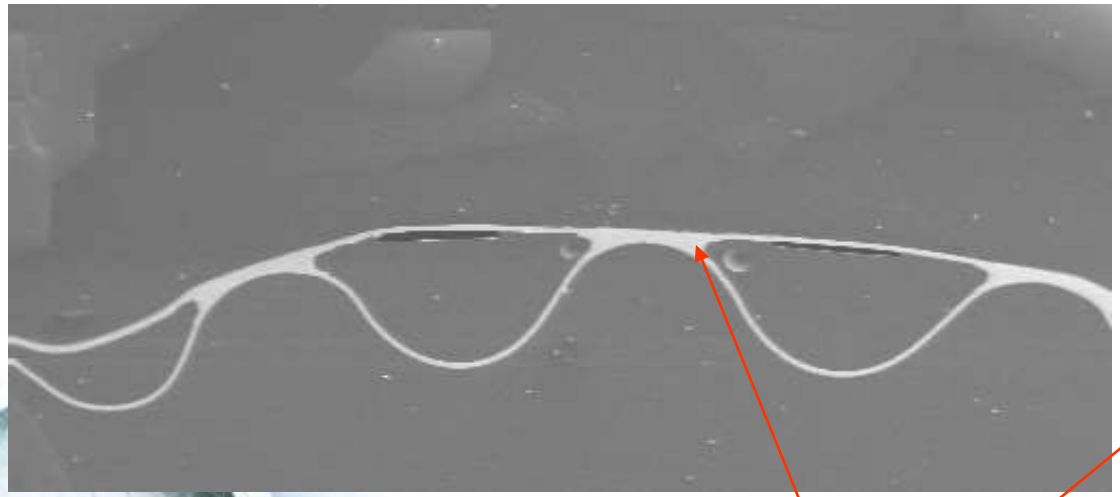


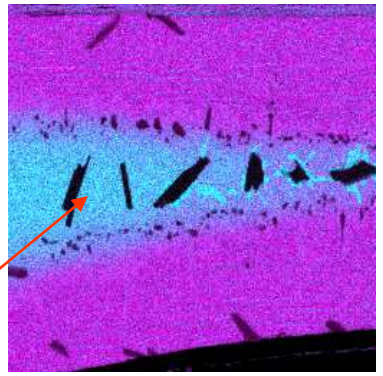
Foil Surface
Pre and Post Oxidation



Brazed Metal Substrates

- Nickel brazed FeCrAl foil
- Highest mechanical shock resistance

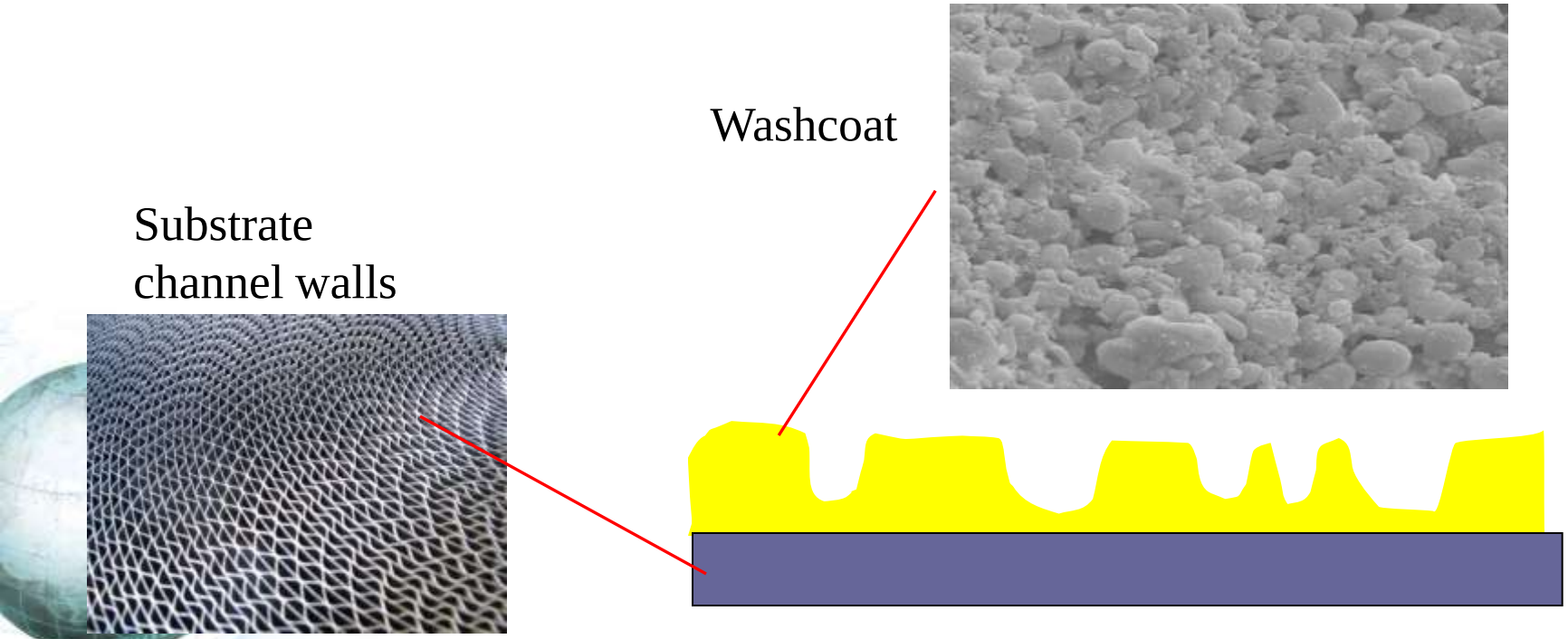




Nickel alloy is formed bonding the foils

Washcoat Application

- The precious metal has to be supported in a way that allows exhaust gas to come into contact with it
- The washcoat provides this and also exponentially increases the surface area



Packaging

Once elements have been coated, the final step in the process is packaging the parts into a housing – either as a converter or combination catalytic silencer.

Sizing, Selection & Design Aspects

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Sizing & Selection

Primary Considerations:

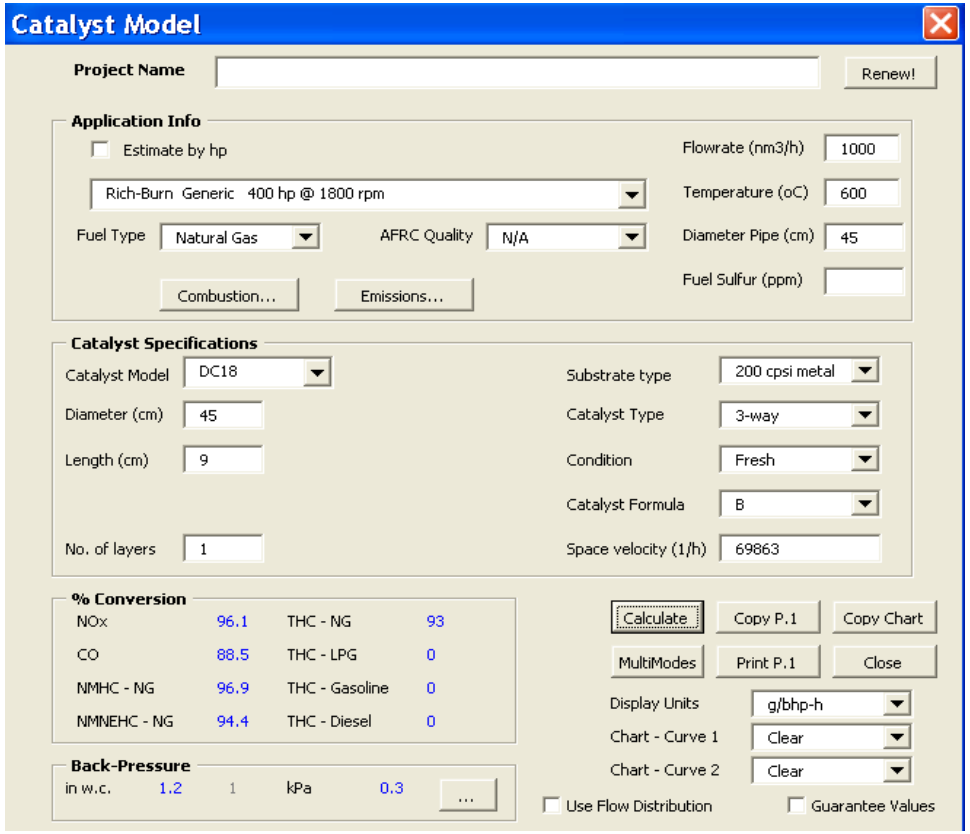
- Engine Model/Type
- Maximum Rated Horsepower
- **Exhaust Temperature @ Max Power**
- **Exhaust Flow Rate @ Max Power**
- **Required Emissions Limits**

Secondary Considerations:

- Fuel Type
- Raw Exhaust Emissions Levels
- Pipe Connection Size
- Allowable Backpressure
- Sound Attenuation Level Required
- Space Constraints (Retrofit Considerations)

Catalyst Design Software

- Exhaust Properties
- Emissions Levels
- AFRC quality (3-way)
- Fuel Properties
- Catalyst Properties (Physical)
- Catalyst Properties (Chemical)
- Deterioration Factor



Optimized Solution

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Packaging Variables

Cell Density

- The larger the corrugations in the foil, the lower the backpressure, but the less surface area which equates to lower performance

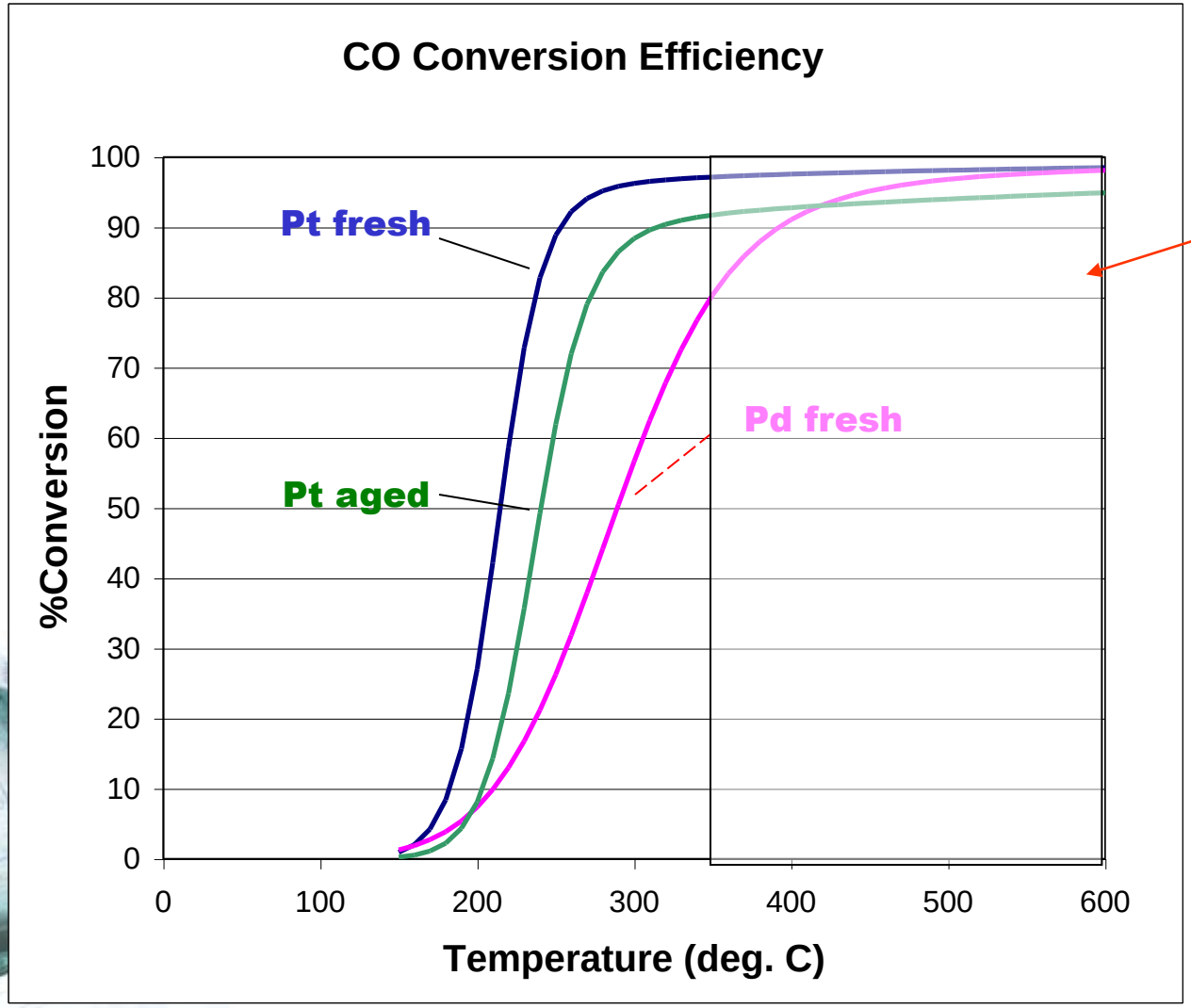
Catalyst Coating/Loading

- Different coatings for different objectives (ie- achieving CO reduction vs. VOC requires less precious metals

Catalyst Arrangement

- Multiple elements in series to achieve really tough standards
- Vertical vs. horizontal flow
- Combination silencer vs. separate converter and muffler

CO Light-Off Curves

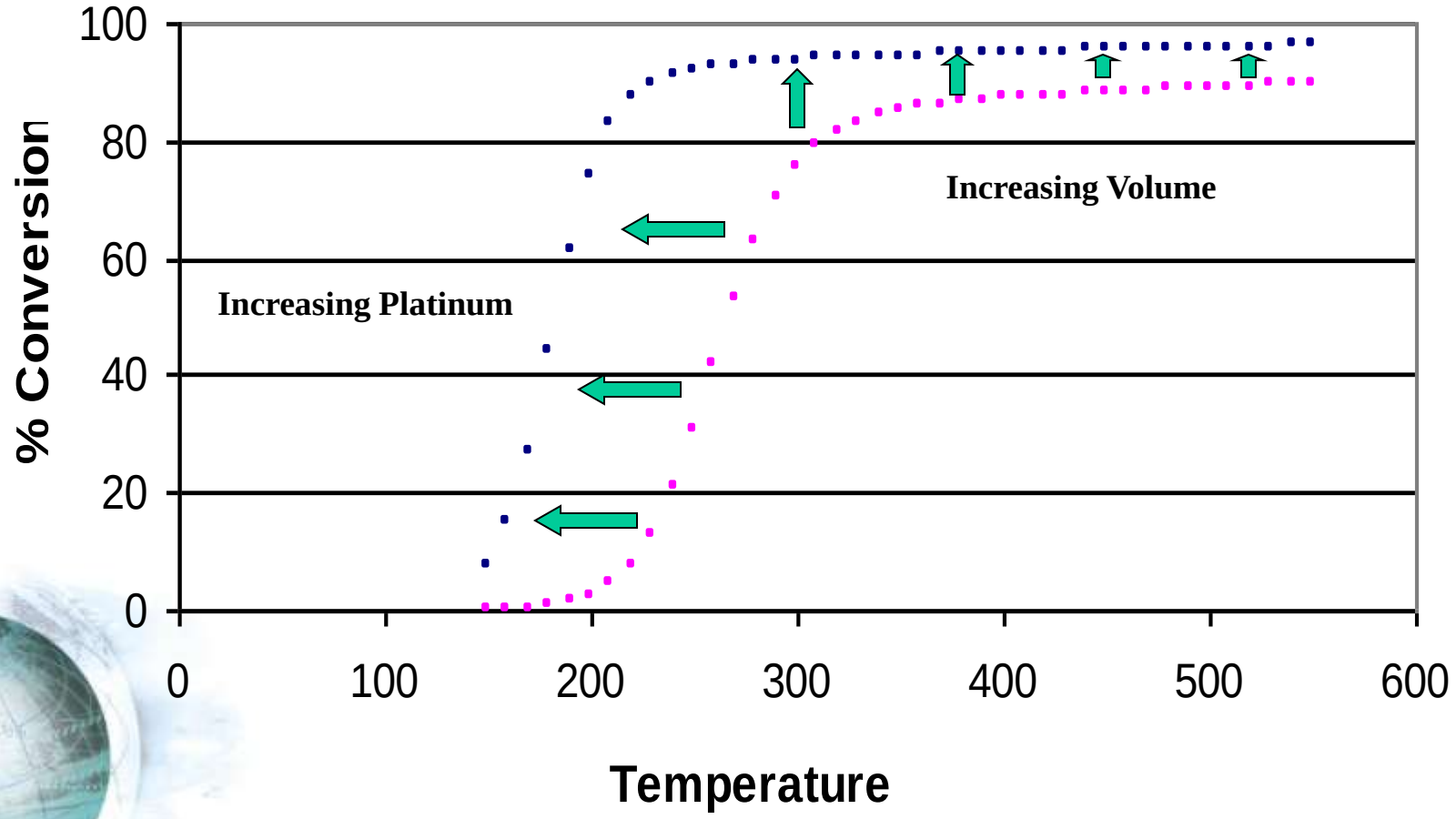


Operating window

Pt catalyst is better for CO conversion

DCL data

Sizing & Selection



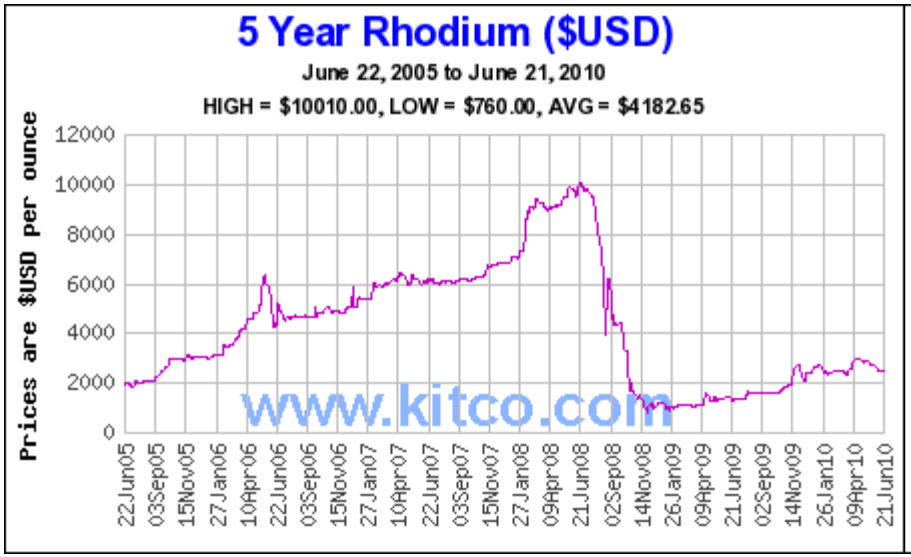
Buying Catalyst

- The only definitive method for determining a quality product is to buy it and run it for a couple years
- However, before the purchase is made it is important to consider what is being bought
- How much, what are the features/benefits & what is the performance warranty period?
- Who makes it, who will support it, how quickly can I receive spares if needed?

Raw Materials: Main Factor

- Precious Metals Commodity Prices
- Many demands for Platinum, Palladium and Rhodium: electrical contacts, spark plugs, converters, analytical equipment, medical equipment, computers, TVs, cellphones, specialty alloys
- Most of the supply occurs in Russia and South Africa: Market Volatility

You Get What You Pay For



- When commodity prices are high, tendency is for sellers of catalyst to reduce the quantity of precious metal in the catalyst
- Be very suspicious of the `low` bid
- Approx. 70% of the cost is Precious Metals

Quality Products

- Few suppliers exist that coat catalyst in North America
- Key is the washcoat durability: will the catalyst still pass an emissions test 8,000 hrs from now
- Low cost typically means frequent element purchases required

Apples to Apples

The fast and simple method for comparison:

Space Velocity = Exhaust Flow/Catalyst Volume

Units of 1/hr (the smaller the # the more catalyst is present)

Simple measure showing how much catalyst volume is being offered by a vendor

(alternatively, calculate the volume of the part being offered by measuring the element)

DCL Products

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Selling DCL

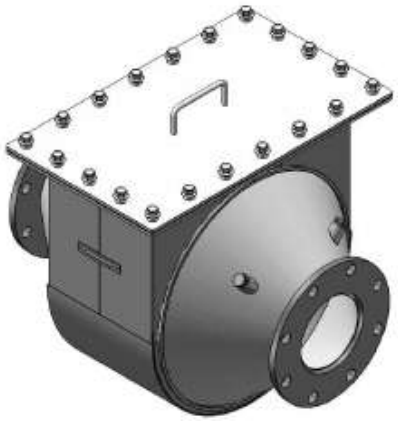
- Fast lead time for almost all products; typical 3 to 10 business days for 75% of our products
- Fast service; quote turn around or production lead time answers and access to technical service engineers
- Sales support; travel with you to visit your customers, available for training presentations, joint marketing, tradeshows…etc
- Vertical integration; high quality more consistent product
- Engineering; additional ports, custom lengths, etc all available at no charge

MINE-X®
Catalytic Converter

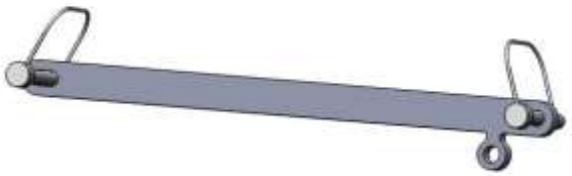
- Element is clamped to two cones
- Features:
  - Foil brazed directly to each other and to the outer shell
  - Extra catalyst capacity via spool pieces
  - Can be provided as a combo design

MINI Quick Lid

- New Product
- Integrates MINE-X diameter catalyst elements into a lid design
- Clamped MINE-X elements are not compatible with MINI QL housings and vice versa
- Small price premium over clamped design
- Can be provided as a combo design



MINI Quick Lid



Lid

Pre-Fabricated Gasket

Retaining System

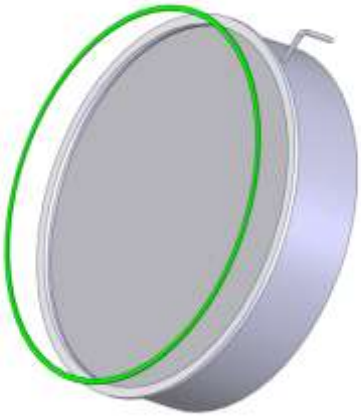
Catalyst Element

Self-Retaining Hardware

Mini Quick-Lid Housing

SS Wire Mesh Gasket

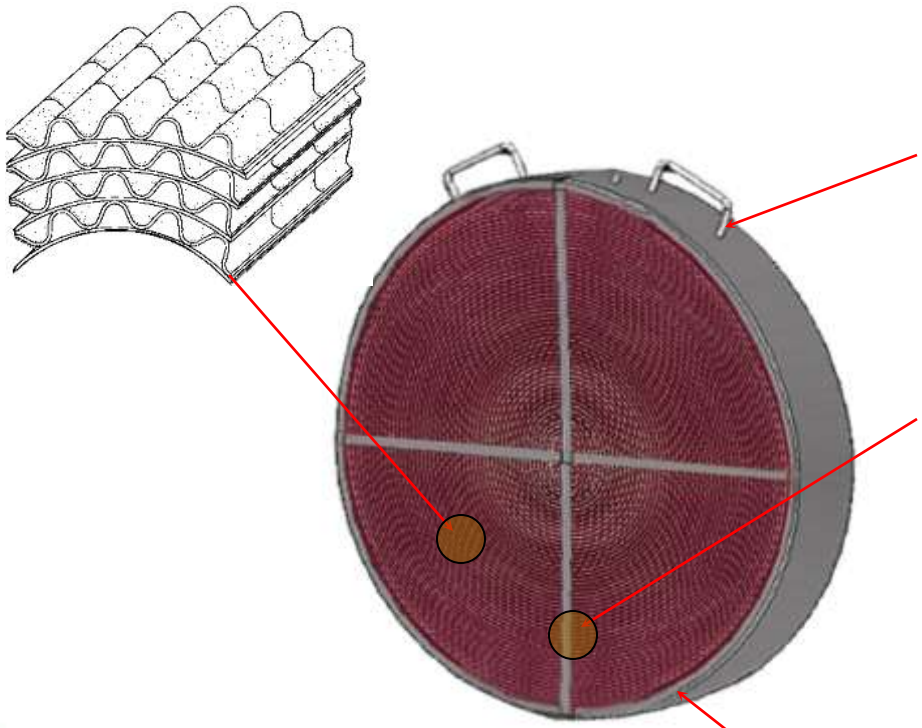
1. Slide catalyst element into the locating slots at the bottom of the housing
2. Align the ring of catalyst element with the ring on the housing
3. Install the retaining system. Insert the pin closer to the element and lock the other end with another pin.



Quick-Lid™

- Best product currently on the market for medium to large industrial engines
- Features:
  - Gasket-less catalyst sealing system
  - Captive hardware system for operator friendliness
  - Can be provided as a combo design
  - Rigid and durable catalyst element

Catalyst Element



Handles for installation and maintenance.

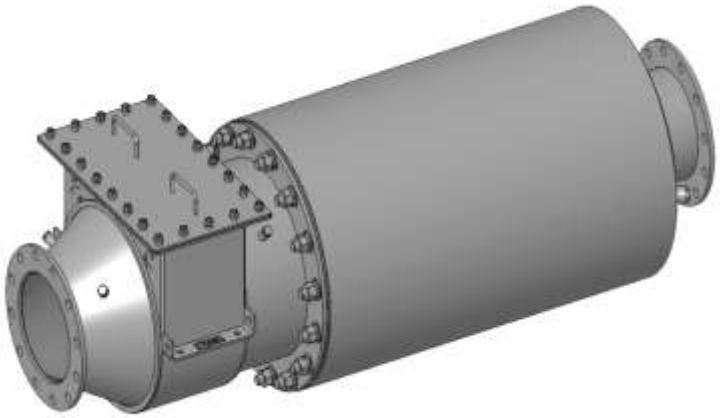
Stiffening bars are inserted across the diameter of the substrate to maintain substrate rigidity and carry foil load.

High-temperature-resistant steel foils of alternating layers of corrugated and flat strips 100, 200, 300 or 400 cpsi (cells per square inch).

C-channel band of 304 stainless steel to provide rigidity and protect operators from foil abrasions.

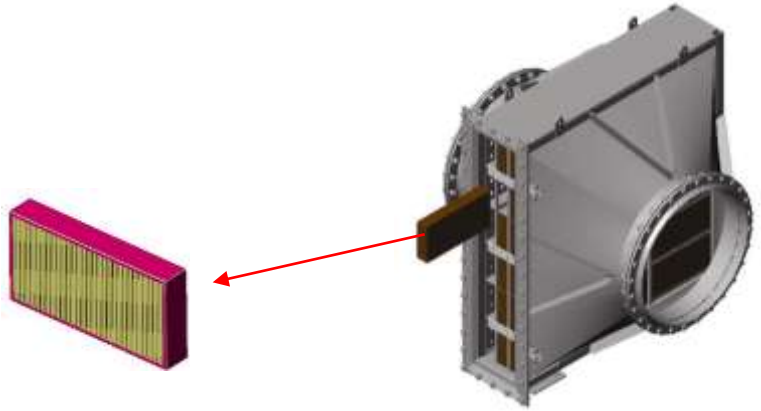
Catalytic Silencers

- MINE-X and Quick-Lid available in 3 standard silencer grades:
  - Industrial (15-20 dBa)
  - Critical (25-35 dBa)
  - Hospital (35-40 dBa)
- Higher specialized noise requirements are available
- Standard Carbon steel, SS304 optional



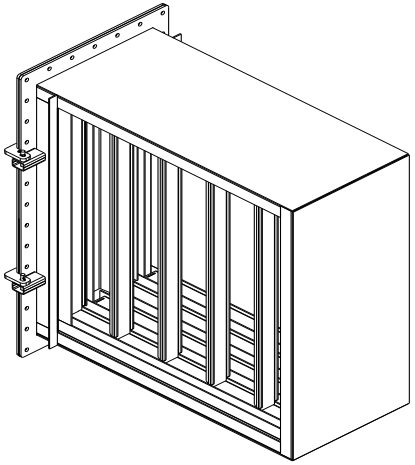
Large Engine Applications

RC Series Housings
-Multiple Rectangular Bricks
-Arranged as modules or individual bricks



Base Mounted Units

RC Series integrated into large vertical silencers



BP/T Monitor

-8000 hr logging
Capability – 2 inputs
-Communications
Module available

Competitors

Selling Against Miratech

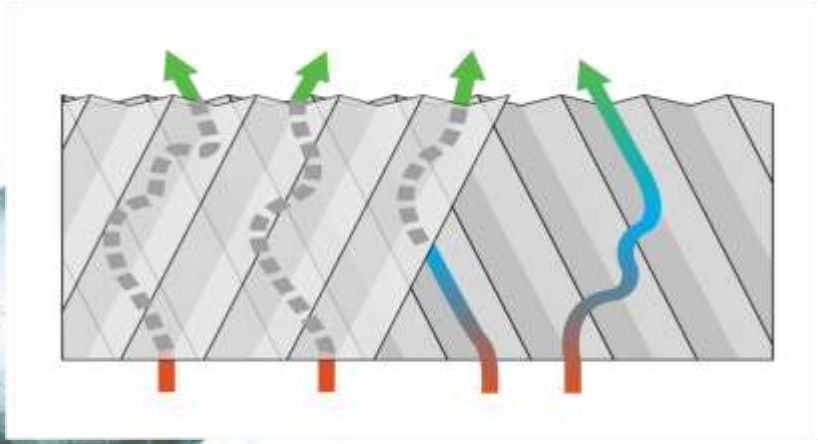
Three Product Lines:

- EQ/MHS/MCS Series (octagonal elements)
  - Very difficult to seal corners with gaskets
  - Foil has tendency to telescope on longer parts and deform
  - Difficult to remove warped frames of the elements from housings

- IQ Series (round elements with hats)
  - Thermal expansion of the hat is slower than the foil resulting in excessive tension that destroys the upper 1/8th of the element over time
  - Gasket seal is an issue also – 2 corners at the top

Selling Against Miratech

- Z Series (rectangular elements with hats in mufflers)
  - Rectangular parts have gasket issues
  - Exhaust flow has to complete two 90 deg turns to pass through
  - Many more bolts on the lid than other housings
  - Internal element supports are long channels that deform after a few heating and cooling cycles



Selling Against Miratech

General Points

- Miratech manufactures nothing – all outsourced
- More than 5 x the number of designs and models than anyone else
- Buys catalyst from BASF and Ecocat in Europe
- Elements are rolled from pre-coated foil
- Housings are outsourced – tolerance & quality issues
- Electrical resistance welding is used for element rigidity: Brazing is 10x stronger &1000x more durable
- Z flow vortex foil breaks down even faster with electrical resistance welds because of the higher aerodynamic resistance relative to straight through channels

-Aftermarket support?...Selling direct

Selling Against JM/WPI etc

- Maxim/WPI, MEI all outsource catalyst and fabricate their own housings
- Housing design and user friendliness are all suspect for these firms – ie – special wrench needed to tighten the MEI parts? All use gaskets to seal
- JM makes the catalyst in Mexico (quality?)
- JM outsources the housings to fabricators
- JM service & response time – many anecdotes from the field of 6 week lead times and 2 weeks to even get a quote
- Other competitors such as EAS and PCA are telemarketers – how can they help our customer base over the phone?

Selling Against Emit

- Emit outsources catalyst
- DCL testing of an Emit part revealed good precious metals loading but poor durability – ie – 6 months of service and the part would fail
- “Dear customer, how long are Emit parts lasting for you?”
- AFRC is also of poor quality and subject to interference from RF
- Focus on smaller engines < 500 HP and poor/minimal experience in diesel engine market

Selling Against GT

- Provides combo silencer design the same as the Z series Miratech (who copied GT)
- Same sealing issues, and GT does not even use a gasket system
- Same issues with deformation of the catalyst support frames inside the housing
- Many GT units were sold empty to packagers, leaving the end-users to find out how to solve the problems
- “When was the last time a GT representative visited you”
- Outsourced catalyst

Installation, Operation & Maintenance

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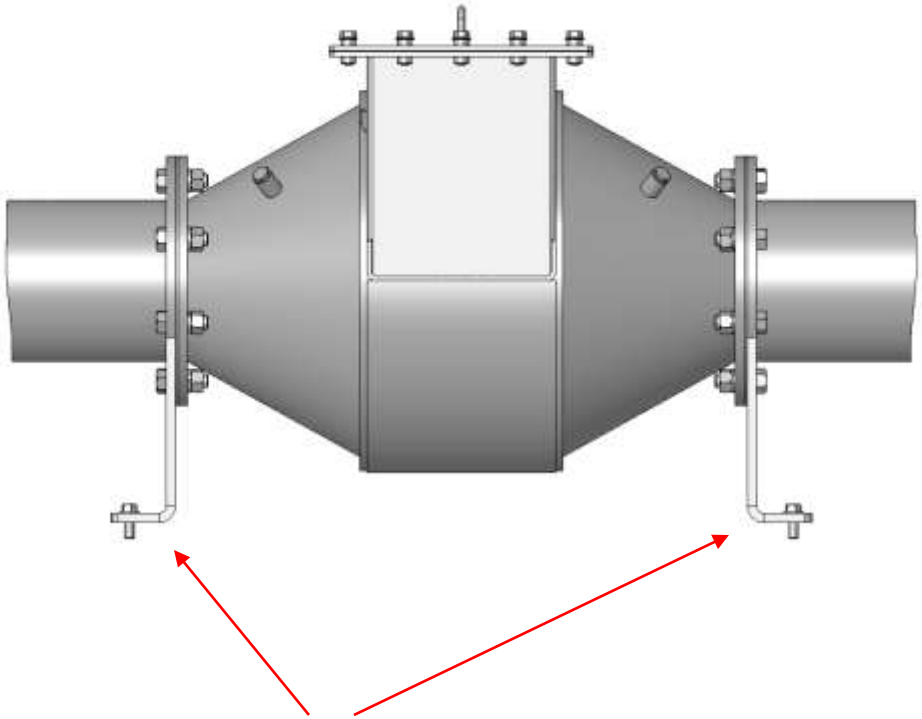
Installation

- Converter mounting: should be isolated from engine vibration and external loads using flex joints/expansion piping
- As close to the engine manifold as possible to retain heat
- Support from both end flanges
- Catalyst should be easily accessible for inspection, washing and/or re-installation
- Water should not collect inside the catalyst
- Conduct leak test if indoors

Installation

- Avoid long piping runs that can thermally expand and damage the converter housing
- If long piping runs exist prior to the converter, insulation is strongly recommended
- Converters should be installed upstream of the muffler
- Backfire relief valves are normally ineffective in preventing damage unless they are in the direct flow path of the exhaust flow

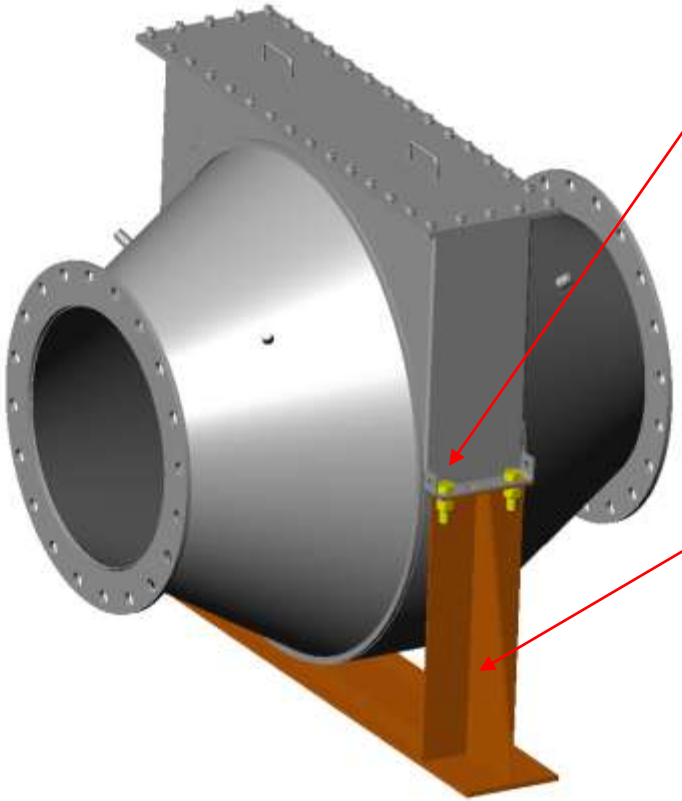
Horizontal Flow Catalytic Converter



45 Degree angle is acceptable

Support the housing from the end-flanges.
Support saddles fixed to wall, cooler, container or other secure location.

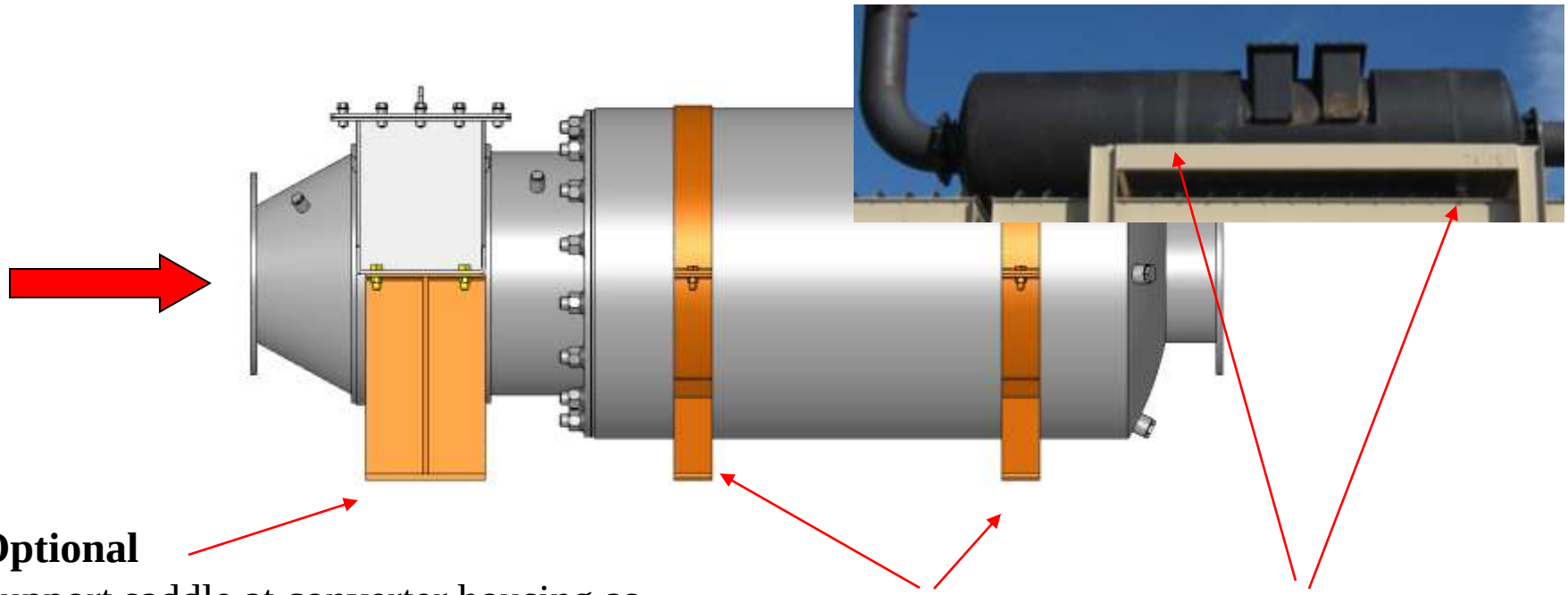
Horizontal Flow



Bolt saddle to mounting brackets of converter

Support saddle fixed to wall, cooler, container or other secure location.

Horizontal Flow Catalytic Silencer



Optional
Support saddle at converter housing as shown, fixed to wall, cooler, container or other secure location. Saddles bolted securely to housing.

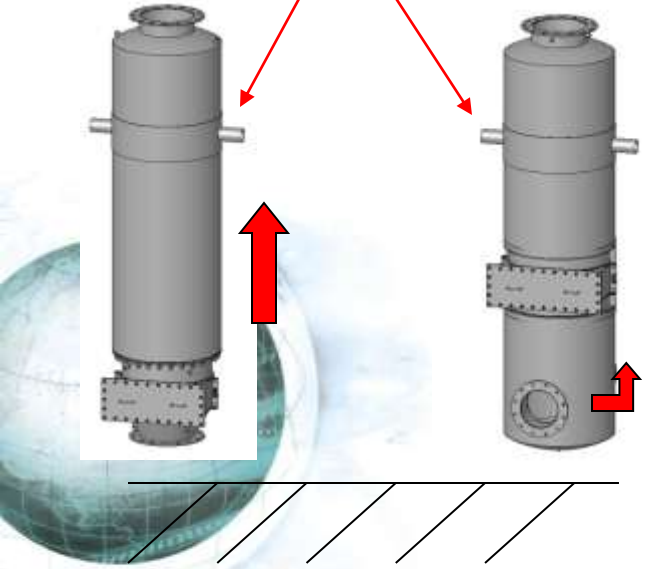
Support saddles at two points as shown, fixed to wall, cooler, container or other secure location. Saddles bolted securely.

Mounting Orientation

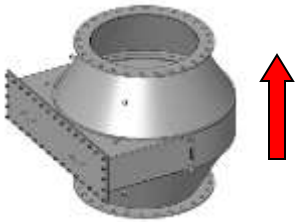
Vertical Flow Orientation

More variables to consider from an installation and catalyst system standpoint, such as support for the element.

Examples



Examples of exhaust gas direction for vertical orientation



Important note:

Mounting a catalytic silencer in the vertical orientation may involve structural components such as trunions, wind load and seismic zone standards, and the need to support a stack. Design details for vertically mounted catalytic silencers must be discussed at the proposal stage.

Engine Operation

Systems Approach

- Engine operation is critical to catalyst performance
- If there is a problem with the engine it will contribute to catalyst non-performance – fines, shutdowns, etc.
- Regular maintenance and adherence to the manufacturers recommendations will aid in maximizing performance & prolonging life
- Eg. Replace O_2 sensors, check timing
- Minimum fuel content of 750 BTU

Engine Operation

- Lube oil
  - Sulfated ash content < 0.6% wt.
  - Normal consumption rate
  - Zinc < 900 ppm, Phosphorus < 400 ppm
- No significant poisons in fuel (zinc, phosphorus, sulfur, chlorinated compounds, heavy metals, silicon compounds)
- Install an over temp shut down switch
- High temperature Max. 1350 ^{o}F (converter outlet)
- Crankcase ventilation post catalyst or via air intake

Catalyst Operation

Key limits for good catalyst performance:

- < 1% Sulfur
- < 1% Calcium
- < 1% Phosphorous
- < 0.5% Zinc
- < 1% Iron
- < 2% collectively Fe, Ca, S, P
- < 200 ppm collectively Pb, Cr, As, Hg, Cu, Sb, Sn, Ni

Concentrations above these limits will begin to degrade performance rapidly

Catalyst Maintenance

Record ΔP and ΔT after 8-20 hrs of operations

- Every 3 months thereafter (2000 h)
  - ΔP and/or ΔT monitoring
  - ΔP change < 0.5 kPa (2” w.c.)
  - ΔT change < 15 ^{o}C (25 ^{o}F)
- Every 1 year (8000 h)
  - Inspect the catalyst substrate
- Every 2 years (16000 h) or as necessary
  - Chemical cleaning of catalyst substrate

Catalyst Maintenance

Alternative maintenance options:

- Remove the catalyst element and reverse its orientation by 180 degrees and replace it
- Use < 200 psi oil free Air or Nitrogen to blow off accumulated ash (do not touch foil with nozzle!)
- For marginal performing elements, consider installing a new element downstream (if extra capacity exists) and keeping the old element in place as a guard and to improve its performance

…Bottom Line

Field Operations:

- Only method to measure performance is to stack test
- ΔP and ΔT are only indicators of potential problems, not performance measures

Laboratory Testing:

- Expensive and impractical for fast answers
- Can confirm or refute presence of poisons and general condition, BUT - no guarantee of performance

Catalyst Cleaning

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Washing Catalyst

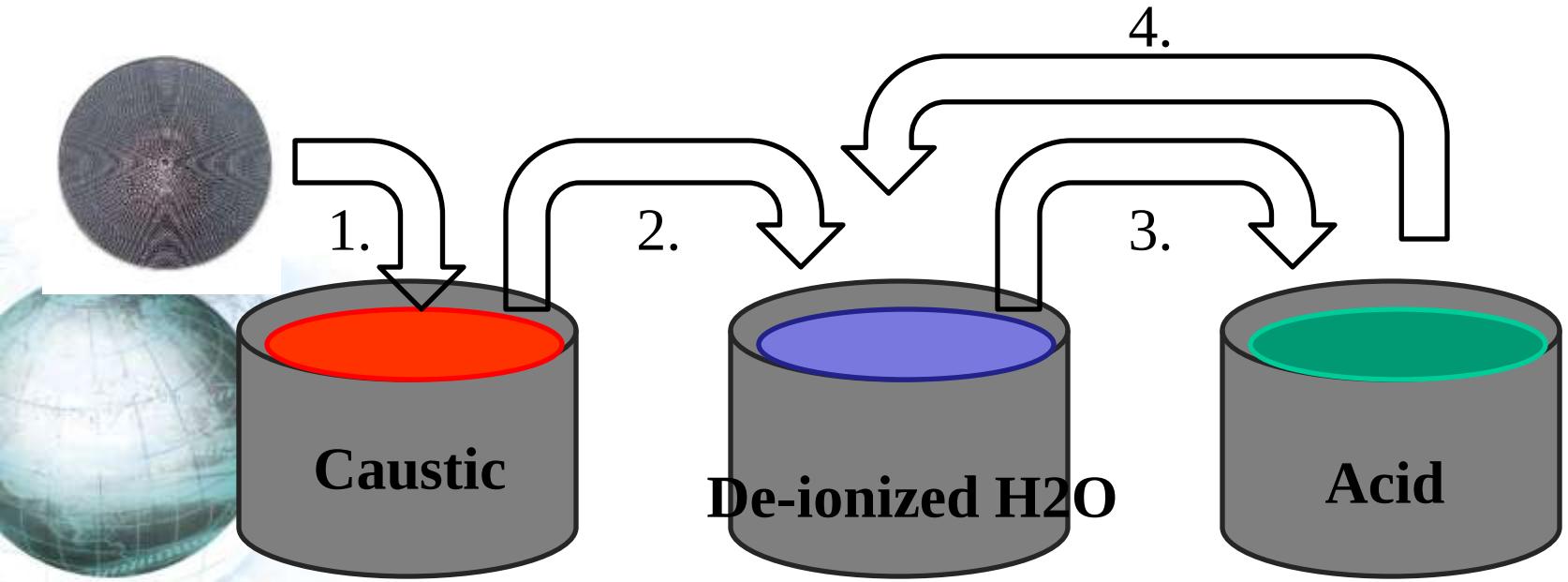
- Chemical process for removing accumulated ash from the surface of the catalyst – extends service life significantly
- Important that correct equipment is employed or catalyst can be damaged (no scrubbing brushes)
- Catalyst material is sensitive to metallic compounds and inorganic compounds present in regular tap water and soap

Washing Catalyst – Frequency

- No fixed rules, entirely engine dependant; 2 stroke engines will require more frequent washing than 4 stroke
- Rule of thumb for high speed, 4 stroke engines – clean no more than twice
- For 2 Stroke or slow speed, clean no more than 4 times

Washing Procedure

- Step 1 – dilute NaOH removes inorganic masking
- Step 2 – Rinse Caustic solution
- Step 3 – dilute Acetic acid removes organic masking
- Step 4 – Rinses Acidic solution
- Step 5 – Catalyst element is dried



Failure Modes:
Catalyst Deactivation

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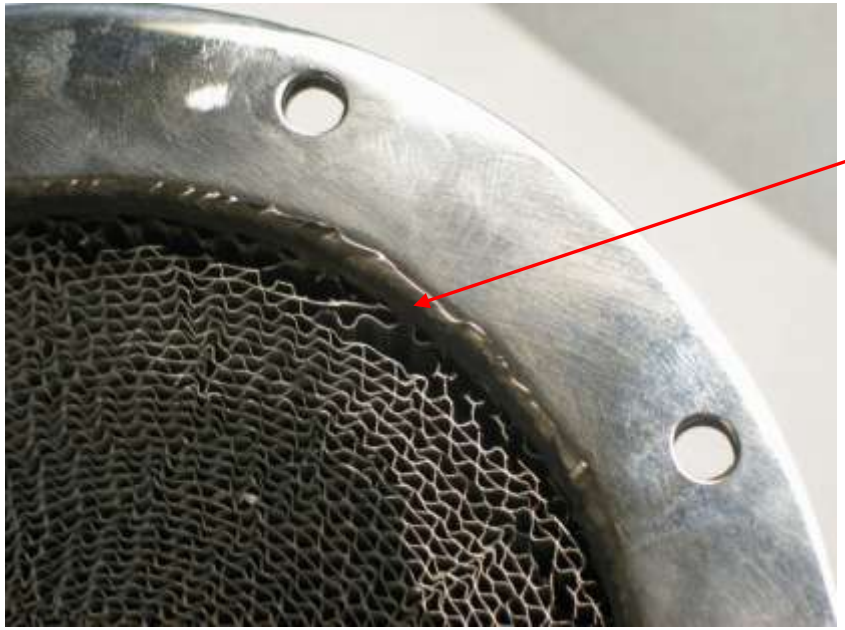
Worst Case…

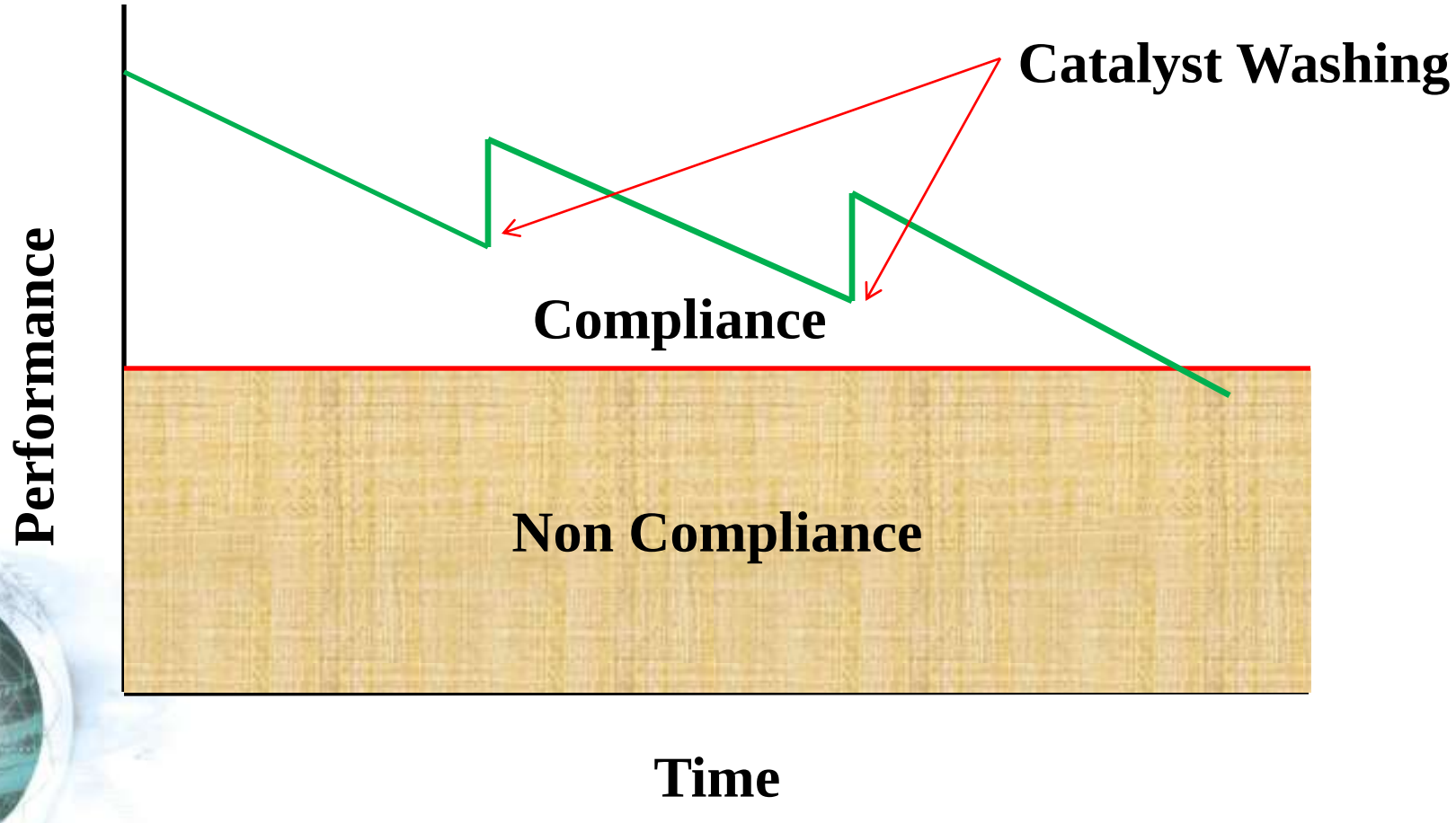
Catalyst Failure



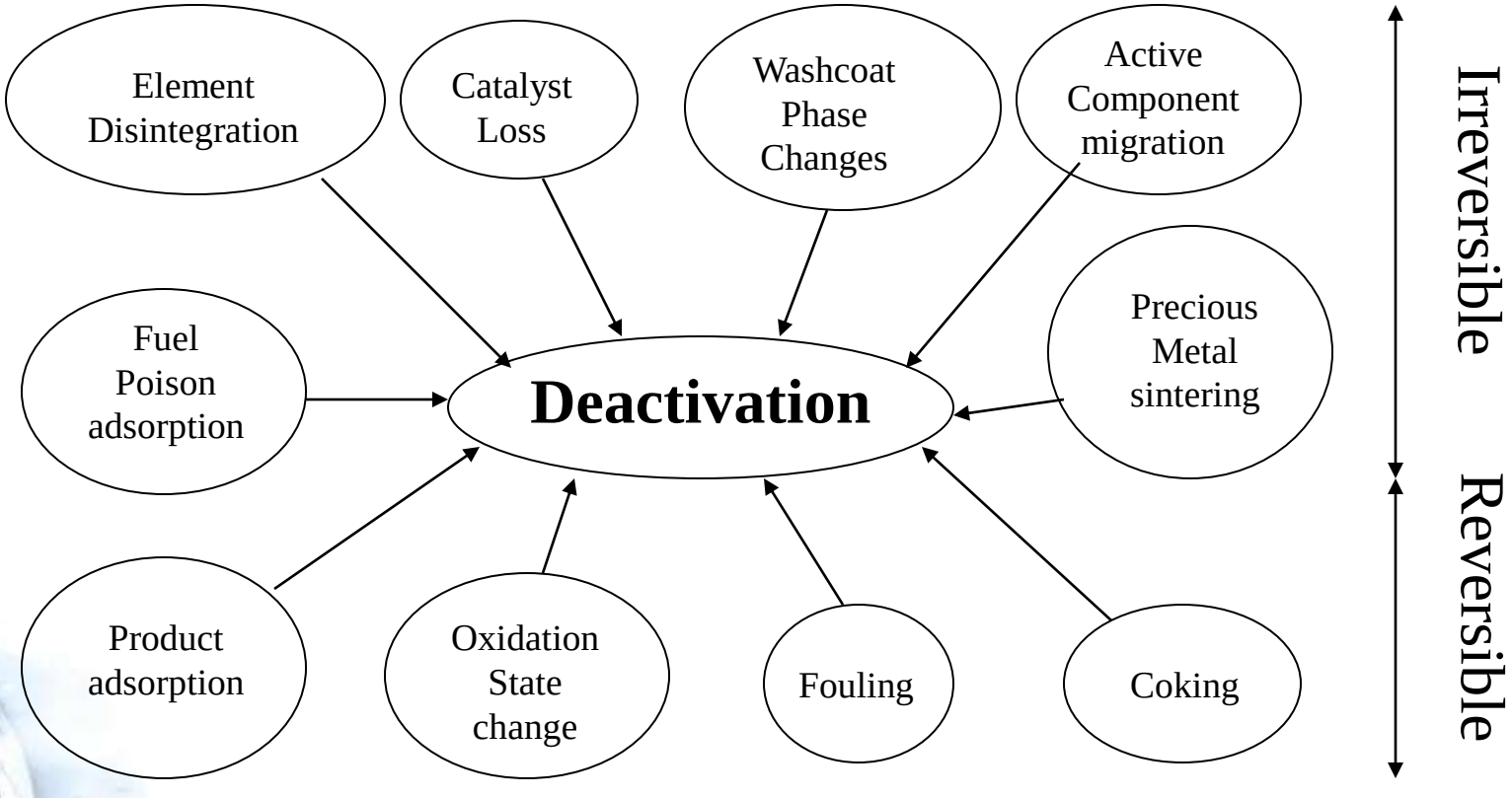
Mechanical Stress:
no flex connection

Massive Temperature
Excursion

Typical Lifecycle (Ideal)



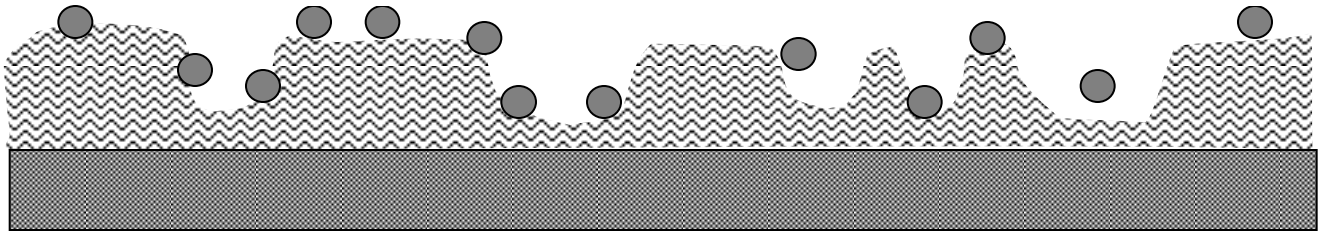
Deactivation



Reproduction Fig 79, 'Environmental Catalysis, Ertl

Ideal Surface

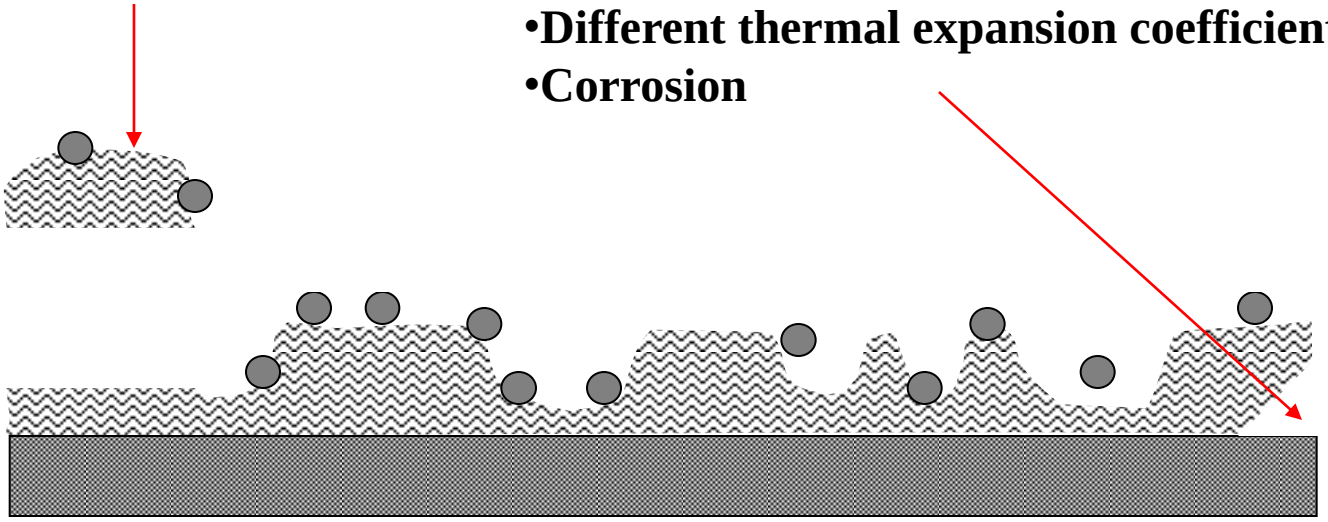
- Good adhesion
- Well-dispersed particles
- Similar thermal expansion coefficients of substrate and washcoat



Attrition

Attrition erosion

- **Different thermal expansion coefficients**
- **Corrosion**



Troubleshooting

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Ideal Catalyst Appearance

- Element should be tan to brown in colour
- Minimal grey or white ash present if used

Troubleshooting

Case 1	High conversion efficiencies are achieved simultaneously for both NO_x and CO	No Problem - relax
Case 2	High conversion efficiencies are achieved for CO or NO_x, but not both simultaneously	Loss of Oxygen storage capacity i.e. catalyst washcoat damaged then catalyst to be replaced or AFR control issue
Case 3	High conversion efficiencies cannot be achieved at all for either CO or NO_x,	Refer to possible engine or converter related problems

Failure Analysis

- BET surface area scan
- PIXE elemental analysis
- X-ray diffraction crystal structure/phase
- SEM surface morphology

Each costs about $500 to perform

QUESTIONS?

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