

# Capital and O&M Benefits of Advanced Multi-Function Catalyst Technology for Combustion Turbine Power Plants

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## ABSTRACT

As combustion turbines become more highly utilized to meet power generation needs, the demand for reliable performance across a wide variety of operating conditions has increased. Wider load flexibility, enhanced operational efficiency, and lower maintenance are all desired, while assuring environmental compliance.

Advanced Multi-Function Catalyst, initially developed and patented by Siemens Energy Inc., and optimized and fully developed into commercial production as METEOR™ by Cormetech, Inc., simultaneously reduces NO<sub>x</sub>, CO, VOCs and NH<sub>3</sub> slip to compliance levels in one catalyst layer. It provides several key benefits, compared to the traditional solution with two separate catalysts (i.e., CO oxidation and SCR), to address the changing dynamics of the power industry:

1. Capital cost reduction through a reduced footprint within the HRSG.
2. Enhanced efficiency and increased MW load operation through reduced catalyst pressure loss (from the single catalyst layer layout combined with Cormetech's latest patented ultra-high surface area, high open area honeycomb in a pleated module).
3. Lower maintenance cost through reduced cold-end fouling from sulfuric acid and ammonium bisulfate (ABS).
4. Broader load flexibility through much lower sensitivity to flue gas sulfur compounds (e.g., SO<sub>2</sub>).

This paper provides an overview of our Multi-Function Catalyst technology, focusing on the functional background, performance data, and value proposition.

## 1.0 INTRODUCTION

The power generation landscape has shifted significantly in recent years. Many old coal plants have been retired, and supply from renewable energy sources is increasing. Due to sustained low natural gas prices, generation from combined cycle natural gas fired power plants has enjoyed steady growth; in April 2015, gas-fired generation actually surpassed coal for the first time (Jell, 2015)<sup>1</sup>. This growth is projected to continue into the foreseeable future, according to the U.S. Energy and Information Administration (EIA) (Ford, 2014)<sup>2</sup>.

The increased deployment of gas fired generation (through new combined cycle (CC) plants and upgrades to existing CC plants) has motivated OEM suppliers in recent years to maximize the efficiency and profitability of gas fired combustion turbines as power sources. These efforts have included a focus on emission control devices, as the higher generation capacity along with the clarification of EPA guidelines and rulings concerning startup allowances (leading to potential retrofits of existing units without installed CO oxidation or SCR catalysts) have driven a greater need for improved emissions compliance solutions.

Oxidation and selective catalytic reduction (SCR) catalysts have long been the standards for the removal of CO and NO<sub>x</sub> from fossil fuel emission sources. The two catalysts have historically been installed in separate layers within the Heat Recovery Steam Generator (HRSG) due to the incompatibility of the CO oxidation catalyst with the injected NH<sub>3</sub> reductant for the SCR catalyst. However, the presence of two separate catalyst layers results in additional pressure drop and parasitic load to the unit. Recent advances in SCR catalyst technology have yielded a unique product that adds the CO oxidation capability to the traditional SCR catalyst in a single layer: Multi-Function Catalyst (MFC). This new technology greatly increases the asset optimization, load flexibility, emissions control and cost profile of natural gas generation.

MFC was initially developed and patented by Siemens Energy, and optimized and fully developed into commercial production as METEOR™ by Cormetech. In combination with Cormetech's ELITE™ module technology for reduced pressure drop, MFC provides an optimal technology for emission control in the fast-growing gas fired HRSG market segment.

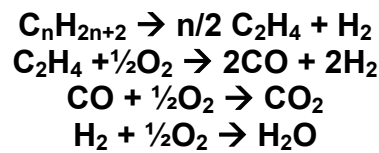
## 2.0 NO<sub>x</sub>, CO AND VOC GENERATION IN COMBUSTION TURBINES

From an overall emissions control perspective, it is important to understand the combustion process and the trade-offs that exist between efficiency and emissions.

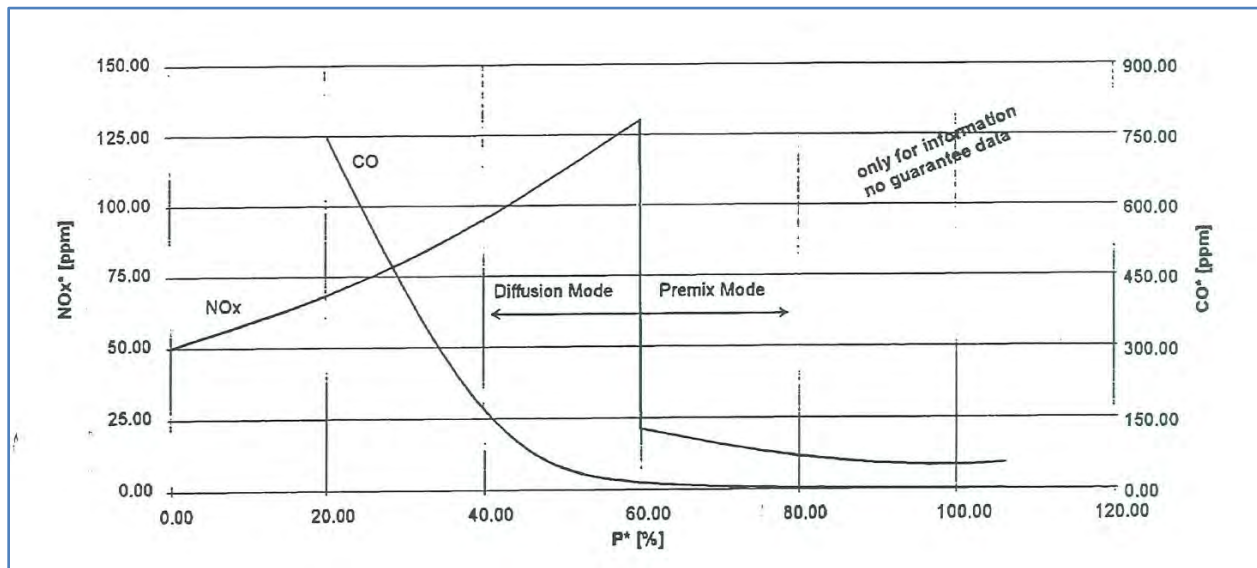
Combustion is a complex chemical and physical process that depends first on the type of flame. There are two basic types of flames that affect the behavior of fuel during its burning in combustion devices: diffusion flame and premixed flame. *Diffusion flame* arises when the fuel and oxidizing agent (e.g., air) combust during the mixing process. Industrial burners normally utilize diffusion flame combustion. *Premixed flame* consists

of the combustion of perfectly (or near-perfectly) mixed reactants prior to combustion. A combustion turbine is an example of a premixed combustion source.

In the case of premixed combustion, the fuel-air mixture oxidizes more readily in the flame zone. Common pollutants from premixed combustion include NO<sub>x</sub>, CO and volatile organic compounds (VOCs). The emissions are affected by combustion turbine design details; their reduction requires a good understanding of fuel, airflow, combustion chemistry, evaporation and mixing. Very low emissions from advanced gas turbines can be achieved by using the Lean Premixed Combustion (LPC) method, a form of dry low NO<sub>x</sub> technology where water is not used to cool the flame in order to reduce NO<sub>x</sub> emissions. To simplify the chemistry of LPC, a global reaction mechanism for hydrocarbon conversion can be written as follows:



CO that is formed in the flame zone is oxidized to CO<sub>2</sub>; however, the rate of CO oxidation is relatively slow compared to the CO formation rate. Figure 1 shows an example chart of load versus GT emissions trends. With GT inlet Guide Vanes (IGV) tuning and other latest combustor tuning upgrades, the NO<sub>x</sub> and CO emissions are even lower than the levels shown in this Figure 1, but they follow a similar trend pattern.

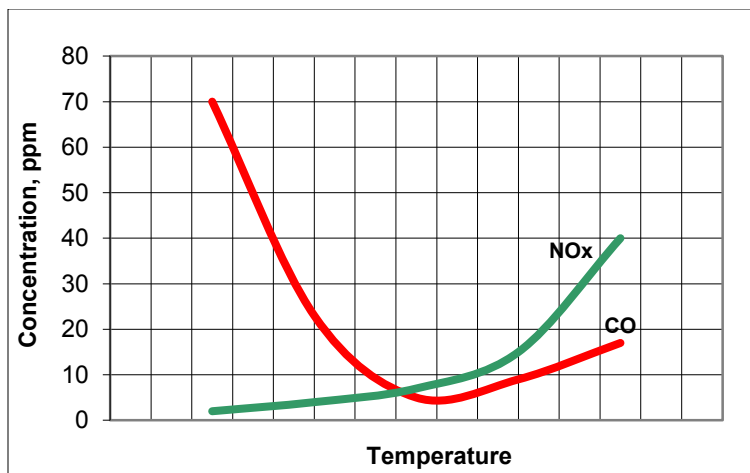


**Figure 1. An Example Relative Power Vs Gas Turbine Exit NO<sub>x</sub> & CO Emissions**

VOC formation occurs as a result of incomplete fuel burnout (i.e., the hydrocarbons are not fully oxidized to CO<sub>2</sub> and H<sub>2</sub>O). In LPC, the rates of CO oxidation and hydrocarbon oxidation are slowed down by the low gas temperature that exists in the lean premixed condition. In addition, the elevated presence of VOCs in the flame and after the flame zone can increase CO emissions, since VOCs react more rapidly with oxidizing radicals

than CO does, further reducing the CO oxidation rate. Thus, if the temperature is too low under lean firing conditions (and/or if there is flame instability), the CO and VOC emissions from the combustion turbine can increase significantly.

It is very important in the design of a combustion turbine (e.g., for nozzles and transitions) to achieve conditions where the temperature of LPC is low enough to reduce NOx emissions, but still high enough to support a high rate of hydrocarbon and CO oxidation, in order to minimize VOC and CO emissions. A hypothetical curve illustrating this tradeoff is shown in Figure 2.



**Figure 2. Pollution Reduction by Control of Flame Temperature**

VOC emissions from gas turbines firing natural gas mostly consist of alkanes, alkenes, aldehydes, aromatics, propylene and propane. The alkanes (C<sub>1</sub>-C<sub>6</sub>) and propane are saturated hydrocarbons; their reaction rate over oxidation catalysts is a strong function of the hydrocarbon chain length (propane, methane and ethane are particularly difficult to oxidize). Formaldehyde and propylene are unsaturated hydrocarbons, which are more reactive than propane and other alkanes. Note that the EPA definition of a VOC excludes CO, CO<sub>2</sub>, methane, ethane, H<sub>2</sub>CO<sub>3</sub>, metallic carbides and carbonates. An example of how total VOC emissions can vary with load for a Siemens GT is provided in Table 1. The total VOC concentration is significant up to 40% load; above 40% load, it has a tendency to decrease to very low concentration (achieving < 1 ppm at base load).

**TABLE 1. EXAMPLE OF TOTAL VOC IN GT EXHAUST VS. LOAD**

Load	20%	40%	60%
Total VOC* (lb/MMBTU)	3.0x10 <sup>-1</sup>	1.2x10 <sup>-2</sup>	3.2x10 <sup>-3</sup>

*\*Based on gas chromatographic analysis.*

It is necessary to stress that VOCs in the gas turbine exhaust are very diverse, being comprised of thousands of organic compounds. Also, the total VOC concentration can vary in a wide range from 1x10<sup>-3</sup> to 20 lb/MMBTU (depending mainly on GT load, but also on the type of GT and operating conditions).

CO emissions are generally low when the gas turbine is running at full load. The turbine design has, in fact, been optimized for reducing CO formation to a minimum level when the turbine is running at full load. However, when the turbine operates at a partial load, CO emissions can increase to high levels that in some cases can exceed several thousand ppm concentration. As the power generation landscape continues to shift, due in part to the increasing amount of energy produced from wind and solar power, more gas turbines are forced to run at partial load conditions. In regions of the US where CO emissions are regulated, having the ability to run at partial load would require the installation of a CO oxidation catalyst for CO removal in order to meet the emission requirements.

### 3.0 TRADITIONAL LAYOUT OF EMISSIONS CONTROL SYSTEM

CO and VOC from gas turbine exhaust gas has traditionally been achieved by using two different catalysts, with an oxidation catalyst arranged upstream of an SCR catalyst, and the injection of ammonia for the SCR reaction done Reduction of NO<sub>x</sub>, between the two catalysts as shown in Figure 3.

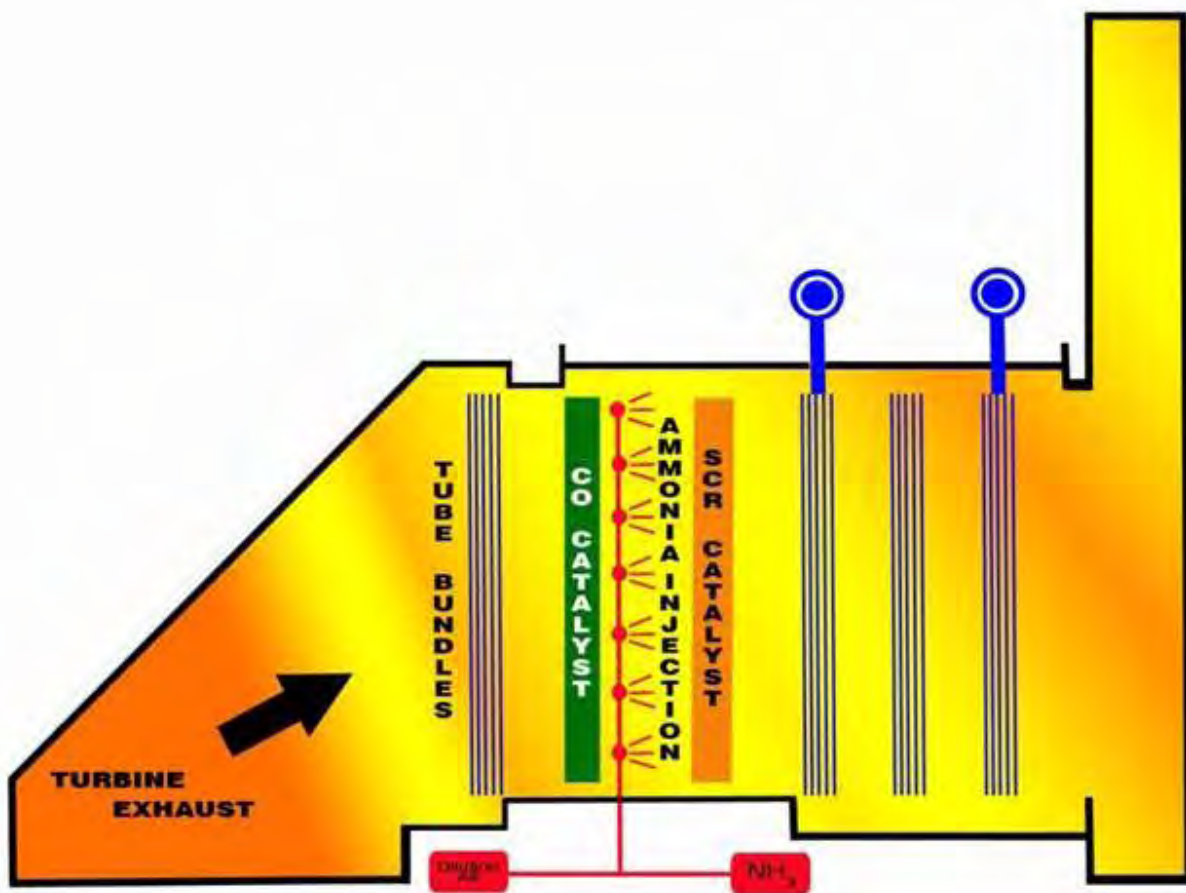
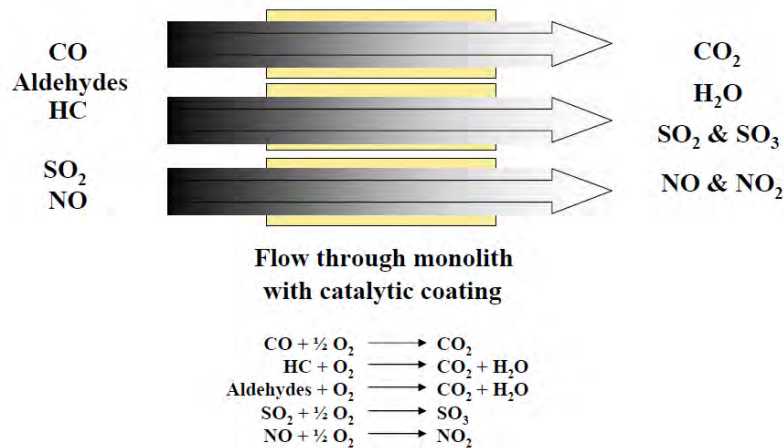


Figure 3. Traditional Catalyst Layout

### 3.1 TRADITIONAL CO OXIDATION CATALYST

The traditional catalyst layout utilizes a very good CO oxidation catalyst, but it comes with some resulting challenges. Situating the oxidation catalyst at a high temperature location minimizes the use of platinum group metals (PGM: Pt and/or Pd) in the catalyst. However, due to the higher gas velocity at the high temperature location, and the small channels of the oxidation catalyst, there is a higher pressure drop that constitutes an important operational cost. Traditional CO oxidation catalyst can oxidize flue gas constituents at high rates, including NH<sub>3</sub> and sulfur compounds as shown in Figure 4.



**Figure 4. Oxidation Catalyst Reactions**

Because the oxidation catalyst is very active in NH<sub>3</sub> oxidation to NO<sub>x</sub>, which is highly undesired, it is located upstream of the AIG (with the CO oxidation catalyst located upstream of the AIG, no injected NH<sub>3</sub> is wasted).

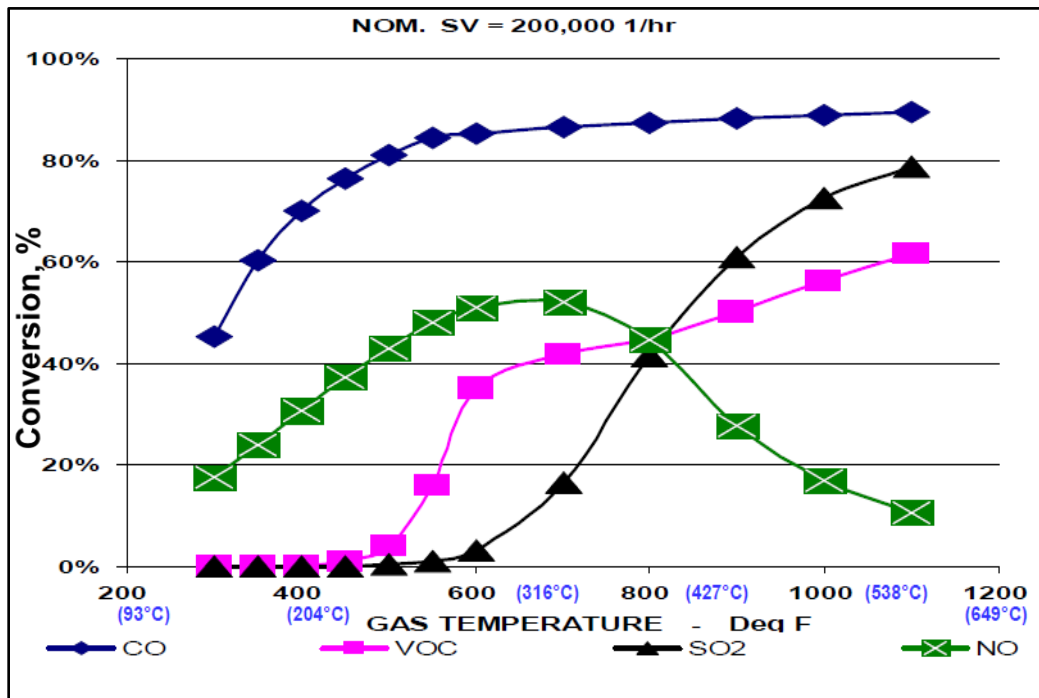
Locating the CO oxidation catalyst downstream of the traditional SCR is not a preferred configuration, because the oxidation catalyst will convert the inherent ammonia slip from the SCR into NO<sub>x</sub>, increasing the SCR catalyst volume required to achieve a target NO<sub>x</sub> reduction efficiency. For this reason, the CO oxidation catalyst has traditionally been placed upstream of the SCR section in HRSG applications.

Additionally, the CO oxidation catalyst can produce elevated levels of NO<sub>2</sub> from NO oxidation (which can impact traditional SCR performance when the resulting NO<sub>2</sub>/NO<sub>x</sub> is >50%) and SO<sub>3</sub> from SO<sub>2</sub> oxidation (which can impact HRSG tube fouling and particulate emissions).

The CO oxidation catalyst is made in monolithic blocks with a large number of parallel channels in order to obtain a large surface area, as shown in Figure 5. Traditional CO oxidation catalyst consists of platinum group metals (PGM) supported on alumina that is washcoated on a metal foil or ceramic substrate. The typical channel size is in the range 1-2 mm. Figure 6 shows a typical set of CO oxidation catalyst performance curves for a GT application.



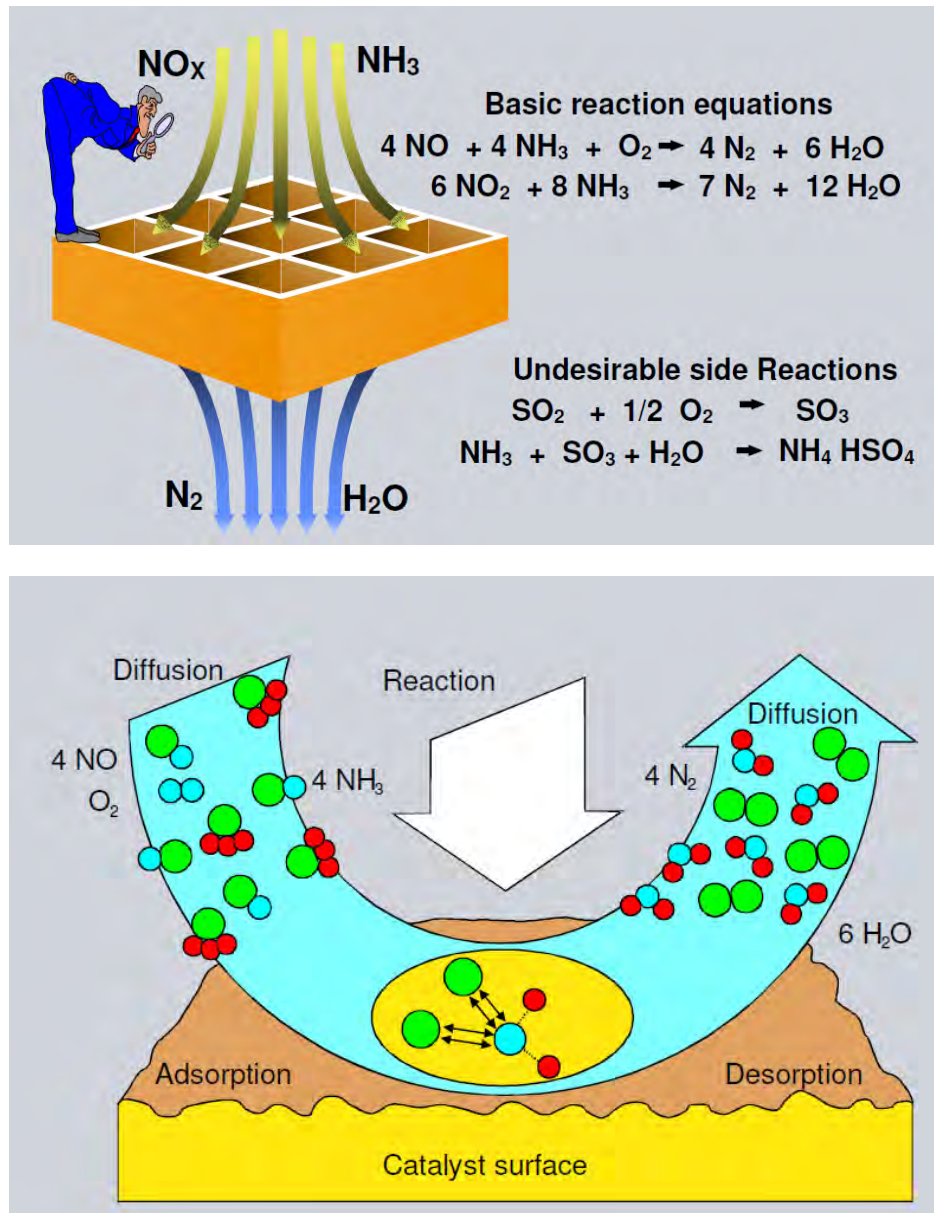
**Figure 5. Monolithic Oxidation Metal Foil Catalyst Assembly**  
 (Source: Siemens HRSG O&M Plant Installation)



**Figure 6. Typical Performance Curves for CO Oxidation Catalyst**  
 (Source: Siemens HRSG O&M Manuel)

### 3.2 TRADITIONAL SCR CATALYST

The Selective Catalytic Reduction (SCR) is a catalytic reaction using ammonia to reduce nitrogen oxides (NO and NO<sub>2</sub>) over a V<sub>2</sub>O<sub>5</sub>-WO<sub>3</sub>/TiO<sub>2</sub> catalyst to form nitrogen and water; the reaction scheme is shown in Figure 7. Note that traditional SCR catalyst has little effect on CO emissions.

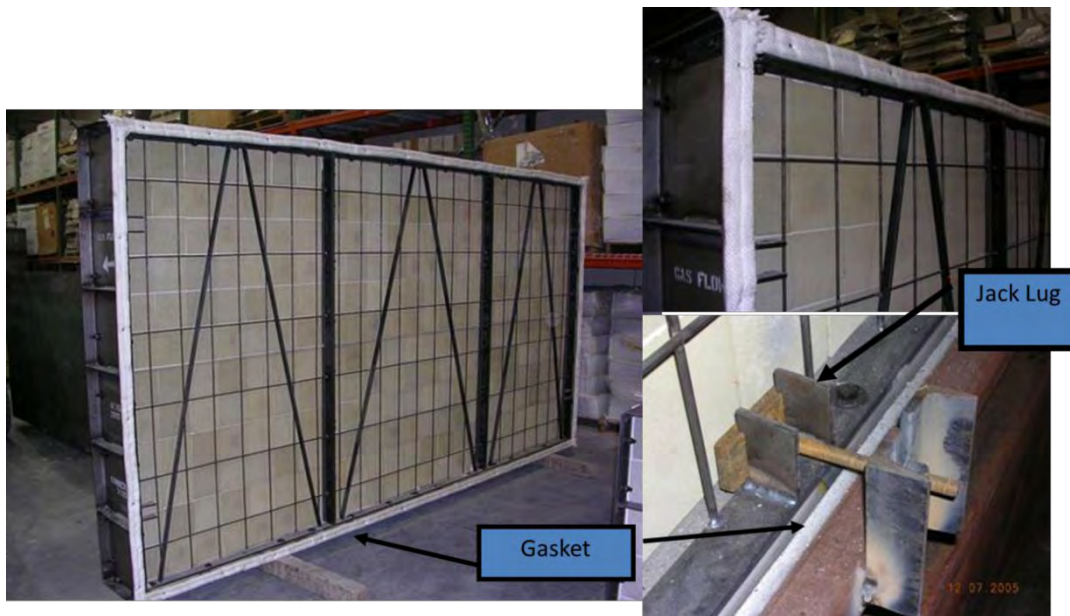


**Figure 7. Chemical Reactions of the SCR Process**

The temperature zone for optimal SCR performance (based on V<sub>2</sub>O<sub>5</sub>-WO<sub>3</sub>/TiO<sub>2</sub> catalyst) is in the range of 300 to 400°C (572 to 752°F). Therefore, the typical layout of an SCR installation on a gas turbine is to place the SCR catalyst inside the HRSG by splitting it up in a way that provides an appropriate temperature at the inlet to the SCR catalyst.

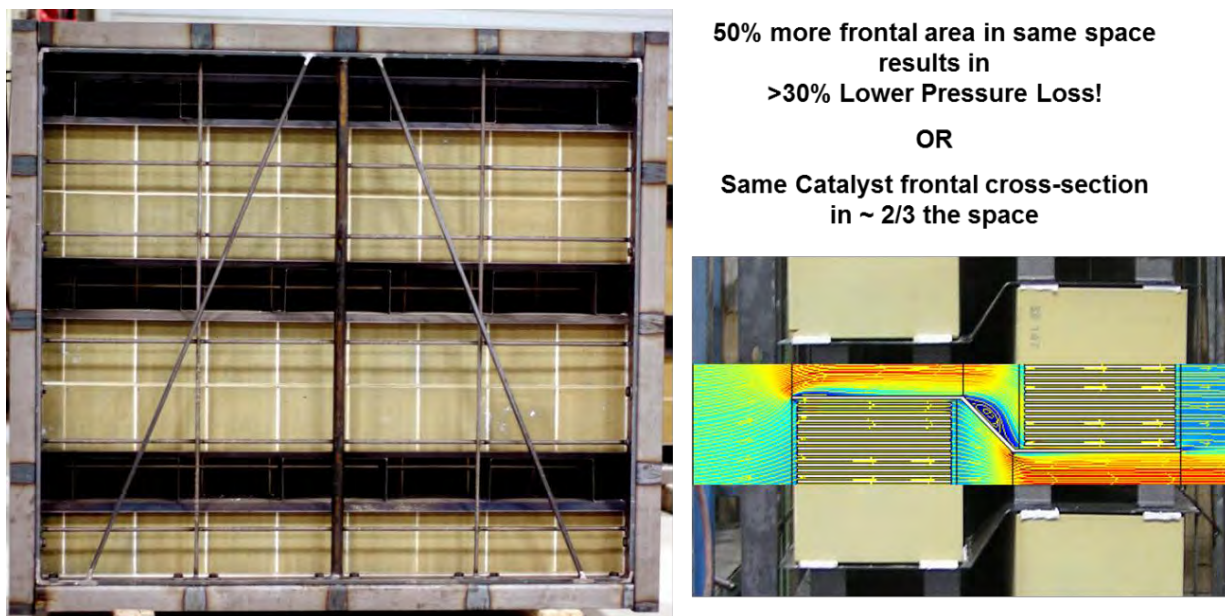


Figure 8 shows Cormetech's standard SCR module for horizontal gas flow HRSG applications. This is the SCR catalyst arrangement used in most of the traditional catalyst layout HRSG applications.



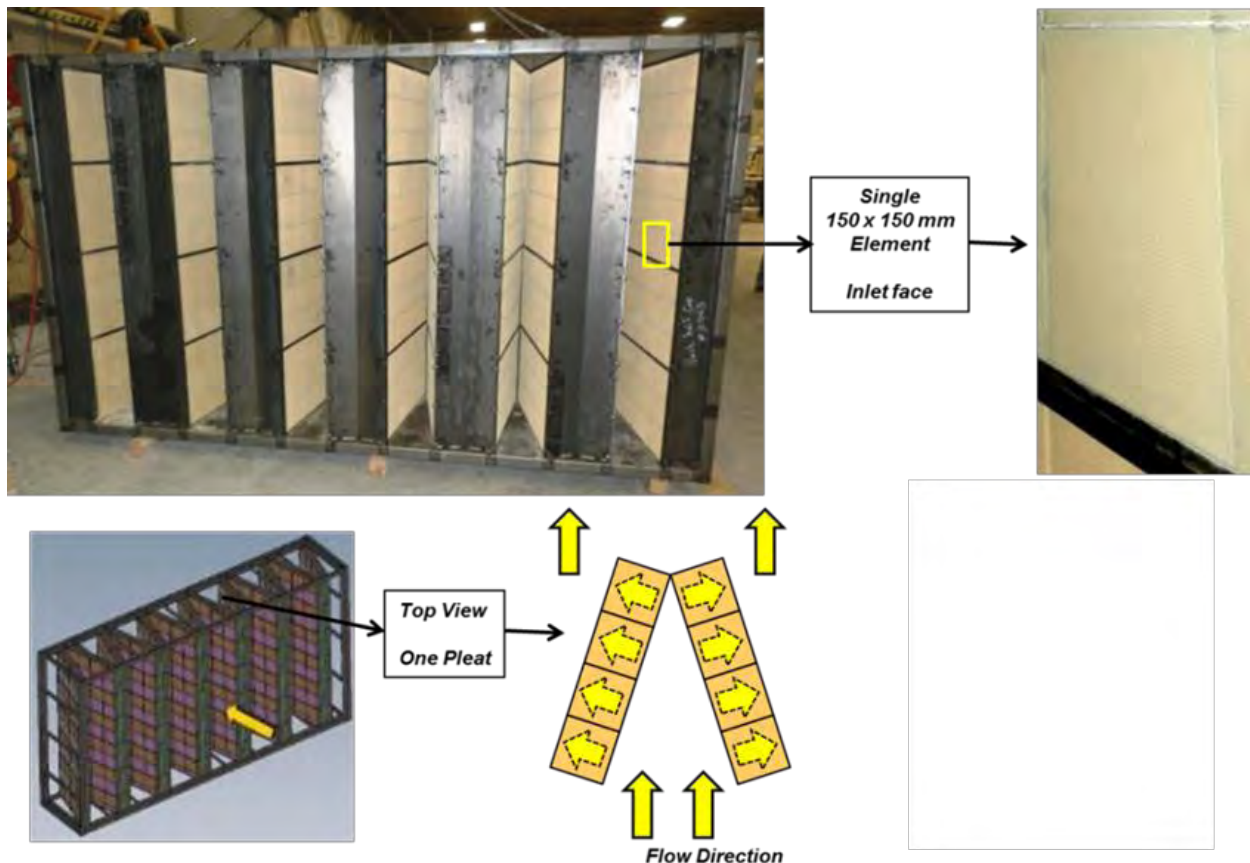
**Figure 8. Cormetech's Traditional Horizontal Flow "Standard Module"**

For applications requiring a lower pressure drop, Cormetech offers a patented advanced SCR module for gas fired HRSG applications as shown in Figure 9.



**Figure 9. Cormetech's Patented "Advanced Module" for Gas-Fired SCR Units**

For applications requiring ultra-low lower pressure drop, Cormetech offers its Elite™ technology consisting of a patent pending Pleated Advanced Module (AMP) and its newest catalyst technology, as shown in Figure 10.



**Figure 10. Cormetech’s Patent Pending “Elite™” Ultra-High Surface Area Module for Deeper Reduction in Pressure Drop Gas-Fired SCR Units**

SCR catalyst is designed and sized to optimize performance for an application’s specific set of inlet conditions; high NO<sub>x</sub> removal efficiencies of >96% can be achieved while still maintaining low NH<sub>3</sub> slip. Achieving good SCR performance requires a well-mixed inlet condition with respect to NH<sub>3</sub> and NO<sub>x</sub> (typical RMS distribution is 5-10%). Areas of the duct where NH<sub>3</sub> is present in large excess relative to NO<sub>x</sub> can lead to increased NH<sub>3</sub> slip.

Figure 11 shows a typical relationship between the NO<sub>x</sub> removal efficiency and NH<sub>3</sub> slip (the design performance targets for this curve are 90% DeNO<sub>x</sub> and 2 ppm NH<sub>3</sub> slip). To improve this trade-off, increasing the catalyst potential through increased volume and/or increased monolith surface area to volume ratio can yield higher DeNO<sub>x</sub> and/or lower NH<sub>3</sub> slip; pressure drop concerns can then be mitigated by the use of the Advanced and Elite™ Module designs.

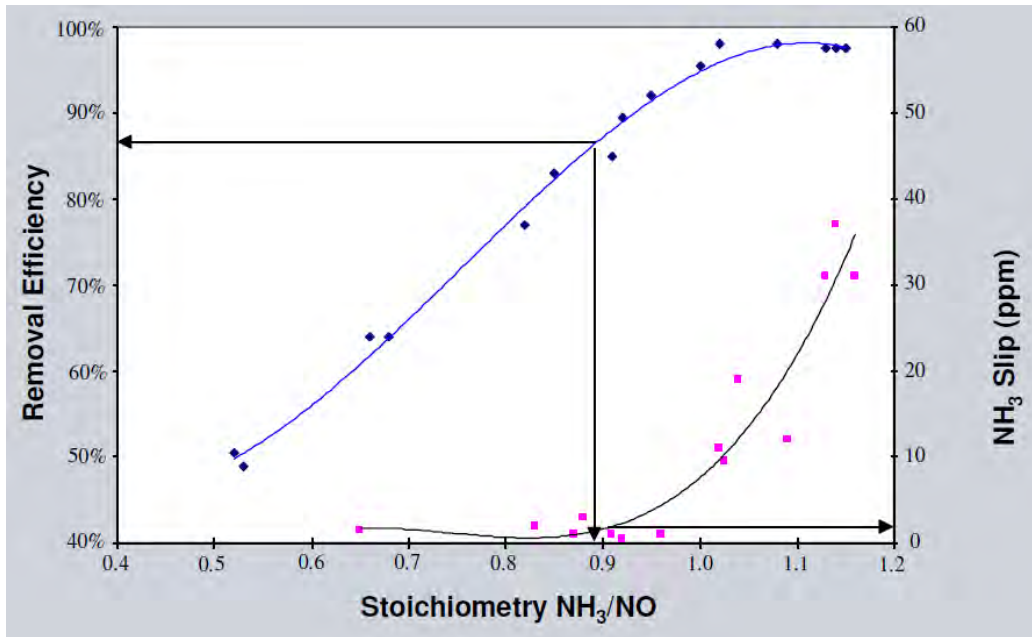


Figure 11. Typical Relationship of NO<sub>x</sub> Removal Efficiency and NH<sub>3</sub> Slip for Various NH<sub>3</sub>/NO Ratio

### 3.3 NEW LAYOUT OF EMISSIONS CONTROL SYSTEM

In the Multi-Function Catalyst (MFC) layout shown in Figure 12, the CO oxidation function is integrated with the SCR function in a single catalyst layer operating in the traditional SCR low temperature range. This layout offers many benefits and values to the combined cycle plant over the traditional layout, which will be reviewed in Section 5.

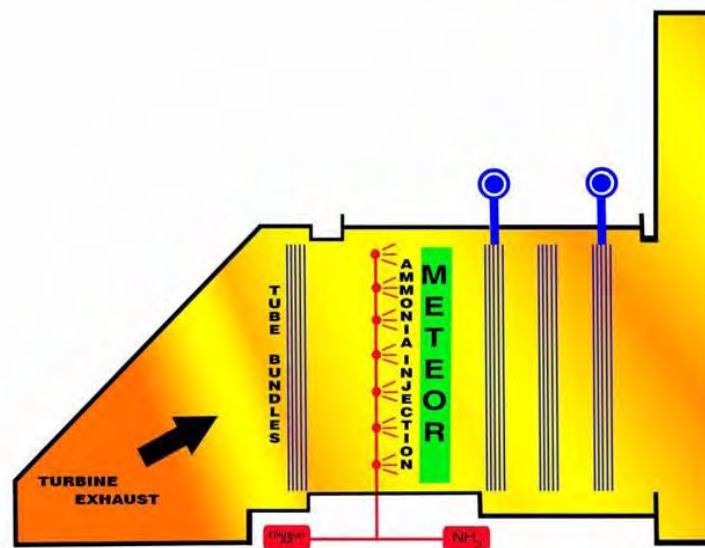
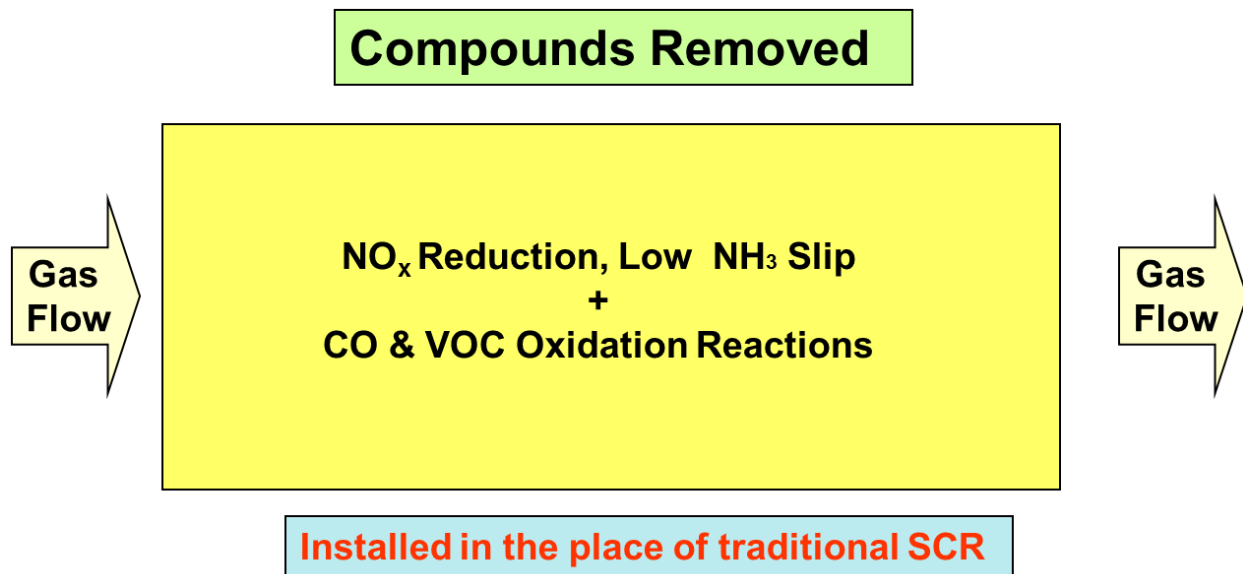


Figure 12. Multi-Function Catalyst (MFC) Layout. MFC is patented by Siemens. METEOR™ is the commercial trademark name from Cormetech.

Figure 13 shows a schematic of an MFC element that combines reduction and oxidizing properties to reduce emissions of NO<sub>x</sub> while maintaining low NH<sub>3</sub> slip and simultaneously oxidizing CO and hydrocarbons.



**Figure 13. Multi-Function Catalyst (MFC) Element Reactions Arrangement**

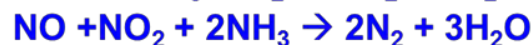
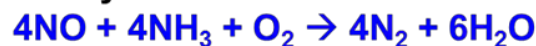
The MFC effectively incorporates the PGM (i.e., Pd and/or Pt) oxidizing functionality into the extruded V<sub>2</sub>O<sub>5</sub>-WO<sub>3</sub>/TiO<sub>2</sub> honeycomb catalyst, enabling the following reactions to take place in the single layer MFC element (note: MFC is typically formulated to yield minimal additional NH<sub>3</sub> oxidation compared to a traditional SCR catalyst; this reaction can be enabled if high NH<sub>3</sub> decomposition activity is required for an application).

- **Oxidizing function**

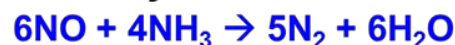
- **CO oxidizes to CO<sub>2</sub>**
- **VOC oxidizes to CO<sub>2</sub> and water**

- **Reduction Function**

- **Primary:**

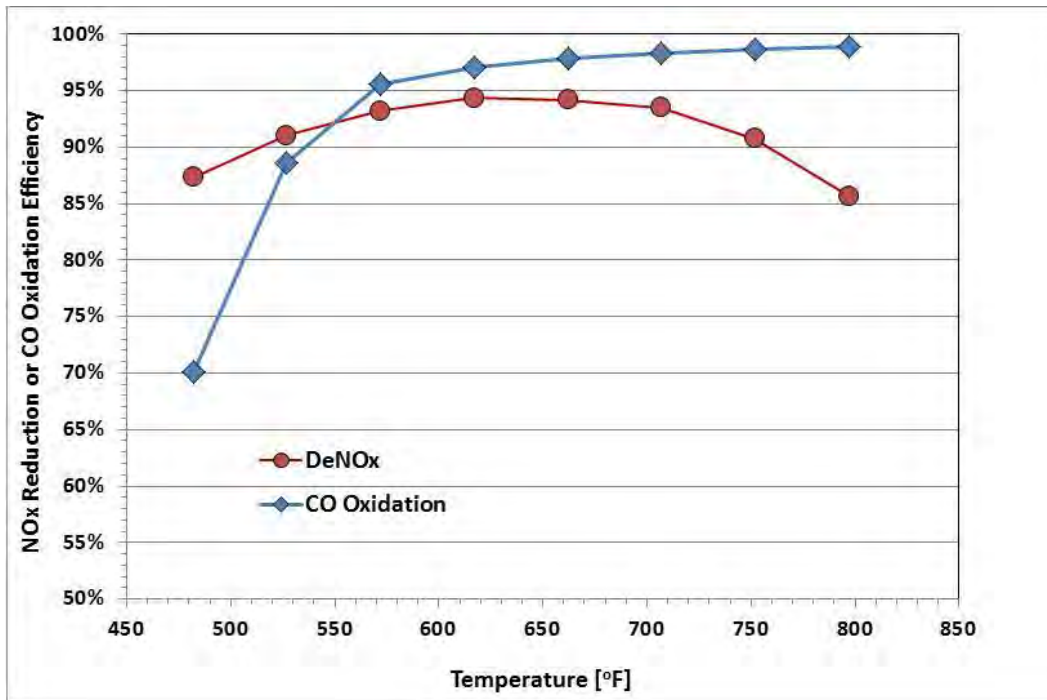


- **Secondary:**



#### 4.0 MULTI-FUNCTION CATALYST (MFC) PERFORMANCE

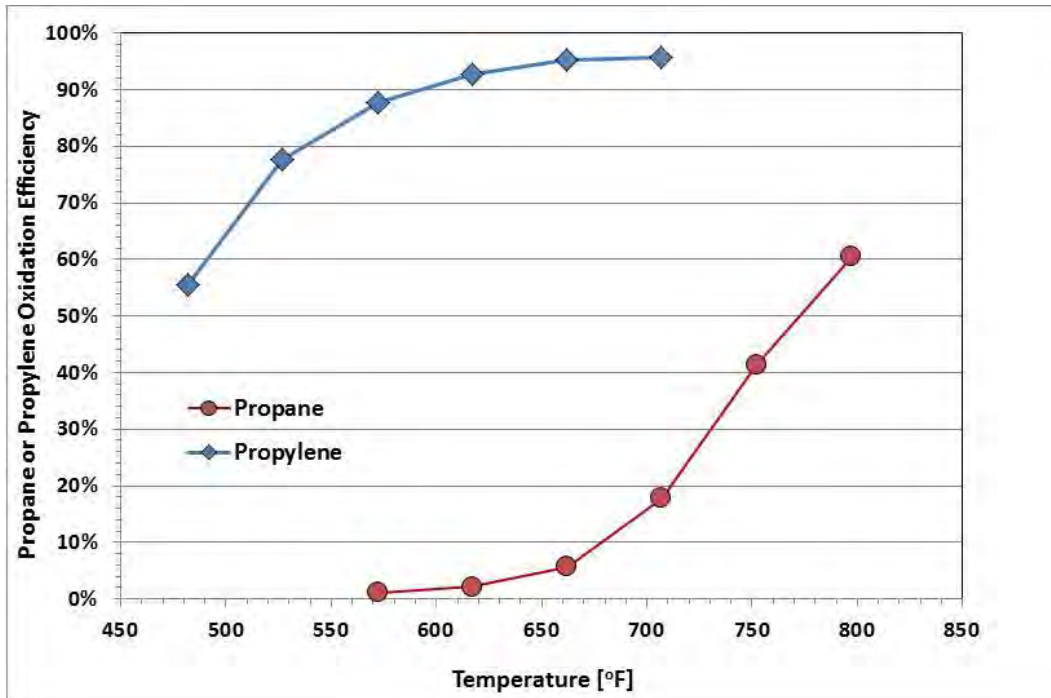
Siemens' earlier R&D stage MFC performance test results were published in 2011 Power Gen Conference<sup>3</sup>. Figure 14 now presents performance data measured for a Cormetech manufactured METEOR™ MFC sample. Both DeNOx and CO oxidation show high conversion rates over a wide temperature range. Note that the formulation of the catalyst can be adjusted to optimize performance in either the low temperature (<525°F) or high temperature (>750°F) regimes. MFC does not generate any appreciable N<sub>2</sub>O; the outlet N<sub>2</sub>O concentration in the lab reactor testing was below 0.5 ppm for all test conditions shown in Figure 14.



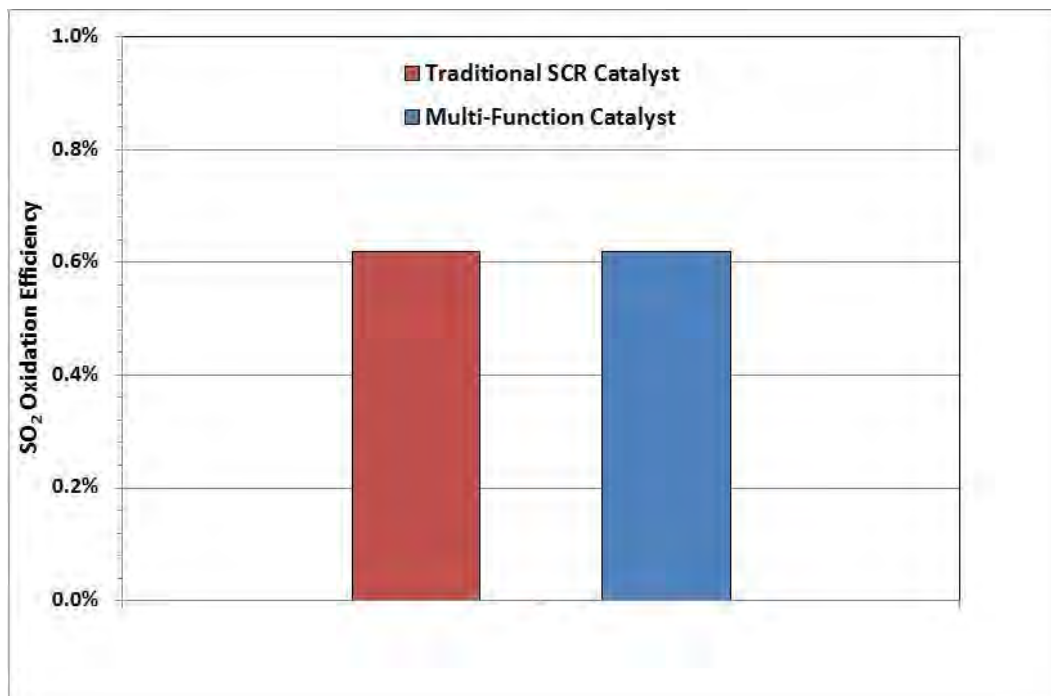
**Figure 14. Multi-Function Catalyst DeNOx and CO Oxidation Performance for a Fixed Space Velocity and Gas Composition ( $NO_x = 25$  ppmvd,  $O_2 = 15\%$ ,  $H_2O = 7\%$ ,  $CO = 25$  ppmvd).  $NH_3$  slip ranged from 3.4 to 6.6 ppmvd for the data set.**

MFC can also achieve high VOC oxidation; Figure 15 shows VOC oxidation data (for propane and propylene) for the same METEOR™ MFC sample that was tested in Figure 14. As mentioned previously, the oxidation activity is dependent on hydrocarbon chain length and the degree of carbon bond saturation (propylene, an unsaturated hydrocarbon, is more reactive than propane, a saturated hydrocarbon).

Figure 16 compares the SO<sub>2</sub> oxidation rate measured for a METEOR™ MFC sample compared to a traditional SCR catalyst sample. These lab reactor data, obtained under a fairly representative HRSG condition (662°F), indicate that MFC has a very similar SO<sub>2</sub> oxidation rate compared to traditional SCR catalyst. Since the traditional CO oxidation catalyst also contributes to SO<sub>2</sub> oxidation (see Figure 6), the MFC layout will have a lower overall SO<sub>2</sub> oxidation rate compared to the traditional two catalyst layout.

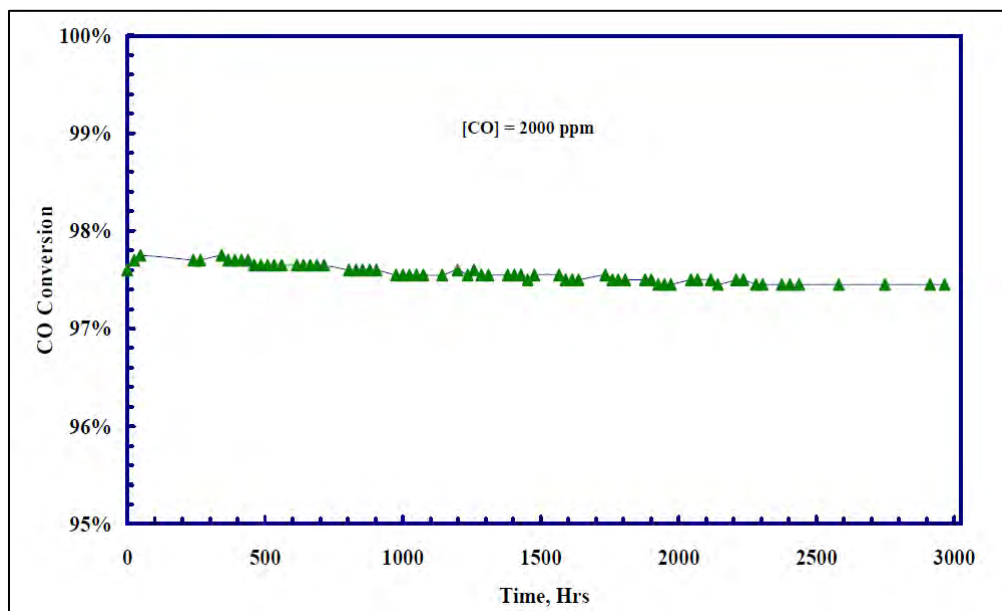


**Figure 15. Multi-Function Catalyst VOC Oxidation Performance for a Fixed Space Velocity and Gas Composition (comparative conditions to Figure 14).**



**Figure 16. SO<sub>2</sub> Oxidation Conversion for Multi-Function Catalyst compared to Traditional SCR Catalyst at 662°F (350°C). Space velocity & gas composition held constant.**

The long-term durability of MFC was evaluated under simulated aging conditions in the lab and under real conditions in the field. Figure 17 shows the test data for the lab aging simulation (aging conditions are listed in the figure caption; note that SO<sub>2</sub> was included in the feed gas stream). The catalyst's activity for CO oxidation held up very well over the 3000 hour aging interval of the experiment, and showed a remarkable stability to extended SO<sub>2</sub> exposure. For the field test, a full size MFC element was installed in an existing SCR catalyst layer within a HRSG application. The element was periodically removed from the unit, tested in the lab, and then reinstalled for further aging. The data are tabulated in Table 2; the catalyst performance was very durable.



**Figure 17. Long Term Lab Durability Test.** Aging conditions were: ~320°C, NO<sub>x</sub> = 25 ppm, NH<sub>3</sub>/NO<sub>x</sub> ratio = 1.0, CO = 50 ppm, SO<sub>2</sub> = 5 ppm, O<sub>2</sub> = 10%, H<sub>2</sub>O = 15%. The inlet CO concentration was periodically spiked to 2000 ppm during the aging to simulate turbine startup conditions; during these spikes, the CO oxidation activity data presented in the graph were obtained.

**TABLE 2. LONG TERM SINGLE ELEMENT FIELD DURABILITY TEST IN A HRSG**

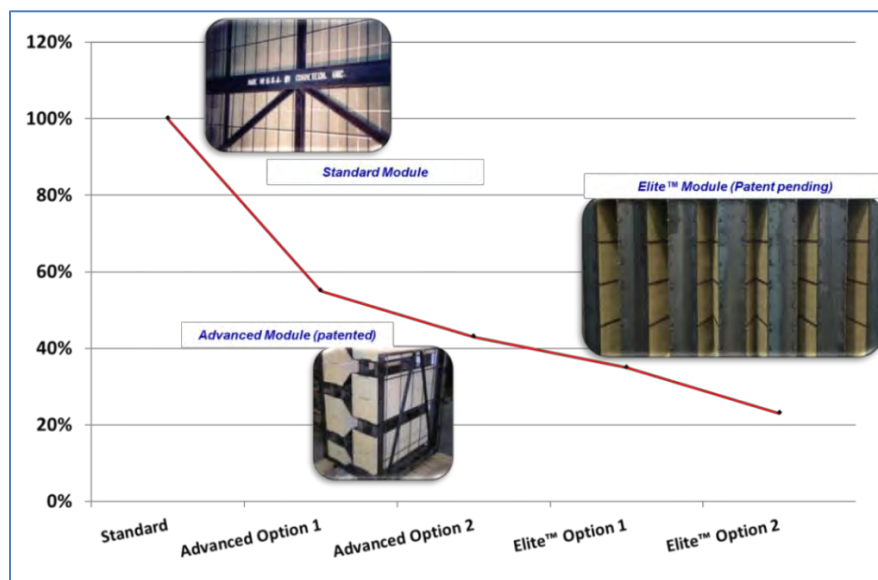
MFC Sample State	NO <sub>x</sub>		CO	
	% DeNO <sub>x</sub>	Absolute % deviation from fresh sample	% CO Oxidation	Absolute % deviation from fresh sample
Fresh	93.4		95.0	
After 7,144 hours	96.4	3.0	94.9	-0.1
After 14,890 hours	96.3	2.9	95.2	0.2
After 22,660 hours	96.3	2.9	95.4	0.4

**The first commercial installation** of Cormetech’s METEOR™ Multi-Function Catalyst was completed in November 2015 at the Ennis Power Company, LLC located in Ennis, Texas. The unit operates behind a Siemens/Westinghouse 501G unit combustion turbine and produces a rated 320-megawatt (MW) electrical generation. Existing SCR catalyst was replaced with CORMETECH METEOR™ to add CO and VOC emissions reduction in addition to NOx removal. In combination with CORMETECH ELITE™ (Pleated Module) technology, these added features achieved a reduced catalyst pressure loss compared to the existing single function SCR catalyst and improved performance allowing for greater operating load flexibility during off-peak hours. The first full scale commercial installation of the MFC is successfully operating and performing very well.

## 5.0 VALUE PROPOSITION FOR MULTI-FUNCTION CATALYST (MFC)

In light of strengthening emission regulations, fluctuating fuel costs, variable electricity demand, and requirements for increased operational flexibility, MFC offers the following benefits:

1. Reduction of NOx, CO, and VOC emissions in one catalyst layer, with low NH<sub>3</sub> slip and low pressure drop (due to the single layer design and its location at the relatively lower SCR temperature). In combination with ELITE™ catalyst technology consisting of ultra-high surface area, high open area product and pleated module construction, the pressure drop can be even further reduced compared to traditional layout systems as shown in Figure 18.



**Figure 18. Pressure Drop Reduction Potential of Cormetech’s Module Designs.**

The MFC formulation is optimized based on specific plant operational requirements and goals to produce a catalyst with the added feature of oxidation catalyst without impacting NOx removal performance. The overall catalyst volume of the single



plane MFC will be at much lower than combined volumes of oxidation and SCR catalysts. This results in a total catalyst volume very similar to SCR catalyst alone thereby reducing total overall reactor pressure drop over a traditional two-layer configuration.

2. Significant cost savings in fuel, power and ammonia consumption due to the lower achievable pressure drop. A decrease in system pressure drop will result in fuel savings over time due to improved thermal efficiency of the CT and an increase in maximum electrical output from the CT, as shown in Figures 19 and 20 as an example for two types of Siemens GTs.

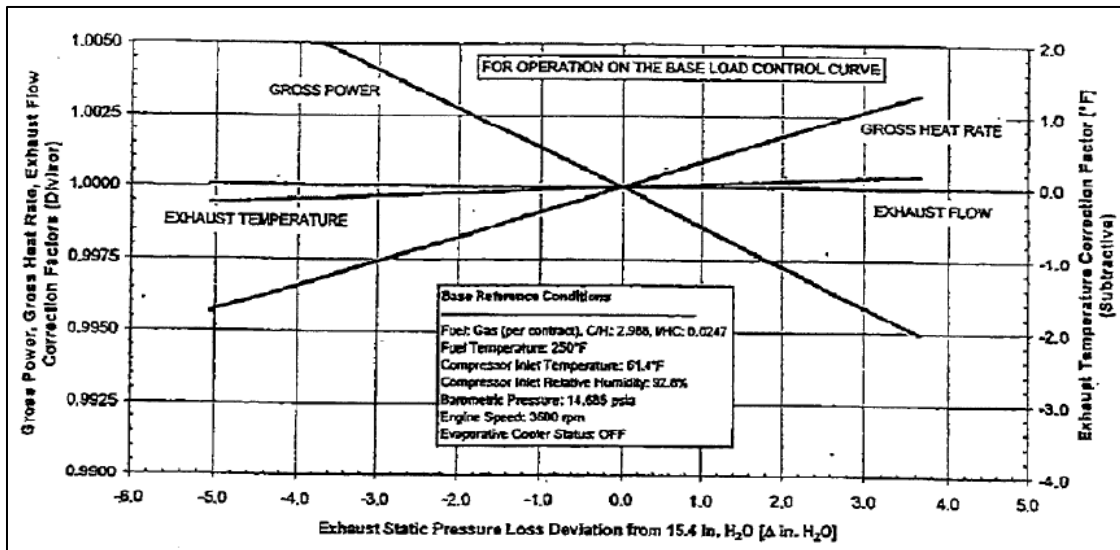


Figure 19. Siemens 501F Class Engine Static Pressure Loss Vs Heat Rate and Gross Power Output Correction Curves.

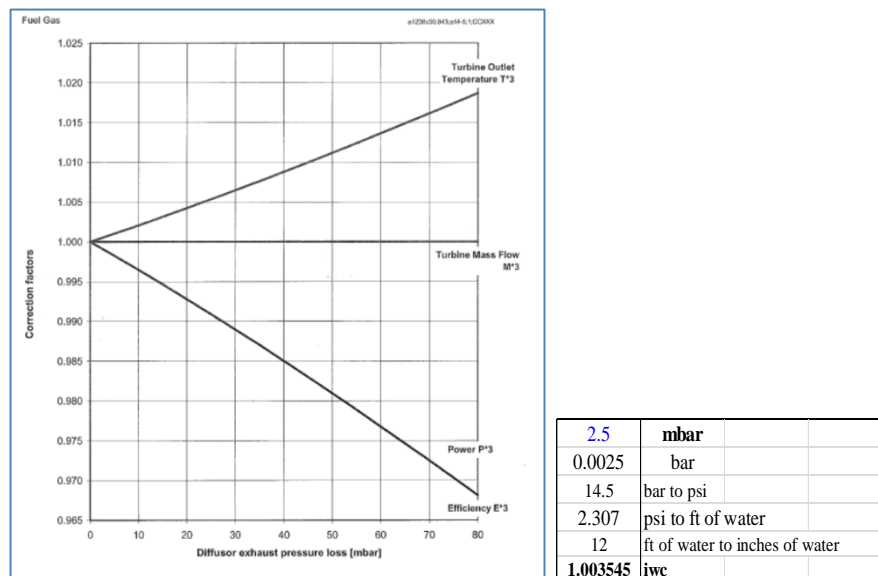


Figure 20. Siemens V84.3 Class Engine Static Pressure Loss Vs Heat Rate and Gross Power Output Correction Curves.

Table 3 summarizes an example cost savings in fuel and increased power output due to a 1.0" WC reduction in pressure drop across the SCR catalyst over a typical expected life of the MFC catalyst (e.g., 8 years), though it could last for more than 8 years. Siemens 501F or V84.3 (shown in above Figures 19 & 20) are similar to GE Frame 7FA, would see similar improvement in both heat rate and reduced fuel cost. The CT simple cycle heat rate was used in the Table 3 calculations.

**TABLE 3. AN EXAMPLE CALCULATION OF COST SAVINGS FROM A 1" WC PRESSURE LOSS REDUCTION ACROSS CATALYST.**

<b>NATURAL GAS FIRING FUEL COST SAVED</b>		
Gross Generation From GT only	MWg	180
Gross Heat Rate of the GT only	Btu/KWh	9,000
Total GT/HRSG system Pressure Drop Reduction	in. WC	1
Average Cost of Natural Gas over Time	\$/MMBtu	3.50
<b>Evaluation Period</b>	<b>Years</b>	<b>8</b>
Operating Hours per Year	hr	6,570
Heat Rate Correction Factor From Siemens Correction for Deviations in Exhaust Static Pressure Loss	-	0.999
Normal Fuel Cost For the Evaluation Period	\$	298,015,200
Fuel Cost for the Evaluation Period With Pr. Drop Reduction Correction Factor	\$	297,717,185
<b>TOTAL FUEL COST SAVED</b>	<b>\$</b>	<b>298,015</b>
<b>REVENUE FROM ADDITIONAL POWER SOLD</b>		
Gross Generation From GT only	MWg	180
<b>Load Factor</b>	-	<b>0.70</b>
Average Daily Load (MWg)	MWg	126
<b>Availability Capacity Factor</b>	-	<b>0.75</b>
Total Hours Operated per Year @ Availability Capacity Factor	Hr	6,570
Annual Gross Power Output (MWH)		827,820
Average Price per KWh Sold	\$	0.09
Revenue from Power Sold For the Total Evaluation Period	\$	573,500,451
GT Power Output Correction Factor From Siemens Correction for Deviations in Exhaust Static Pressure Loss	\$	1.0015
Revenue from Power Sold for the Evaluation Period With Pr. Drop Reduction Correction Factor	\$	574,360,702
<b>TOTAL INCREASED REVENUE FROM INCREASED POWER</b>		<b>860,251</b>
<b>TOTAL \$ SAVED DUE TO 1" REDUCTION IN PRESSURE LOSS DURING THE EVALUATION PERIOD</b>	<b>\$</b>	<b>1,158,266</b>

As can be seen from the above example in Table 3, the initial capital cost of the MFC is recovered during its expected life time just from the reduced fuel and increased power output savings.

3. Significant cost savings in fuel, power and ammonia consumption due to the ability to achieve lower loads and still meet emission requirements. Plants generally require stack CO emissions of  $\leq 10$  ppm down to  $\sim 50\%$  GT Load (ambient dependent); they desire the flexibility to operate at lower loads instead of shutting down. With an ability to operate at lower loads, improved power reliability and availability, such as increased unit dispatch, may be realized by reducing the time to

achieve base load. The reduction in cold start frequency would yield lower O&M costs due to extended life of gas turbine and HRSG parts (reduced fatigue).

Furthermore, in recent years, increased plant cycling and demand response requirements due to increased power availability from renewables has resulted in plant operators looking for ways to increase operational flexibility and cycle to lower loads during off-peak hours. Configuring a turbine for low load operation involves many factors including reconfiguring burner firing from Premix mode to Diffusion Mode, tuning with IGVs, among others as discussed in Section 2 and shown in Figure 1.

Often, however, these efforts are not enough to ensure the plant can stay below its CO emission requirements, and there may not be enough space allocated to install a second catalyst layer for CO control. MFC can enable the unit to operate at lower stable load down to 40% without issue within the space constraints of the existing SCR reactor, allowing the unit to operate at hot stand-by low load mode during off peak dispatch grid demand period. For example, the plentiful availability of renewable power in the state of Texas regions warrants coal or CC gas plants to operate either at reduced loads or to shut down. Certain CC plants without installed CO catalysts currently pay the Grid to take their power for allowing them to stay at relatively higher loads, because these Units cannot operate at lower loads due to their low-load high CO emission problems. MFC can solve this issue by providing both NO<sub>x</sub> and CO reduction capability, allowing these CC Units to operate at stable lower loads down to 40% without shutting down, thus saving money for the plant, and also minimizing the cyclic stress to the GT parts and HRSG associated with frequent cold start/shut down cycles for the unit originally designed for base load operation.

4. Reduction in the footprint of a new HRSG, since it involves only one catalyst layer, results in a more cost competitive HRSG design. Alternatively, it could allow for a more accessible space design of the heat transfer surfaces. For retrofits, the reduced footprint requirement would make it easier for plants that do not have the space for a CO oxidation catalyst allocated in the original design. For O&M costs, the single layer design would reduce scaffolding costs.
5. Reduction in the SO<sub>2</sub> to SO<sub>3</sub> oxidation rate compared to traditional layout systems. In the MFC layout removal of CO oxidation catalyst reduces the SO<sub>3</sub> generation rate compared to the traditional layout (MFC has a similar SO<sub>2</sub> oxidation compared to traditional SCR catalyst, as was shown in Figure 16). The lower SO<sub>3</sub> generation rate could lower maintenance costs, through reduced cold-end fouling from ABS, which forms from SO<sub>3</sub> and NH<sub>3</sub> slip (and H<sub>2</sub>O).
6. In existing HRSG units operating at reduced loads (e.g., below 70%) with a certain type of CO oxidation catalyst installed, NO to NO<sub>2</sub> emission conversions as high as 80% have been measured. High NO to NO<sub>2</sub> conversion increases the NO<sub>2</sub>/NO<sub>x</sub> ratio entering the SCR catalyst. At colder SCR inlet temperatures (i.e., <600°F), which occur at low loads and at low ambient temperatures, these higher NO<sub>2</sub>/NO<sub>x</sub>

ratios greatly reduce the SCR's effectiveness; NOx reduction compliance may no longer be achievable. One solution is to replace the SCR catalyst with a catalyst formulation designed for high NO<sub>2</sub> applications. An alternate solution is to use MFC, which eliminates the high NO to NO<sub>2</sub> conversion issue with a similar catalyst volume and much lower pressure drop, allowing the unit to operate at lower loads (down to GT stable load of 40%), while still meeting all of the NOx, CO, VOC, and NH<sub>3</sub> slip compliance requirements. Note that GT loads below 40% are typically the start-up ramping rate loads.

7. Greater resistance to sulfur deterioration (Figure 17) due to the inherent tolerance of the TiO<sub>2</sub> support of the MFC to sulfur gases, allowing greater flexibility to operate at lower catalyst temperatures (i.e., low load) without need for regeneration.

## 6.0 CONCLUSIONS

Advanced Multi-Function Catalyst, initially developed and patented by Siemens Energy Inc., and optimized and fully developed into commercial production as METEOR™ by Cormetech, Inc.:

- Simultaneously reduces NOx, CO, VOCs and NH<sub>3</sub> slip to compliance levels in one catalyst layer located at traditional SCR catalyst location.
- Provides key benefits to address the changing dynamics of the power industry:
  - Total emissions regulation compliance.
  - Extended operating flexibility by extending the unit load operating range.
  - Reduction of corrosion of the HRSG section downstream of the SCR.
- Recovers its capital cost within its life span.
- Has been successfully deployed at a full-scale combined cycle HRSG unit and is successfully operating and performing very well.

## 7.0 REFERENCES

1. (Ford, 2014) [http://www.eia.gov/todayinenergy/detail.cfm?id=17571#tabs\\_SpotPriceSlider-1](http://www.eia.gov/todayinenergy/detail.cfm?id=17571#tabs_SpotPriceSlider-1)
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