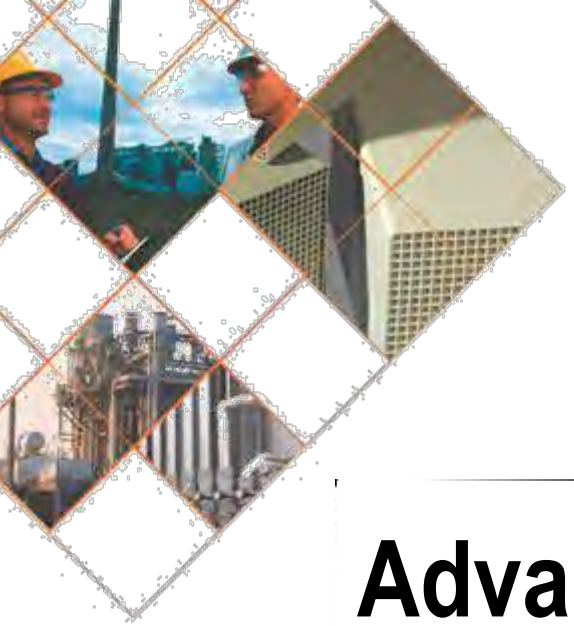
REINHOLD ENVIRONMENTAL Ltd.

2017 NOx-Combustion-CCR Round Table Presentation

February 27 & 28, 2017, in Cleveland, OH / Hosted by FirstEnergy



CORMETECH

CLEANER AIR THROUGH INNOVATION

Advances in Catalyst Solutions For Gas Fired Applications

NOx-Combustion-CCR Round Table

February 28, 2017

Overview

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CLEANER AIR THROUGH INNOVATION

- Key needs for gas-turbine air pollution control
- Advanced tools to meet needs
- Case studies
- Other applications
- Wrap-up

Key Needs for Gas-Turbines

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- **Meet emissions control requirements**
  - DeNOx
  - CO and VOC reduction
  - NH_3 slip limit
  - Under a variety of conditions
    - Temperature - Combined Cycle & Simple Cycle
    - High NO_2
    - Start-up and load cycling

- **While minimizing cost of compliance**
  - Low capital cost
  - Low maintenance cost
  - Low parasitic power loss (Low pressure drop)
  - Minimize NH3 usage
  - Minimize or eliminate operation constraints

Advanced Tools to Meet Needs

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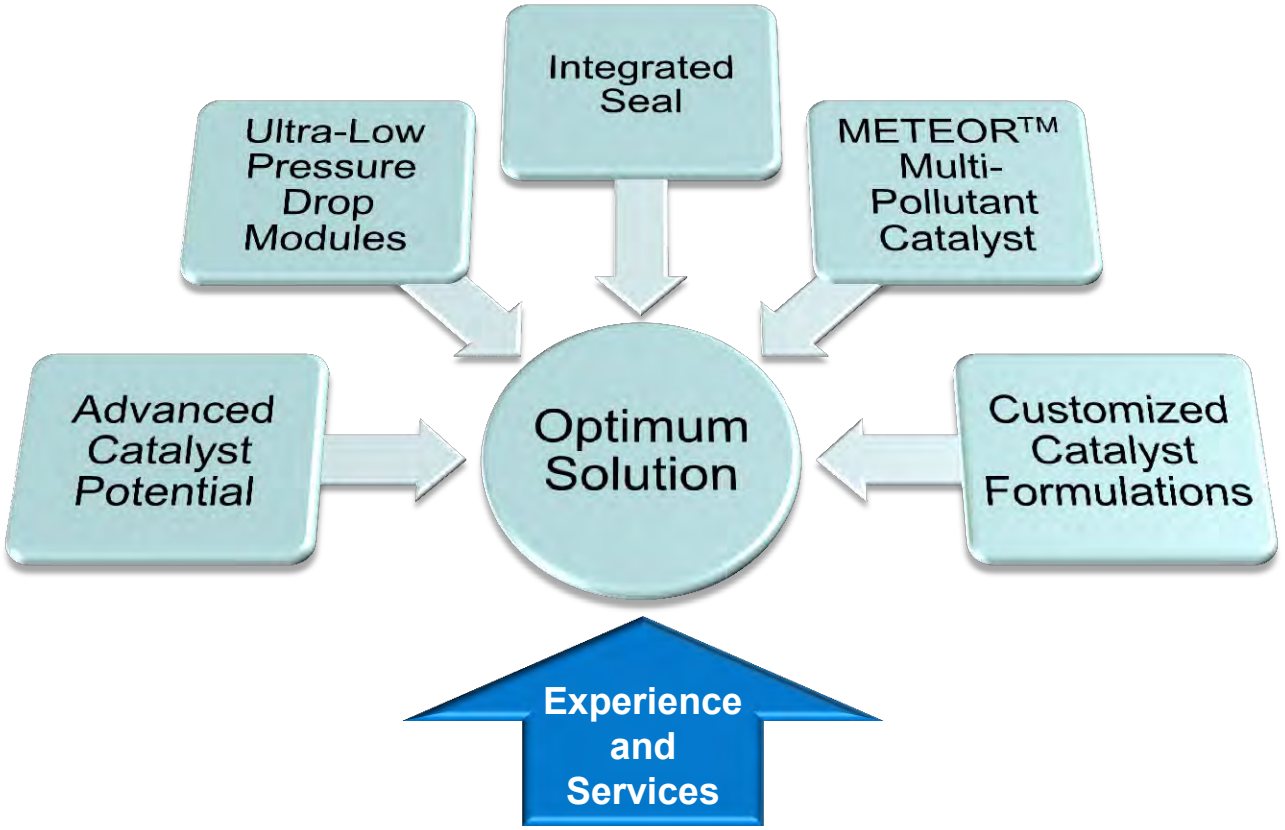
Stand-alone or combinations



State-of-the-art emission control solution capability

Traditional Horizontal Flow Modules

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- Pressure drop reductions require costly duct expansions.
- Difficult to add catalytic capacity without increasing pressure drop
- In some cases, sealing requires maintenance.

Advanced Module

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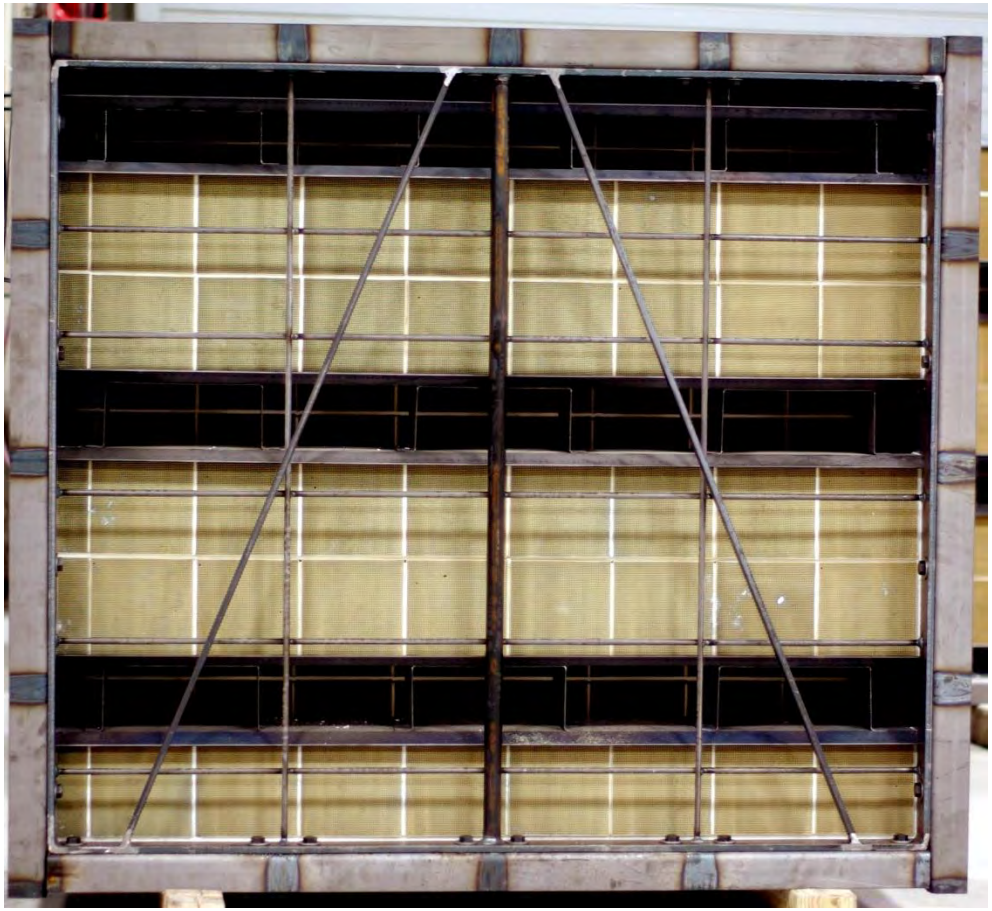
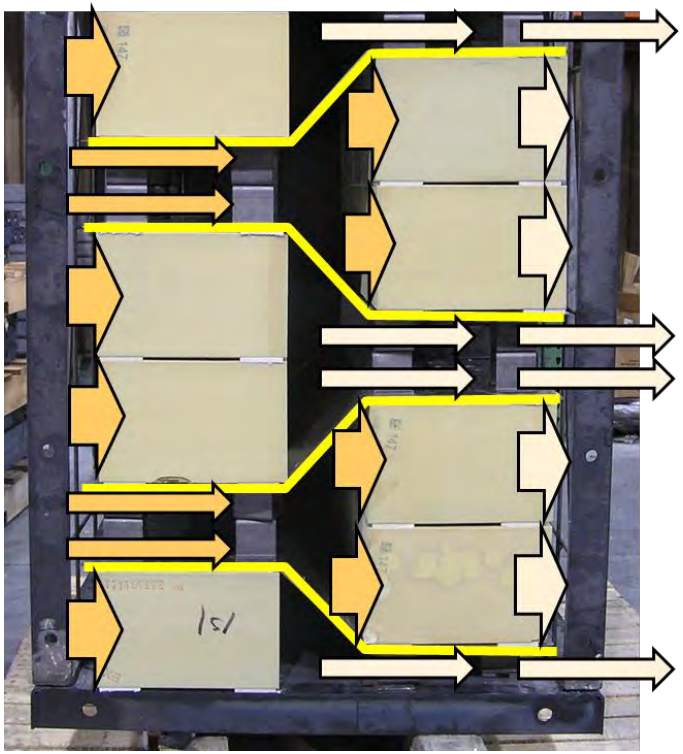


Patented: US 8,329,126

More frontal area in same space results in >40% Lower Pressure Loss!

No need to expand duct to achieve lower pressure loss.



Elite™ Platform

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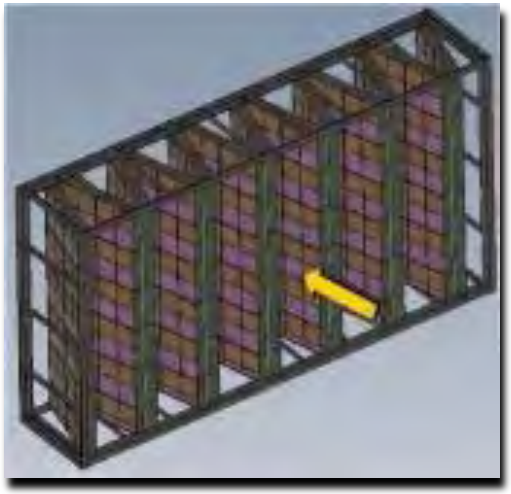
Combines three advanced tools

Pleated Module



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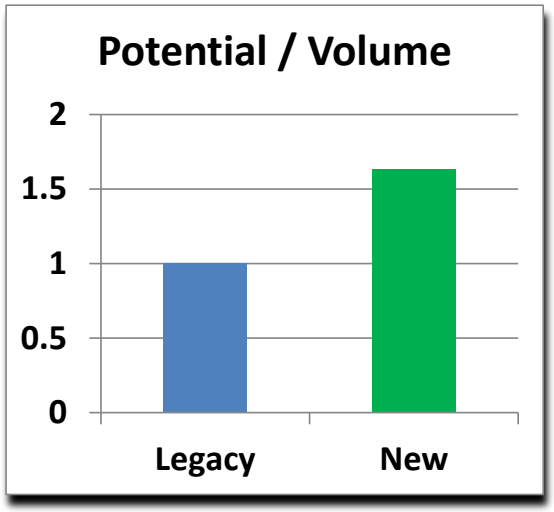
Advanced Catalyst Potential
60% Higher



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Integrated Seal

Patent Pending

Result:

- **Step-change** reduction in pressure drop: **60–75% Lower!**
- **Vastly improved** emission control solution capability
- **Innovative** seal to prevent need for maintenance

Pleated Module w Integrated Seal

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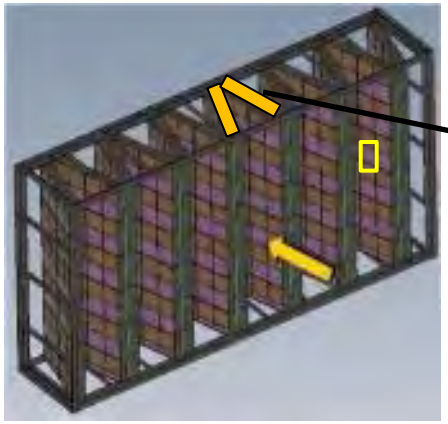
CLEANER AIR THROUGH INNOVATION

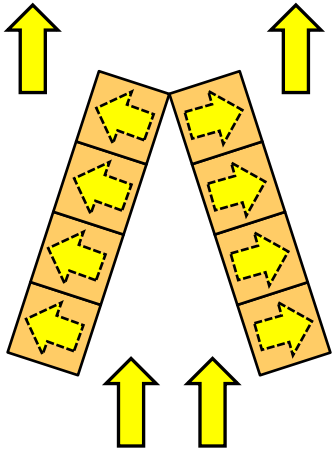
Single 150 x 150 mm Element

Inlet face



Top View

One Pleat



Flow Direction

Patent Pending

Reduced Pressure Loss

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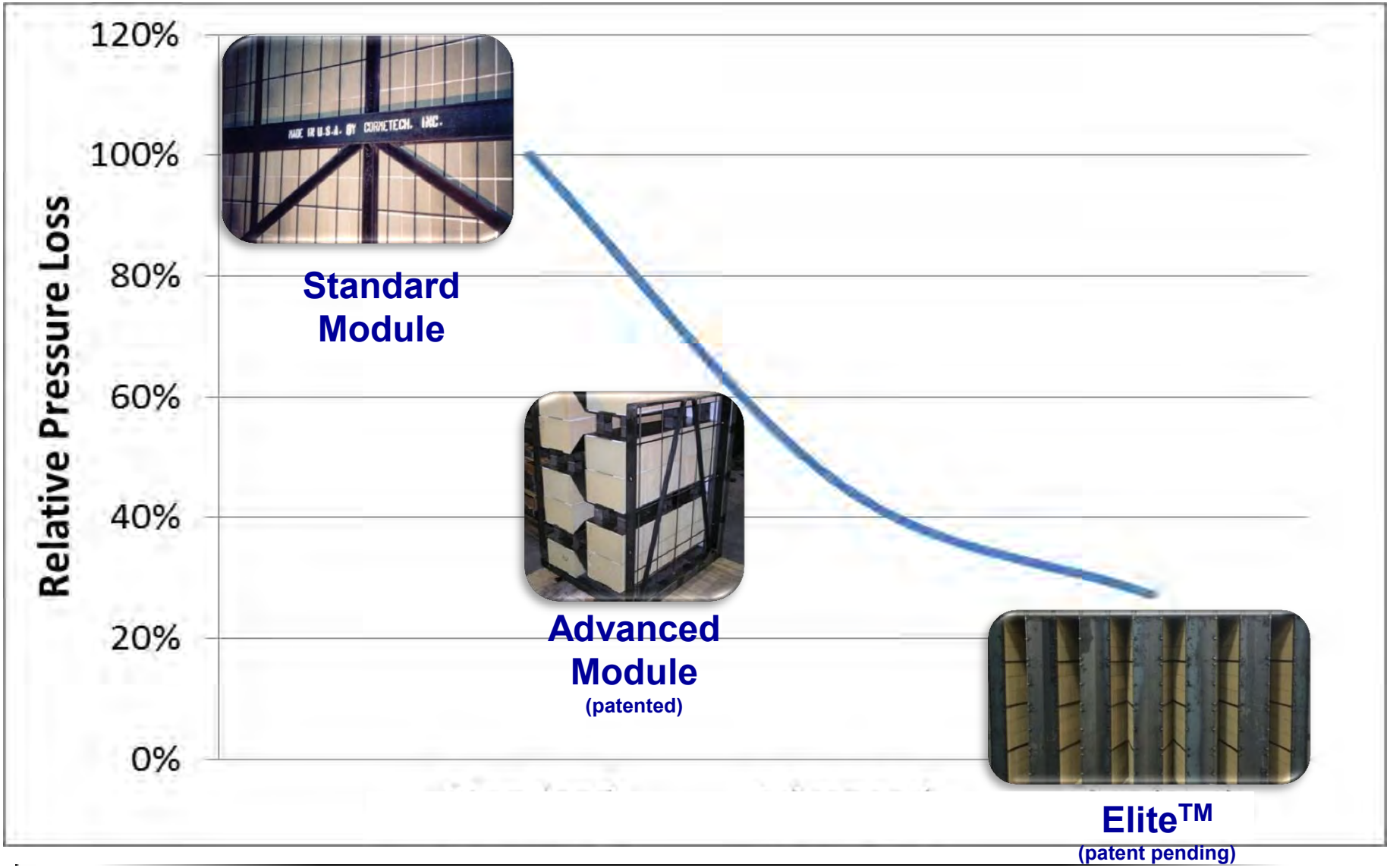

Financial Benefit of Reduced Pressure Drop

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Actual 240 MW GT Example

- Reduced DP by 2" H_2O

- **Full load:**
  - Increased power sold.

- **Intermediate load:**
  - Lowered gas consumption.

- **Total Benefit: $95K/yr**

Table as presented at POWER-GEN International 2016 by Cormetech, ENGIE, Ennis

Saving due to new pressure loss @ Full Load	
GT gross MW generated	240
Pressure drop reduction (inch H2O)	2
Natural Gas price $/MMBtu	3
Catalyst guarantee (year)	5
Operating hours per year	4380
Annual gross power output MW	1051200
Price of electricity sold $/MWh	30
Power output correction with correction curves for pressure drop	1.002
Total revenue for electricity sold	$157,680,000
Total revenue for electricity sold with new pressure drop	$157,995,360
Increase revenue from power sold over 5 years	$315,360
Annual revenue increase from power sold/unit/year	$63,072

Saving due to new pressure loss @ Intermediate Load	
GT gross MW generated	200
GT Gross Heat Rate Btu/kWh (HHV)	11500
Pressure drop reduction (inch H2O)	2
Natural Gas price $/MMbtu	3
Catalyst guarantee (year)	5
Operating hours per year	3066
Heat rate correction with correction curves for pressure drop	0.9985
Total gas consumption	$105,777,000
Total gas consumption corrected with new pressure drop	$105,618,335
Gas consumption saving from improved heat rate over 5 years	$158,666
Annual gas consumption saving/ unit/ year	$31,733

Total net benefit over 5 years	$474,026
Annual net benefit/unit/year	$94,805

Lower DP achieves tangible financial benefits

Supercharged SCR

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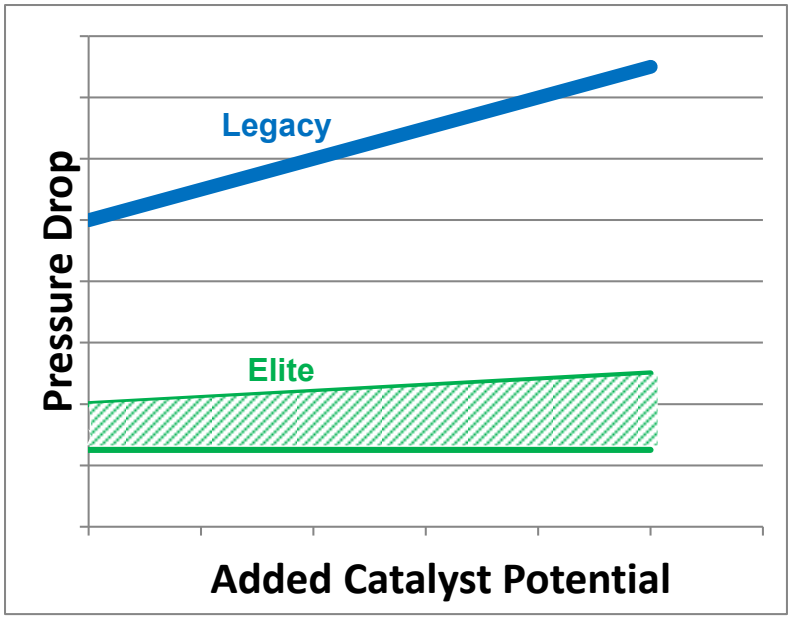
CLEANER AIR THROUGH INNOVATION

Elite™ with Advanced Catalyst Potential enables with <u>much less pressure loss penalty</u>



Potential emissions control <u>solutions</u>:

- **Reduced NH_3 slip / Reduced ammonia usage**
  - **Reduces ammonia cost**
  - **Less tube fouling**
- **Higher NOx reduction**
- **Longer life**
- **Added features, e.g. CO reduction**

Traditional HRSG Layout

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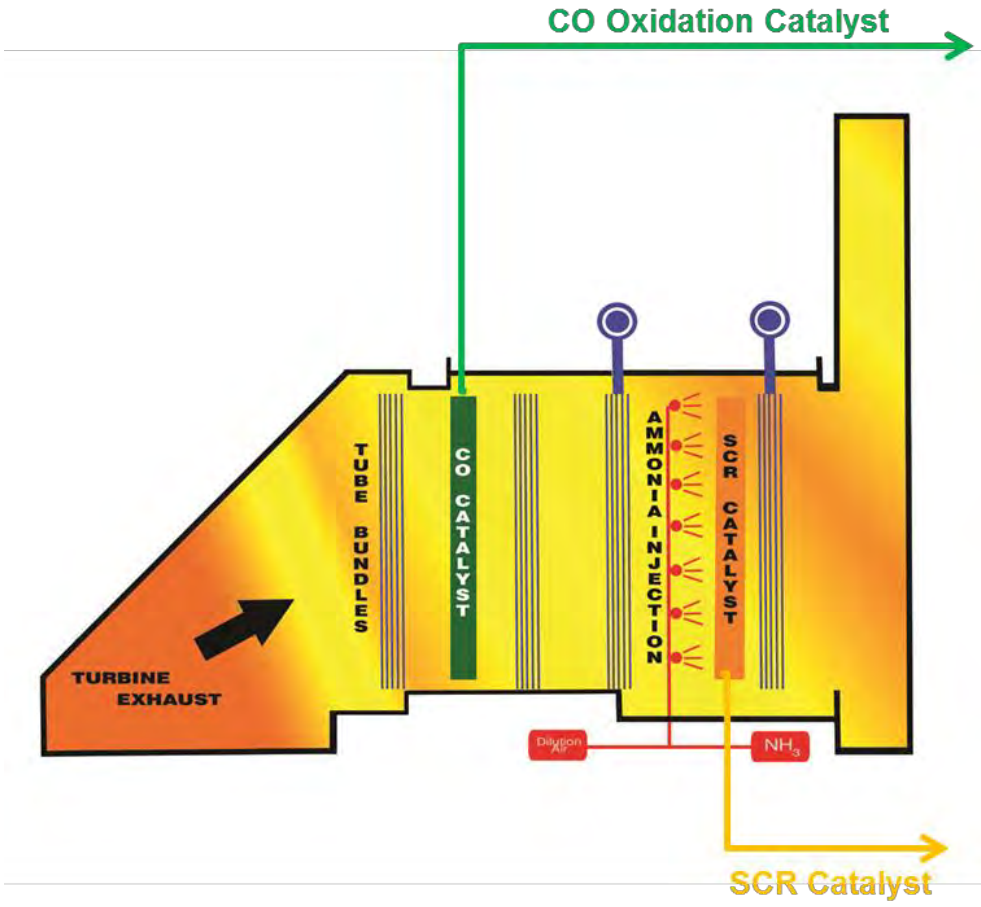
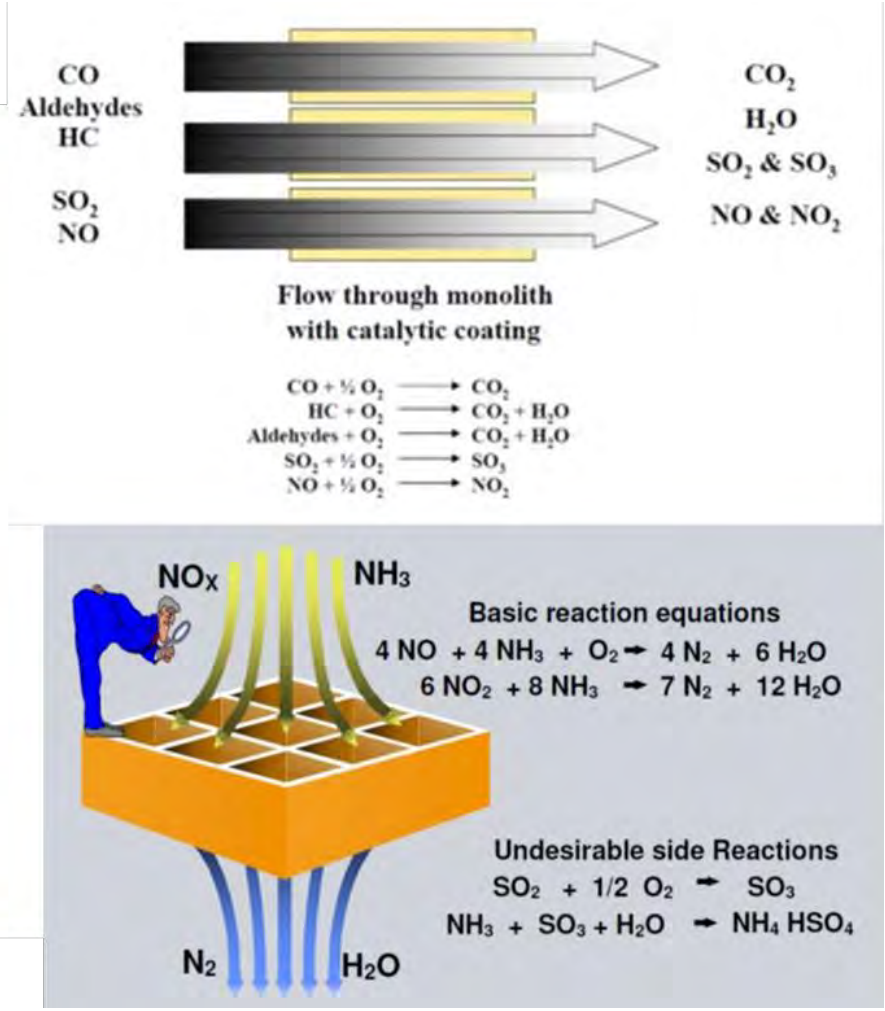
CLEANER AIR THROUGH INNOVATION

→ *CO Oxidation Catalyst* → *AIG* → *SCR Catalyst*



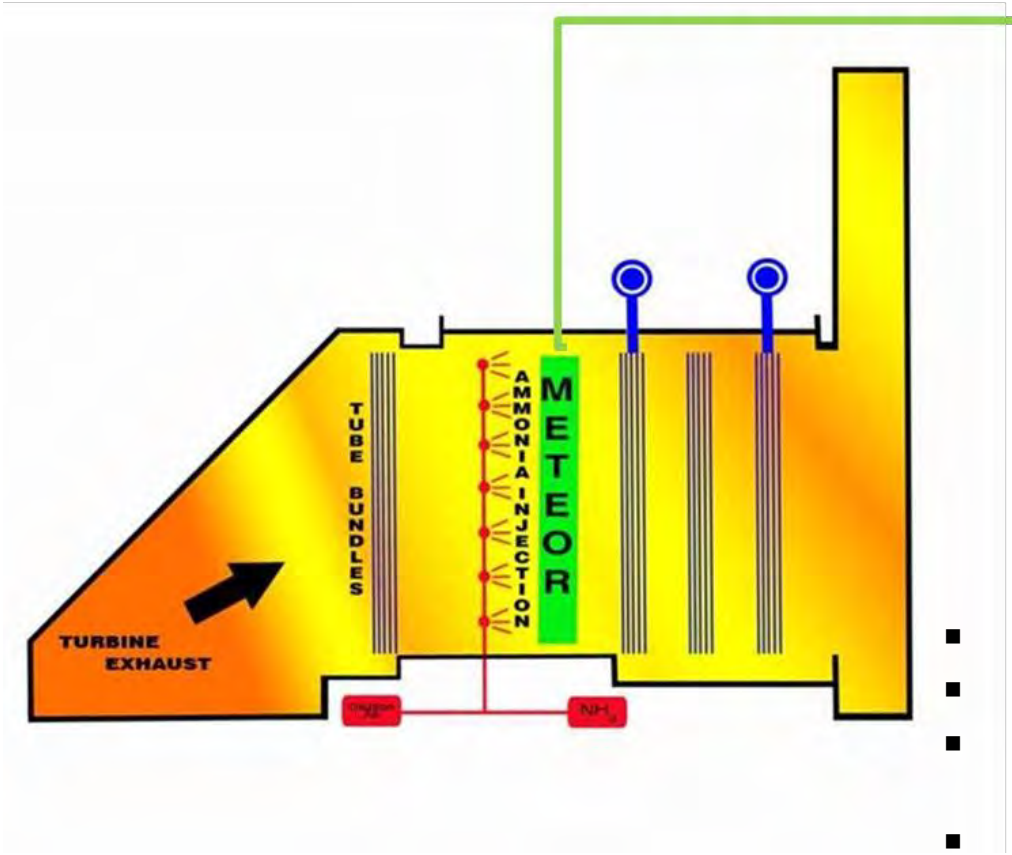


Multi-functional METEOR™

CORMETECH
CLEANER AIR THROUGH INNOVATION

All in one catalyst layer

CORMETECH METEOR™



Oxidizing Function:

CO oxidation to CO_2

VOC oxidation to CO_2 and H_2O

Reduction Function:

$4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O$

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

$6NO_2 + 8NH_3 \rightarrow 7N_2 + 12H_2O$

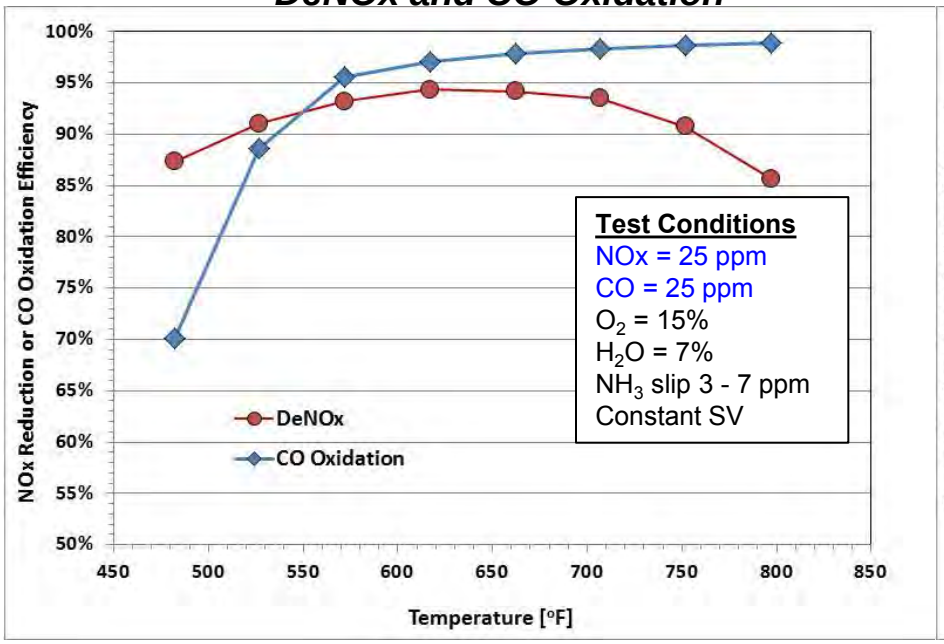
- **SCR** functionality → V_2O_5-WO_3/TiO_2
- **Oxidation** functionality → PGM (Pd and/or Pt)
- Initially developed and patented by **Siemens Energy** (US 7,390,471)
- Optimized and fully developed into commercial production by **Cormetech**

METEOR™ - Example Reactor Data

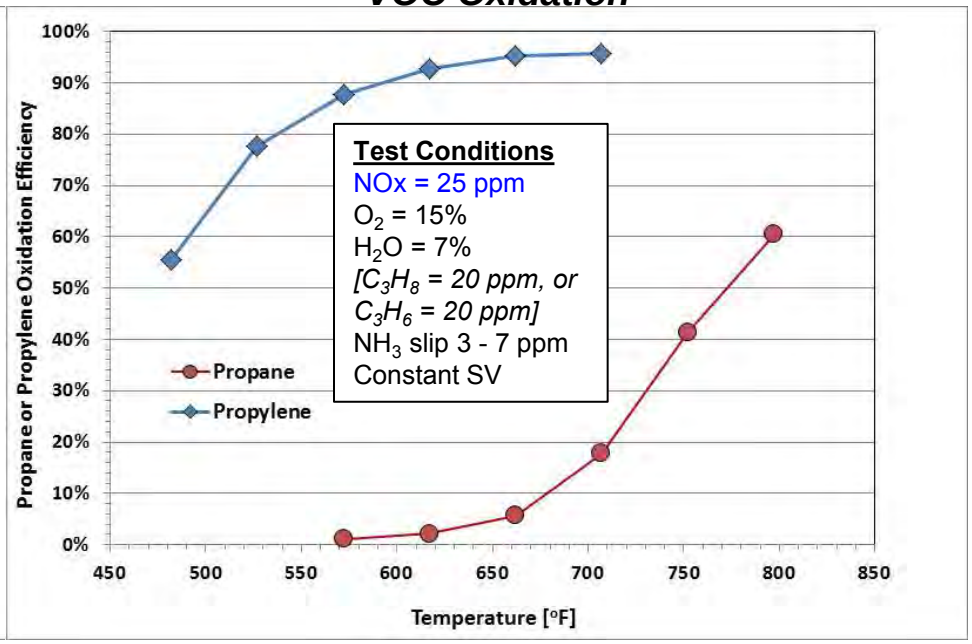
CORMETECH
CLEANER AIR THROUGH INNOVATION

- **DeNOx** and **CO oxidation** → high conversion rates over wide temperature range.
- Active for **VOC oxidation** → rate depends on hydrocarbon speciation.
- **PGM loading** can be adjusted to optimize performance at low/high temperature.
- **Applications:** CCGT, SCGT, diesel/gas RE, refinery process units

DeNOx and CO Oxidation



VOC Oxidation

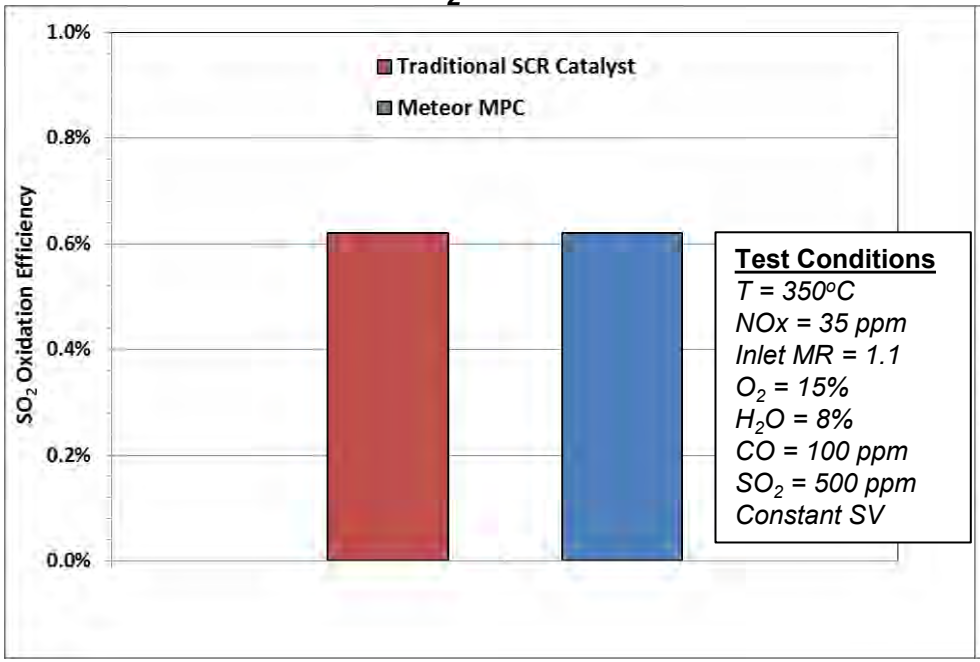


METEOR™ - Sulfur Tolerant

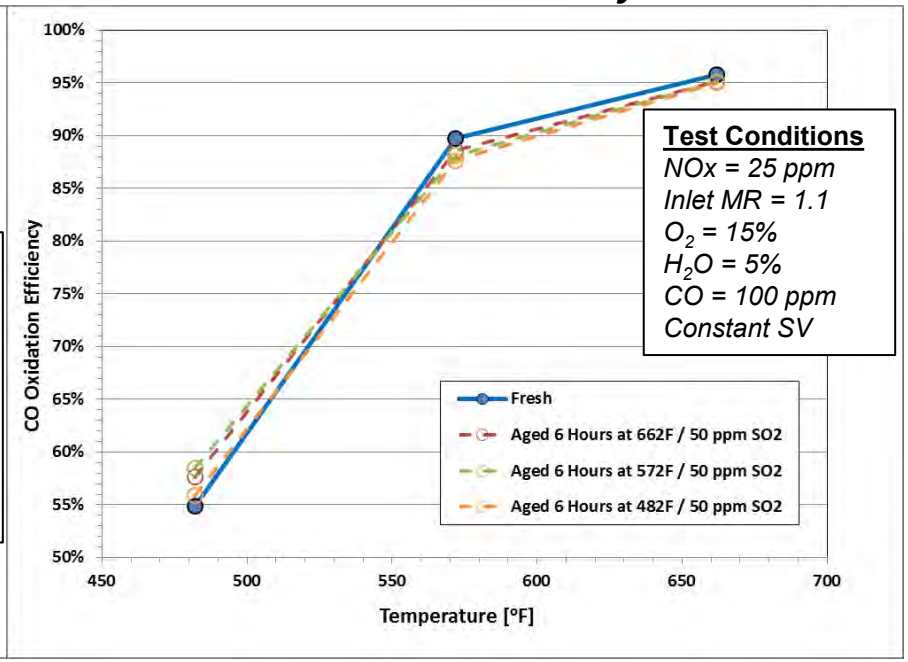
CORMETECH
CLEANER AIR THROUGH INNOVATION

- **Similar** SO_2 oxidation rate as traditional SCR catalyst.
- Short-term exposure to **50 ppm SO_2** has **no significant impact** on CO oxidation.

SO_2 Oxidation



Sulfur Durability



METEOR™ - Benefits

CORMETECH
CLEANER AIR THROUGH INNOVATION

- **Simplicity:** *one catalyst layer vs. two.*
  - Smaller footprint in HRSG.
  - Lower pressure drop.
  - Lower capital and O&M costs.

- **Flexibility:** applicable to new units, retrofits, and replacements.

- **Lower SO_2 oxidation rate,** relative to the traditional two catalyst layout.
  - Potential for reduced backend fouling.

- **Highly resistant to sulfur** compounds in the flue gas.
  - Broader load flexibility from reduced sensitivity to sulfur fouling agents when operating at low temperature.

Plant Ennis Case Study

CORMETECH
CLEANER AIR THROUGH INNOVATION

As presented at POWER-GEN International 2016

- **Combination of advanced tools deployed:**
  - METEOR™ for combined NOx, CO, and VOC reduction
  - Elite™
    - Pleated modules with Integrated Seal
    - Advanced Catalyst Potential

METEOR™ MPC in ELITE™ Configuration

FULL-SCALE INSTALLATION
Ennis Power Company, LLC

CORMETECH
CLEANER AIR THROUGH INNOVATION

- **Ennis Power Company, LLC (Ennis, Texas).**
- Siemens 501G unit combustion turbine (**340MW** combined cycle mode).
- **METEOR™ MPC / ELITE™** replaced existing SCR catalyst in November 2015.
- **Guaranteed emission reductions** of NOx, NH_3 slip, CO and VOC.
- Successfully operating. Currently at >5,000 hours run time.

As presented at POWER-GEN International 2016

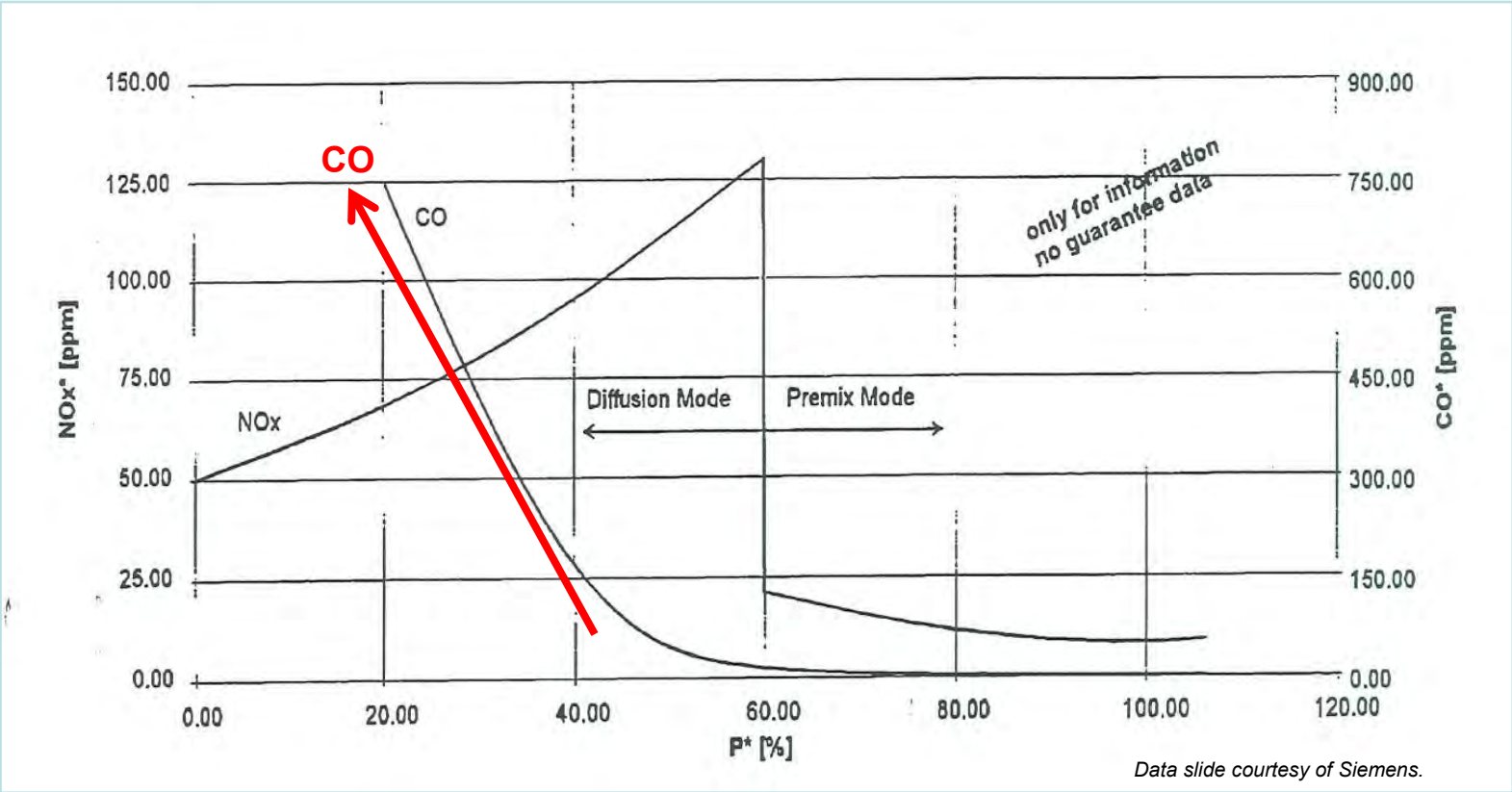
FULL-SCALE INSTALLATION
Ennis Power Company, LLC
Motivation

CORMETECH
CLEANER AIR THROUGH INNOVATION

Replacement of existing SCR layer with a METEOR™ MPC catalyst layer enabled:

(1) Capability to operate at lower loads while maintaining CO emission compliance.

(2) Faster compliance of CO emissions during unit startup.



Data slide courtesy of Siemens.

As presented at POWER-GEN International 2016

FULL-SCALE INSTALLATION
Ennis Power Company, LLC
Field Test Data (April 2016)

CORMETECH
CLEANER AIR THROUGH INNOVATION

- **Field testing validation:** measured SCR inlet and outlet gas composition
  - SCR inlet = GT exhaust gas.
  - **Fresh catalyst** achieved **~99% CO oxidation** at **36% GT load point**.
  - DeNOx achieving target value. NH_3 slip is very low due to the fresh catalyst state.

		GT Exhaust Gas Composition		SCR Outlet Gas Composition		Meteor SCR Catalyst Performance		
GT Load	SCR Temperature (°C)	GT Exhaust CO (ppm)	GT Exhaust NOx (ppm)	SCR Outlet CO (ppm)	SCR Outlet NOx (ppm)	SCR CO Oxidation	SCR DeNOx	SCR Outlet NH_3 Slip (ppm)
98%	342	0.5	29.4	0.0	7.8	100%	74%	0.7
76%	334	0.6	32.8	0.0	6.7	100%	80%	0.7
36%	322	**172**	44.0	**2.2**	6.7	**98.8%**	85%	0.5

As presented at POWER-GEN International 2016

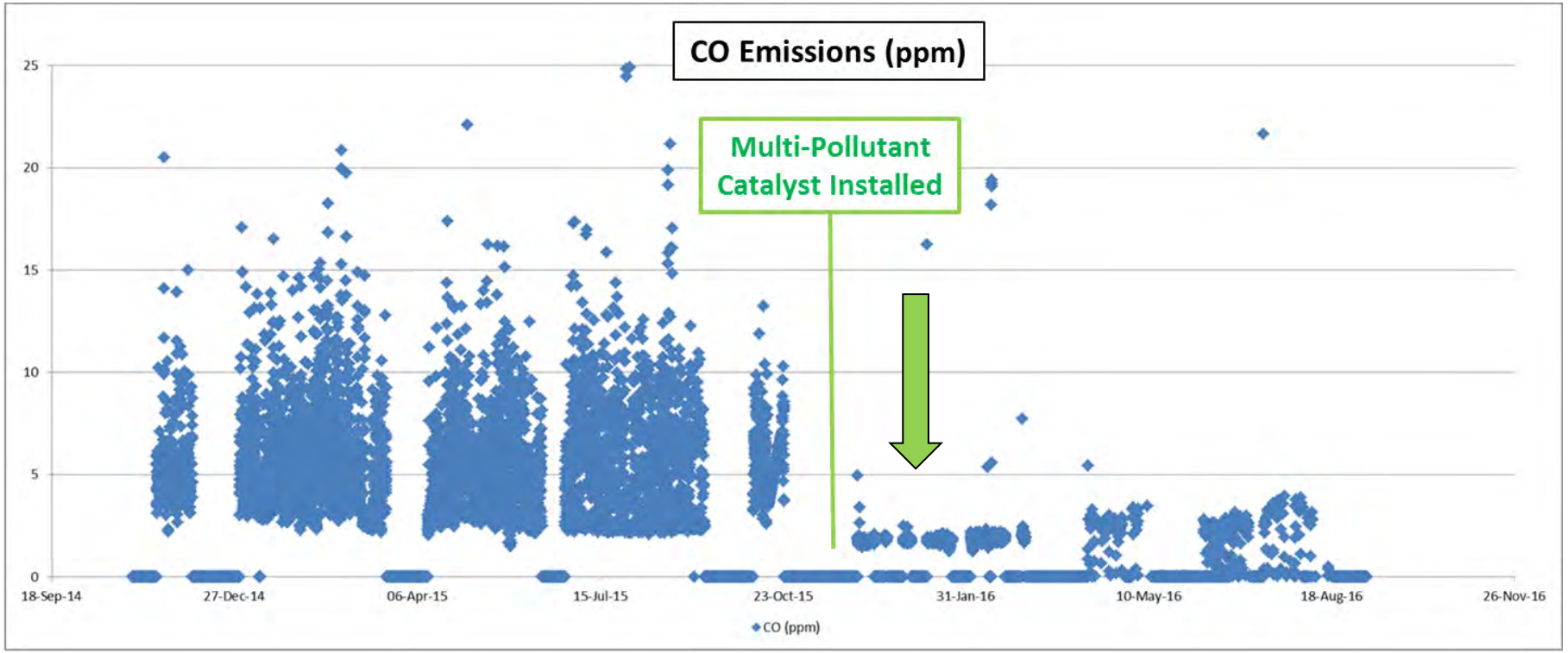
FULL-SCALE INSTALLATION

Ennis Power Company, LLC

Plant Operating Data

CORMETECH
CLEANER AIR THROUGH INNOVATION

- **CO emissions reduced after METEOR™ MPC installed.**

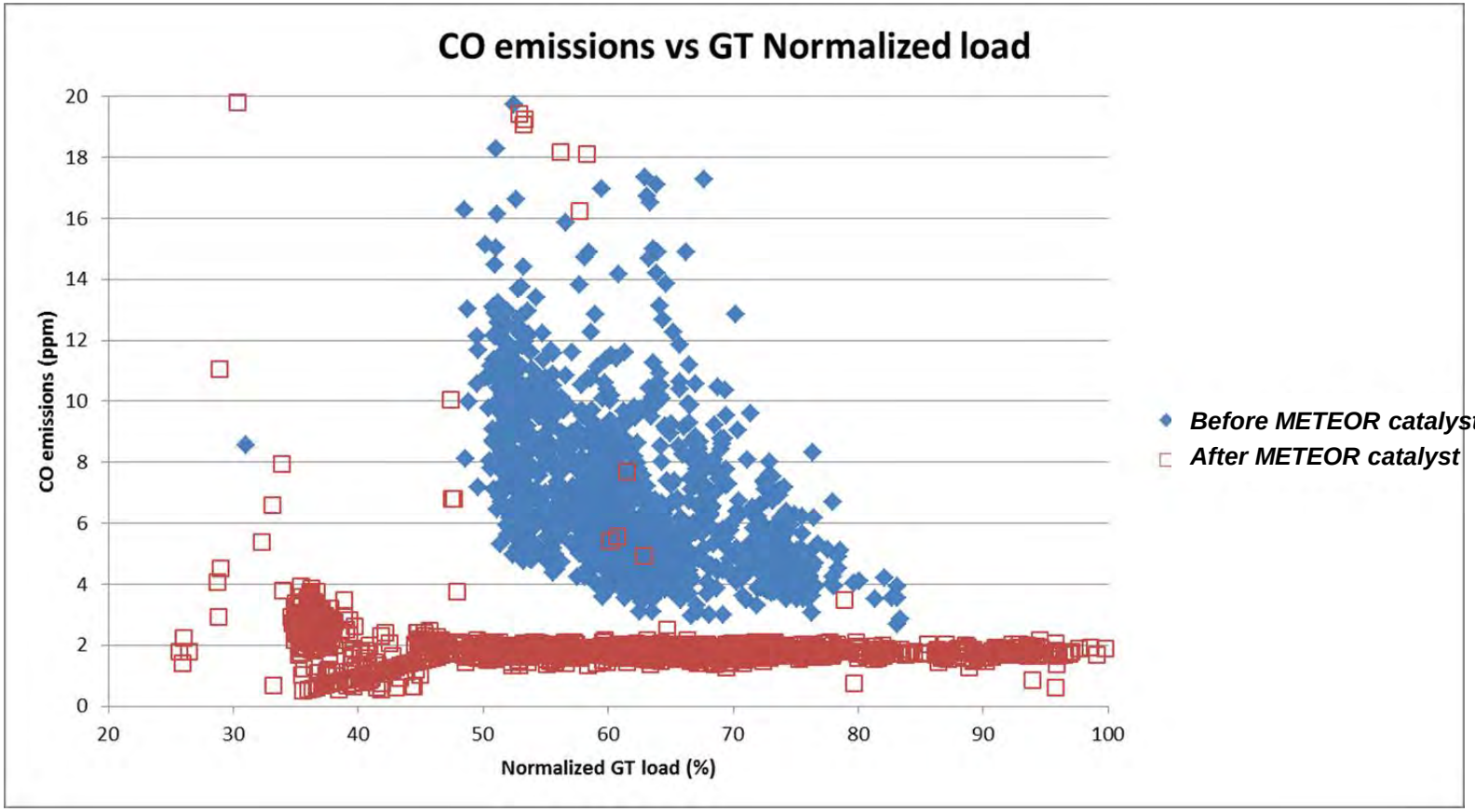


As presented at POWER-GEN International 2016

FULL-SCALE INSTALLATION
Ennis Power Company, LLC
Plant Operating Data

CORMETECH
CLEANER AIR THROUGH INNOVATION

- **CO emissions vs. GT load: impact of METEOR™ MPC installation.**

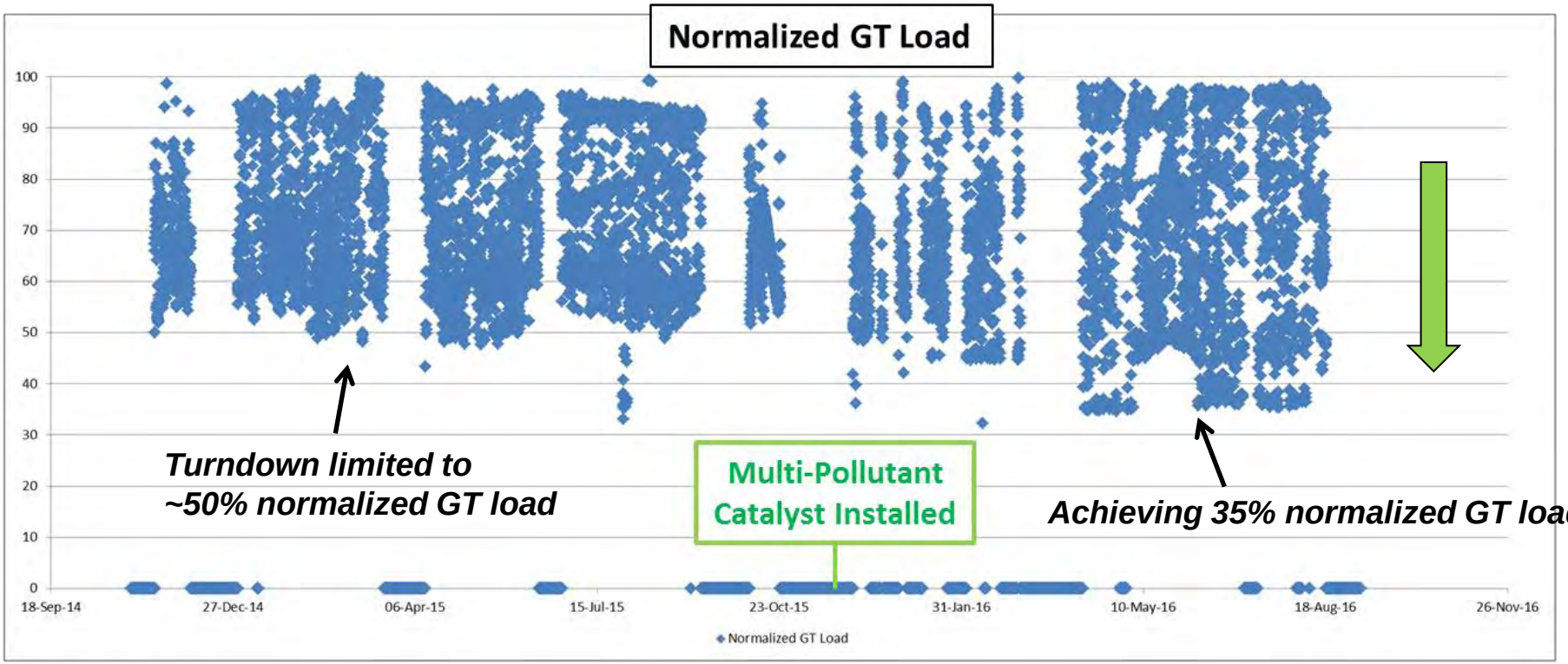


As presented at POWER-GEN International 2016

FULL-SCALE INSTALLATION
Ennis Power Company, LLC
Plant Operating Data

CORMETECH
CLEANER AIR THROUGH INNOVATION

- **METEOR™ MPC installation increased the unit's turndown capability.**

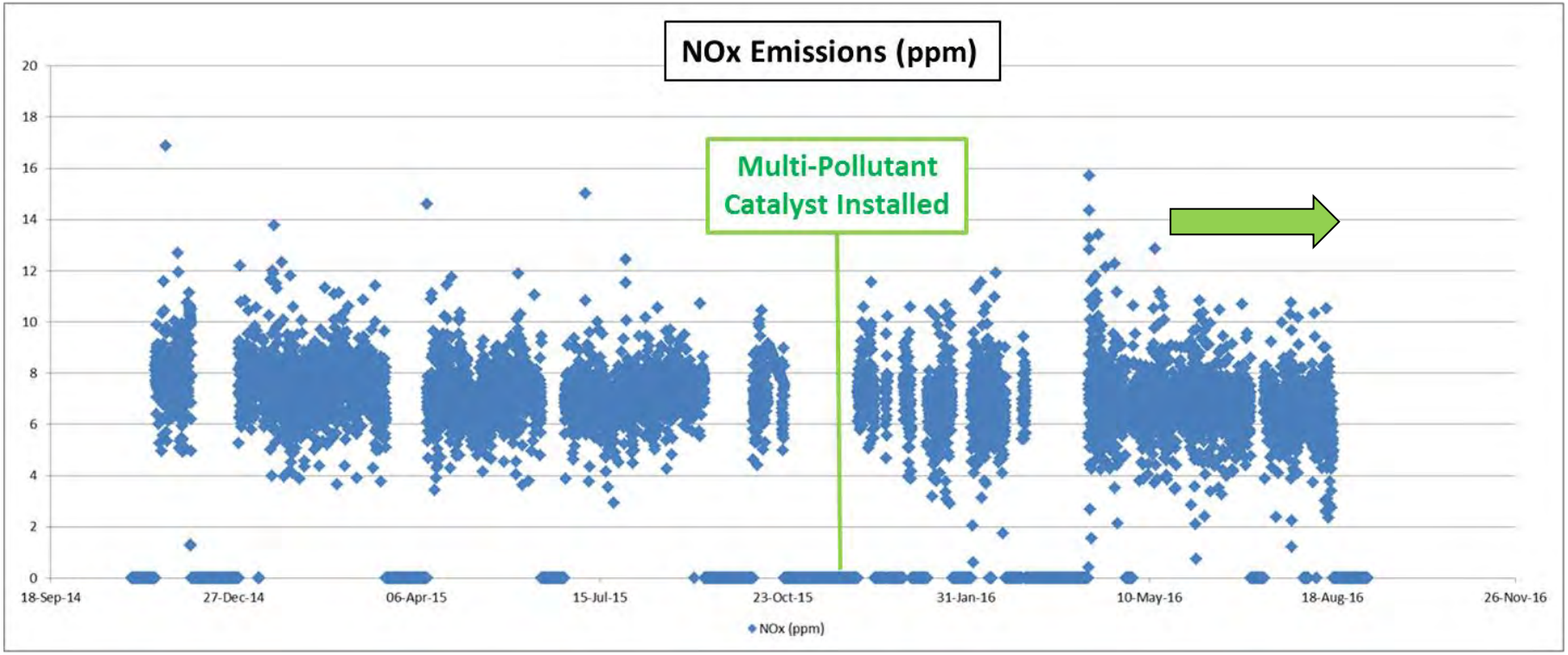


As presented at POWER-GEN International 2016

FULL-SCALE INSTALLATION
Ennis Power Company, LLC
Plant Operating Data

CORMETECH
CLEANER AIR THROUGH INNOVATION

- **Same NOx emissions (per design).**

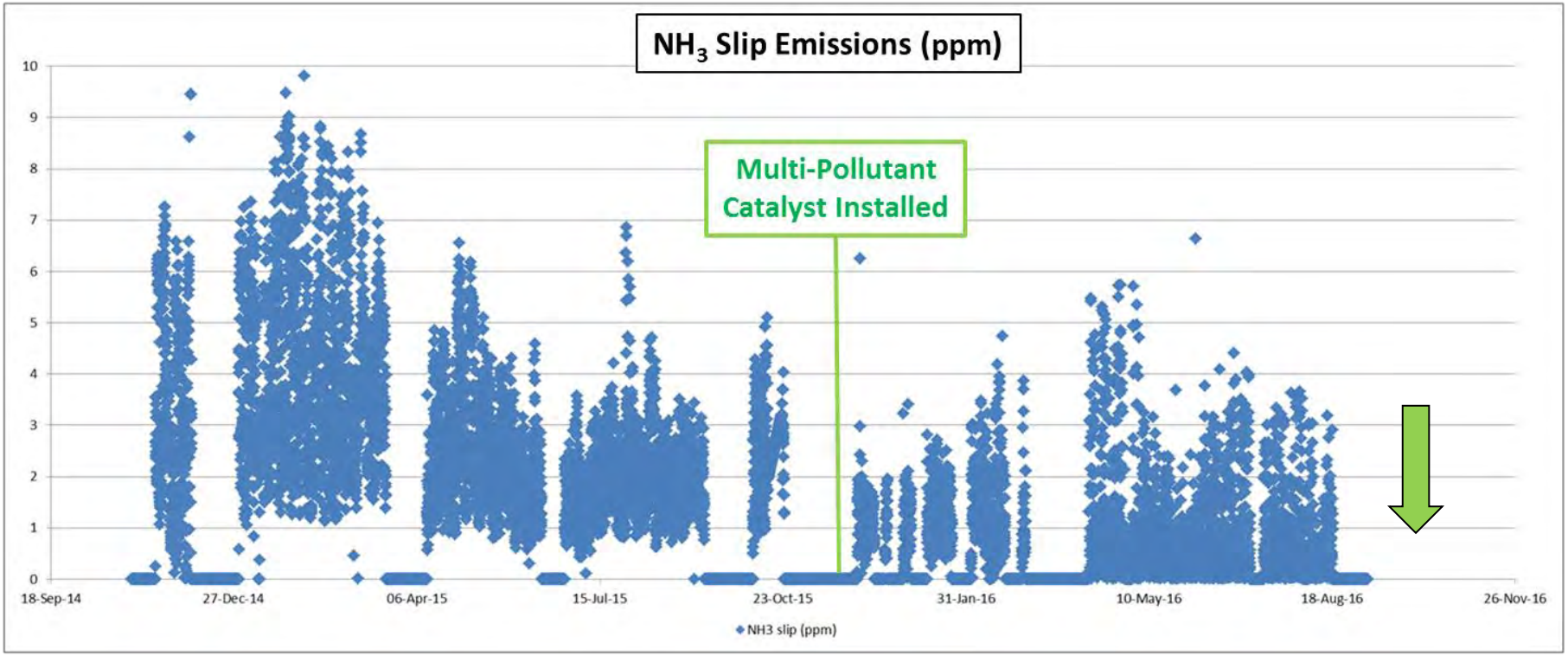


As presented at POWER-GEN International 2016

FULL-SCALE INSTALLATION
Ennis Power Company, LLC
Plant Operating Data

CORMETECH
CLEANER AIR THROUGH INNOVATION

- **Lower NH_3 slip emissions (fresh catalyst).**

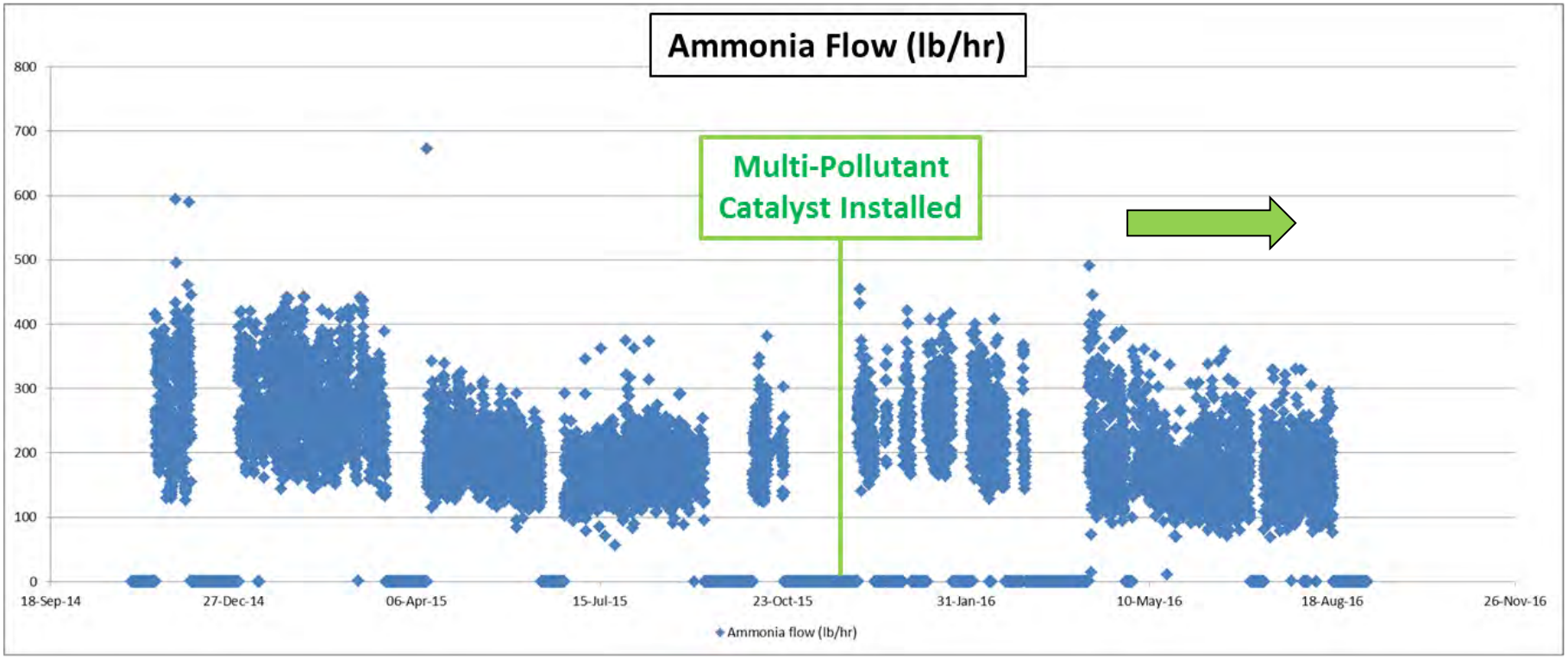


As presented at POWER-GEN International 2016

FULL-SCALE INSTALLATION
Ennis Power Company, LLC
Plant Operating Data

CORMETECH
CLEANER AIR THROUGH INNOVATION

- **No change in NH_3 usage rate after METEOR™ MPC installation.**

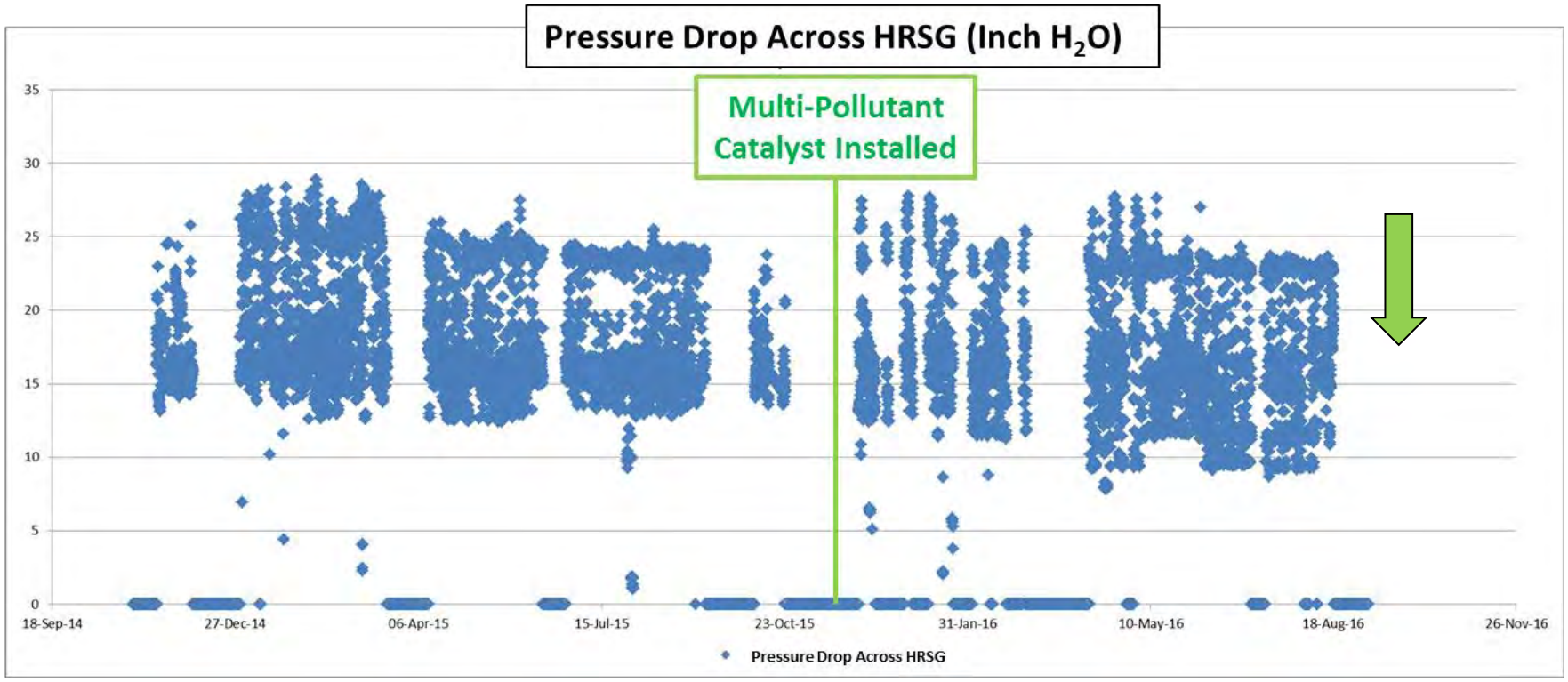


As presented at POWER-GEN International 2016

FULL-SCALE INSTALLATION
Ennis Power Company, LLC
Plant Operating Data

CORMETECH
CLEANER AIR THROUGH INNOVATION

- **~2 inch H_2O reduction in system backpressure (compared at constant flow)**



As presented at POWER-GEN International 2016

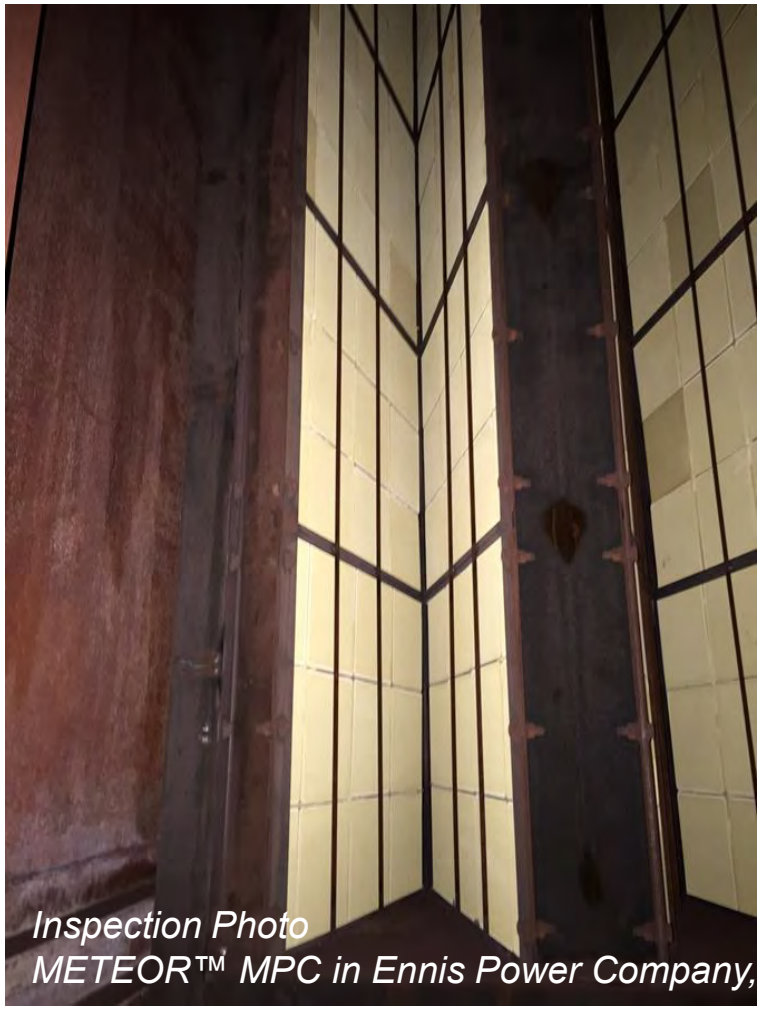
FULL-SCALE INSTALLATION
Ennis Power Company, LLC
Catalyst Audit

CORMETECH
CLEANER AIR THROUGH INNOVATION

Inspected catalyst on October 25, 2016:

The catalyst was in excellent condition, and the cells were clean and open. These observations are consistent with the measured back pressure trends.

Successful Operation Continues



Inspection Photo
METEOR™ MPC in Ennis Power Company,

As presented at POWER-GEN International 2016

High NO_2 SCR Catalyst

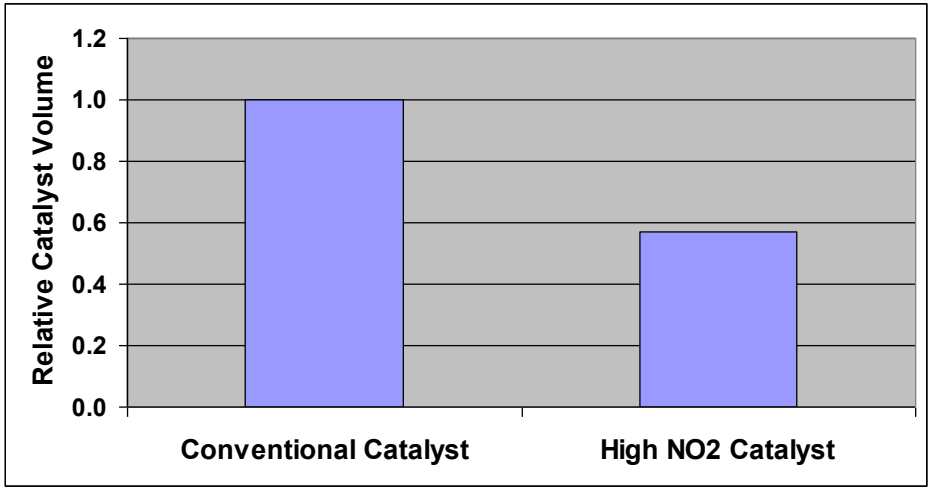
CORMETECH
CLEANER AIR THROUGH INNOVATION

NO2 can be >50% of NOx under certain conditions. When >50%, "Slow" SCR reaction effect:
$6NO_2 + 8NH_3 \rightarrow 7N_2 + 12H_2O$

High NO_2 Catalyst accelerates rate of "Slow" SCR Reaction:

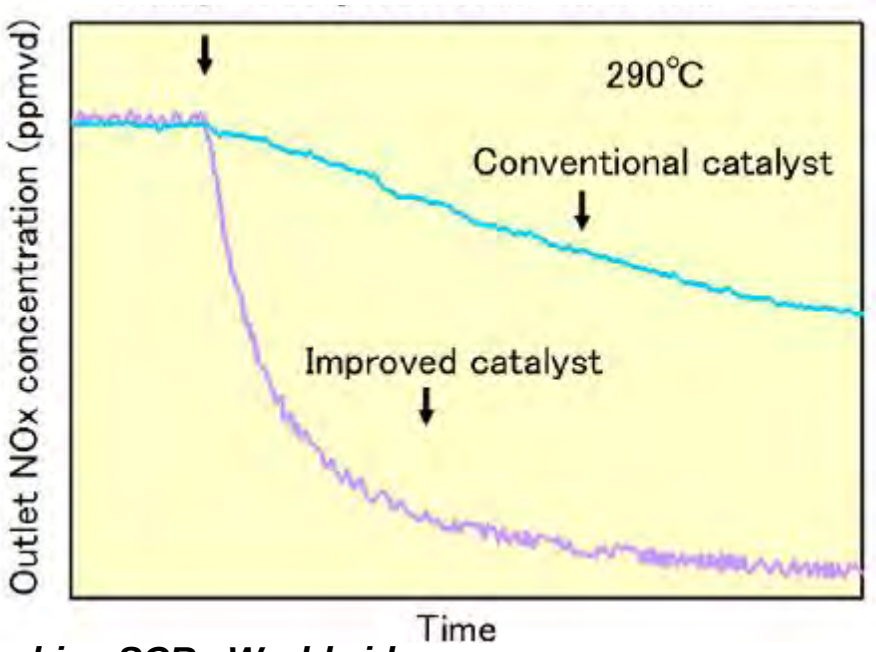
Much higher activity than conventional catalyst under high NO_2 conditions.

Example: 332°C, NO_2/NO_x = 95%



Lower Volume = Lower Pressure Drop

Faster transient responses at high NO_2. Improved load following and cold start-up performance.

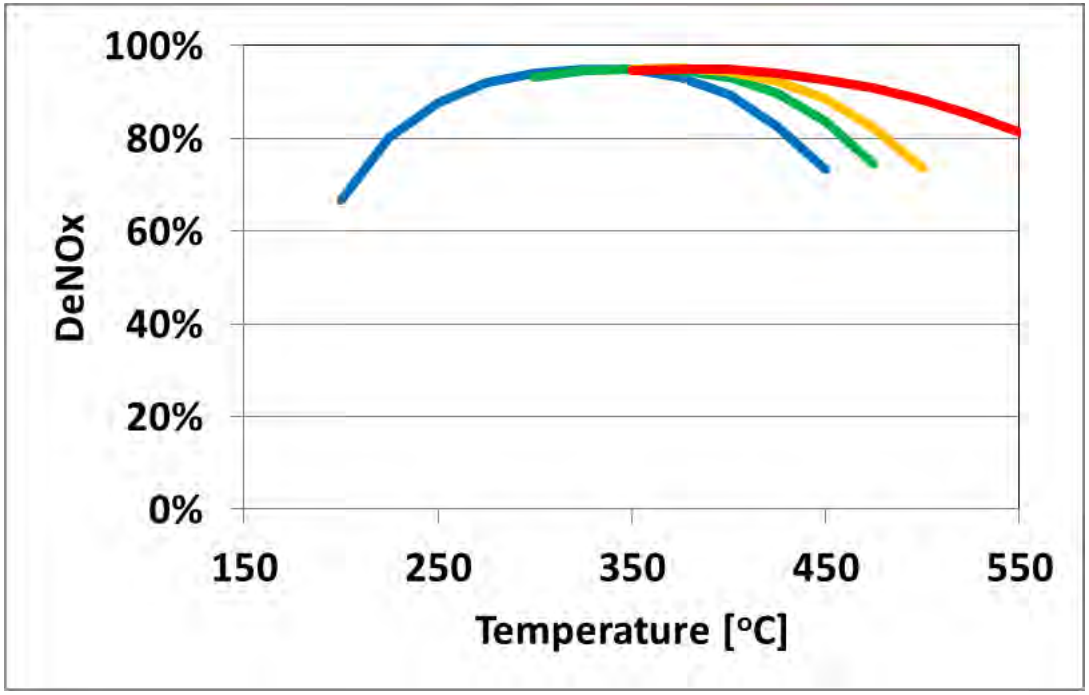


In Operation in Several Gas Turbine SCRs Worldwide

Tools for Various Temperature Ranges

CORMETECH
CLEANER AIR THROUGH INNOVATION

Formulations to meet a range of operating windows:



Formulation for Combined Cycle GT Applications

Formulations for Simple Cycle GT Applications

Case Study – Plant A

CORMETECH
CLEANER AIR THROUGH INNOVATION

Customized Catalyst Formulation for 100MW Simple Cycle GT

- Needs:
  - Operate at 840 °F (450 °C)
  - DeNOx: 91%
  - Ammonia slip: 7 ppm
  - CO reduction: 95%
- Solution:

Extended Temperature Range Formulation + **METEOR™ For High Temperature**

Custom combination achieves high DeNOx and high CO reduction while maintaining good ammonia utilization

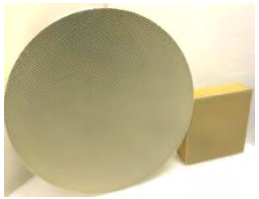
Other Applications of Advanced Tools

CORMETECH
CLEANER AIR THROUGH INNOVATION

- METEOR™ applied to ammonia slip reduction
  - Solving a transient emissions problem during cycling of load
- METEOR™ for gas-firing on coal-fired boiler
  - Exploring potential in order to meet CO emissions requirements
- Reciprocating engines
  - Integrated seal
  - Advanced Catalytic Potential
  - METEOR™
  - Customized Formulations

24 inch ULFA

Canisters



13 inch LFA

Meeting Needs with Advanced Tools

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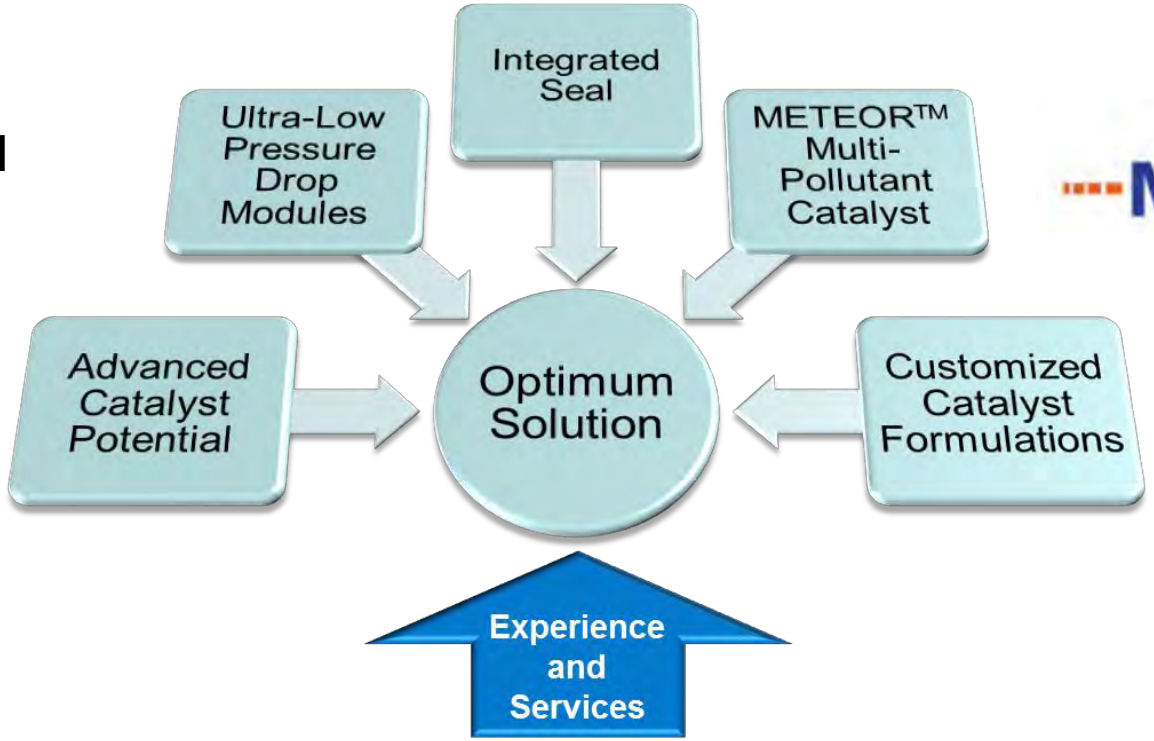
CLEANER AIR THROUGH INNOVATION

Elite™



CORMETECH METEOR™

Meeting emissions control requirements

- DeNOx
- CO and hydrocarbon reduction
- NH_3 slip limit
- Under a variety of conditions

While minimizing cost of compliance

- Low capital cost
- Low maintenance cost
- Low parasitic power loss
- Minimize NH3 usage
- Minimize or eliminate operation constraints

State-of-the-art emission control solutions!