“Designing CO Oxidation Catalyst for Your Permit Requirement”

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February 5, 2015

Starting Point: Application Design
(system variables that affect emissions)

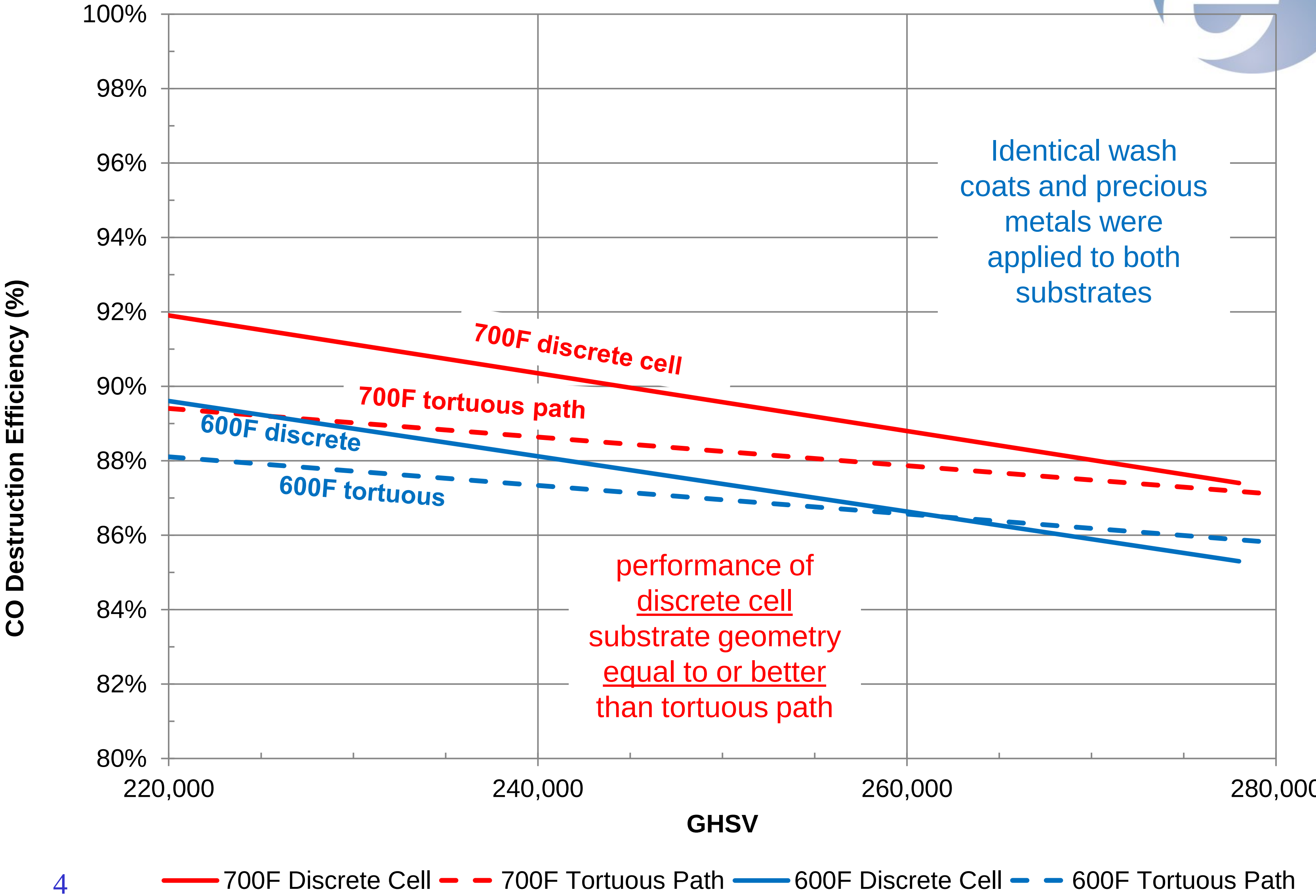
- **Information input**
  - engine name and model
  - fuel type(s) and sulfur content
  - water injected or evap cooling? (water quality)
  - HRSG or simple cycle (no. starts/stops/yr.)
  - Duct firing? Fuel type.
  - exhaust mass flow rate, catalyst operating temp,
  - % flow and temperature variation
  - Inlet emissions, (CO, VOC, NO/NO_2, SO_2)
  - performance requirements
    - (% reduction CO, VOC, NO-NO_2, SO_2-SO_3)
    - Start-up & shutdown performance included?
  - desired warranty period and service life
  - installation information;
    - NEW or REPLACEMENT
    - Gas Path Size
    - allowable pressure drop

It's possible to "over specify":
- low temperature
- very high performance
- very low pressure drop
- small gas path
- lot's of starts & stops
- long warranty period
- "cheap"

Catalyst Design
(catalyst variables that affect emissions)

- substrate cell geometry and geometric surface area
- wash coat formulation & loading
- precious metal formulation
- precious metal loading
- method of applying precious metals
- gas hourly space velocity

Oxidation Catalyst Performance
Discrete Cell vs. Tortuous Path



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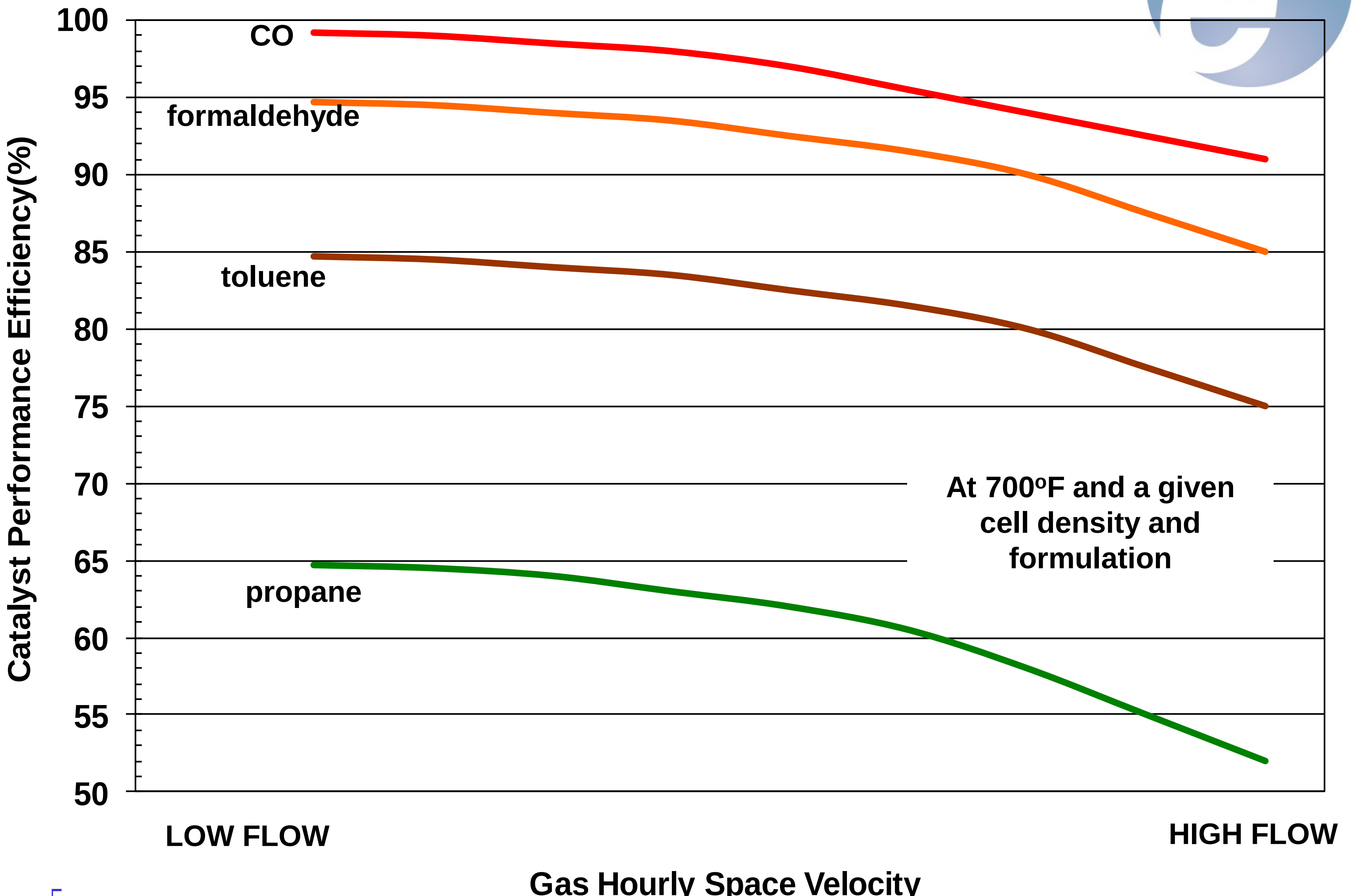
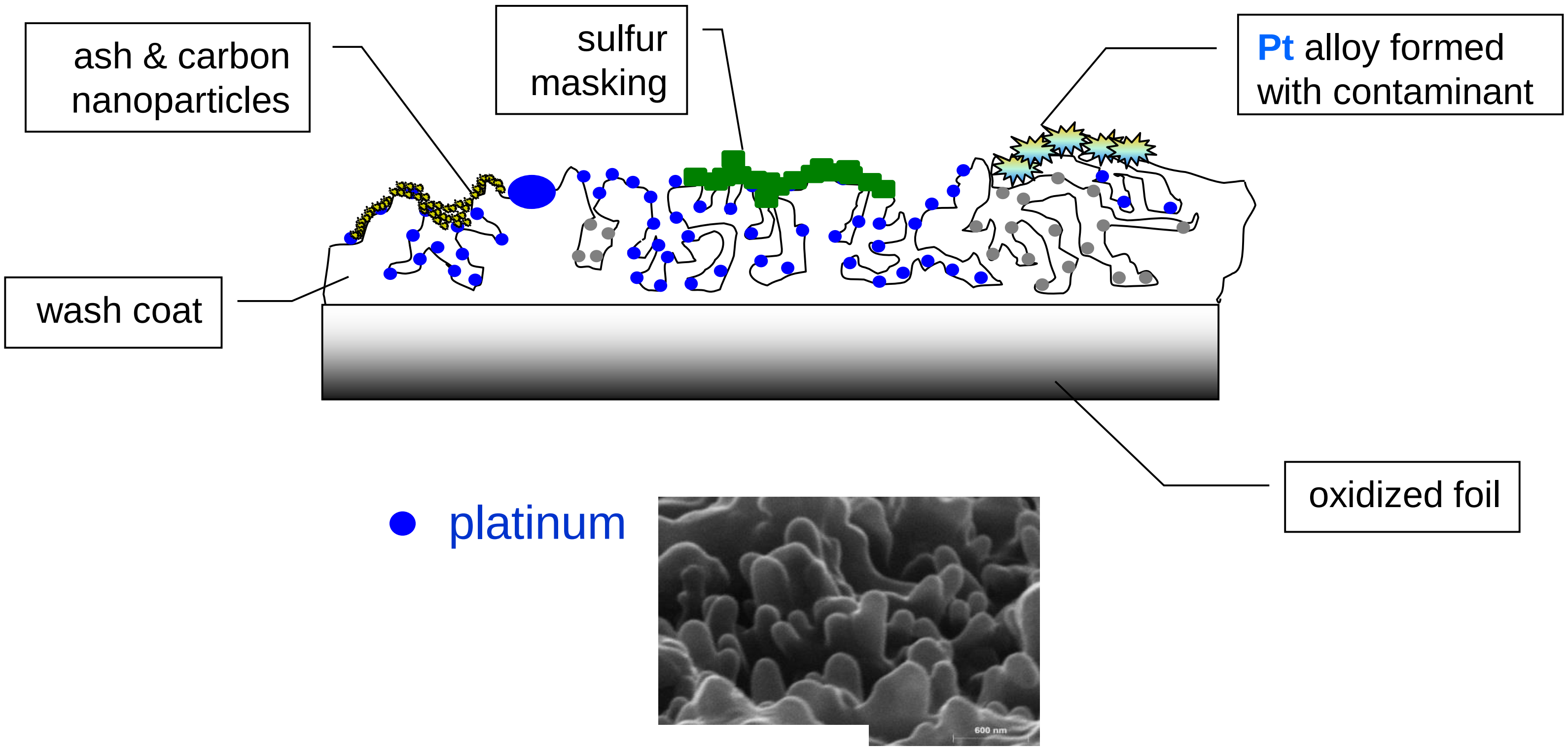
Oxidation Performance for CO & VOC Families



Low Catalyst Temps Impose Other Risks to Owner

- BEWARE: Below 600°F a number of contaminants are prone to accumulation
  - Even common masking agents (sulfur) could be problematic
  - If mixed with high temp cases, desorption is possible
- Of >240 installations the few that experienced high levels of contamination
  - All below 600°F
  - All accumulated enormous amounts of sulfur and phosphorous

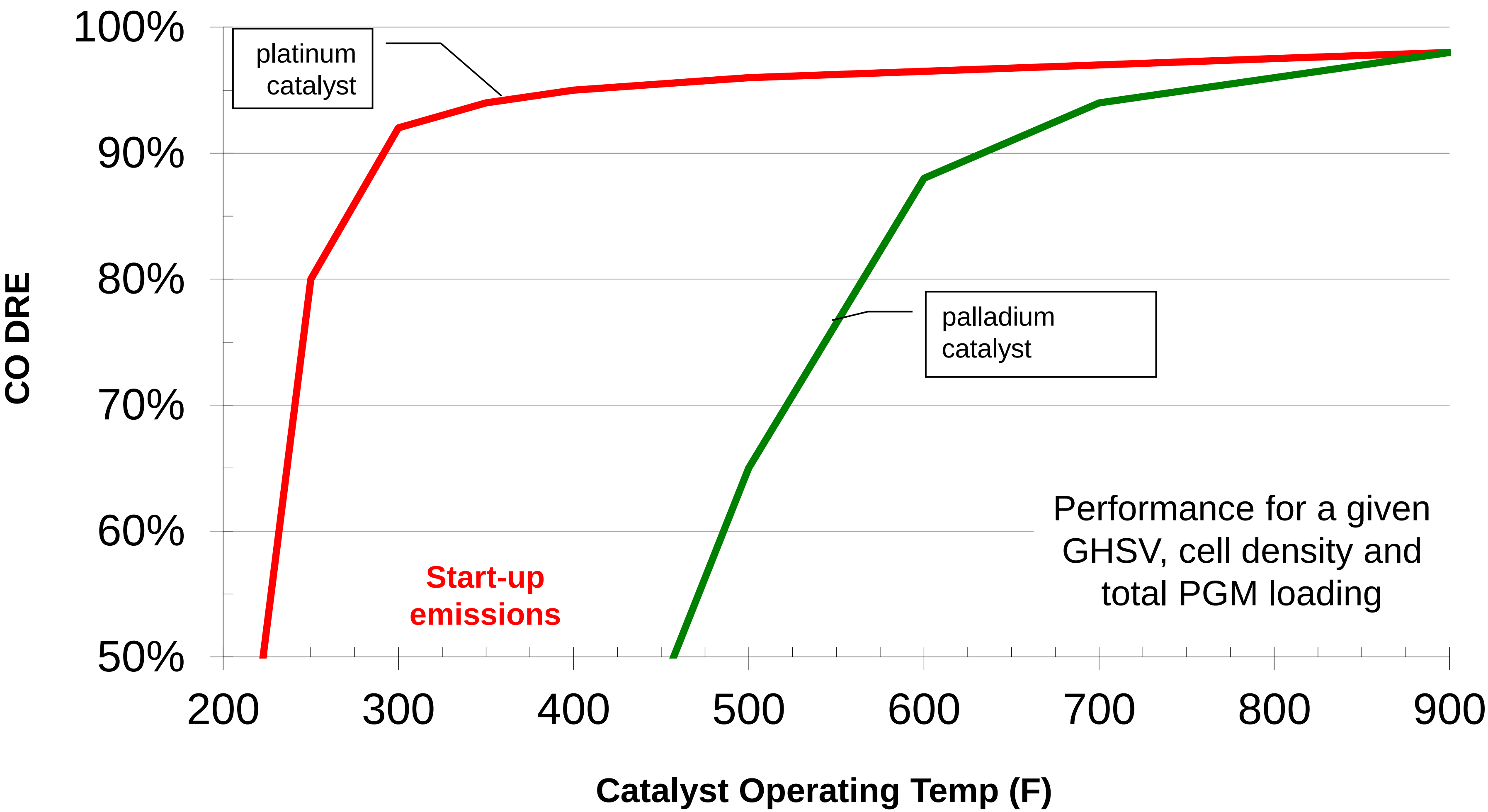
Examples of Chemical Contamination



Selecting Precious Metals for Oxidation Catalyst

	Platinum	**Palladium**
CO	Best	Good when new
VOCs	Best	Good when new
Light-off temp	250-400^{o}F	400-650^{o}F
Catalytic activity	High	Moderate
Thermal stability	Good to 1200^{o}F	Good to 1200^{o}F
Poison resistance	High	Low
Response to chemical washing	Good	Poor
Durability	High	Low to moderate
Price per troy oz.	$1560	$690

Oxidation Performance Platinum vs. Palladium



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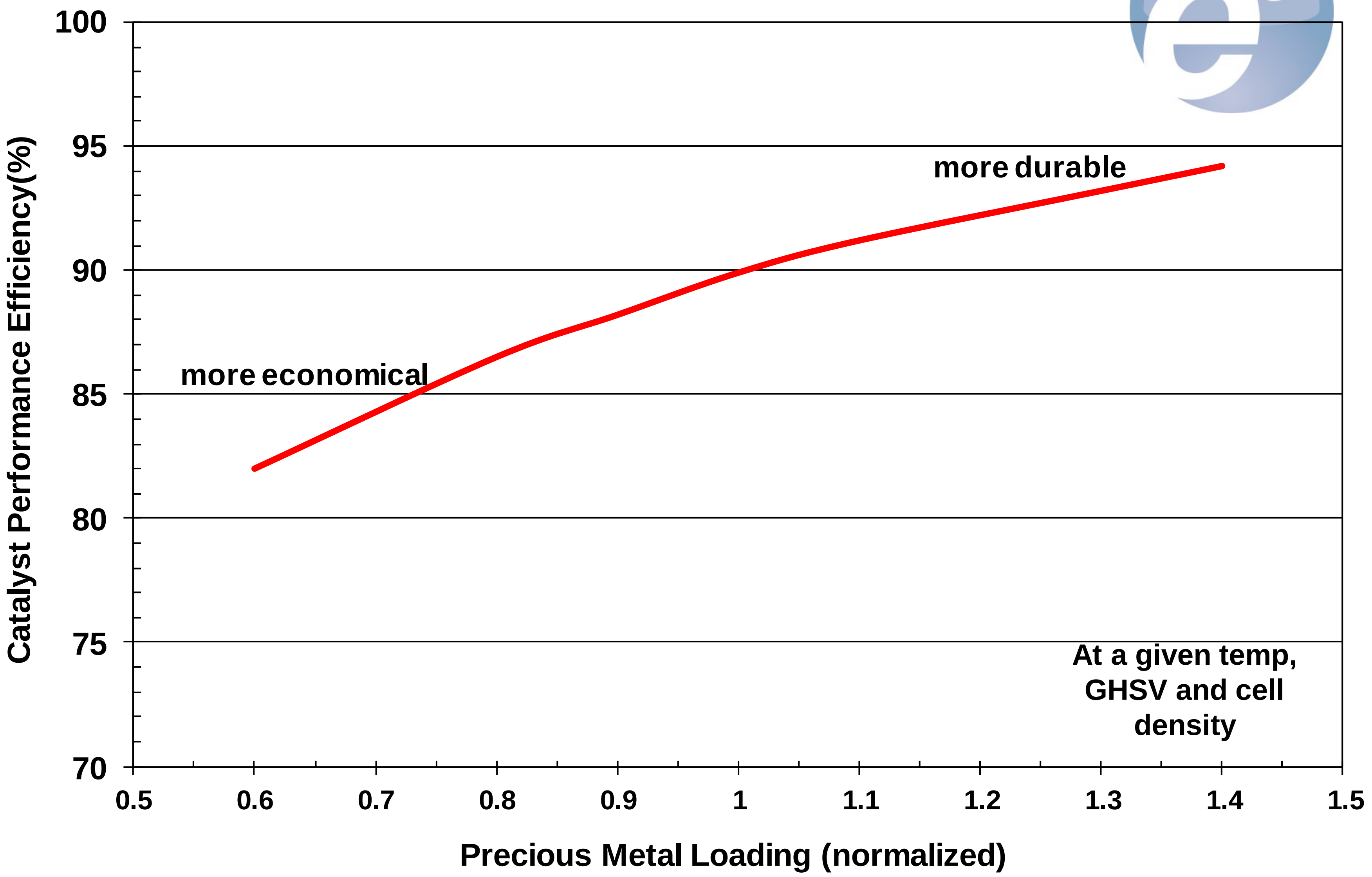
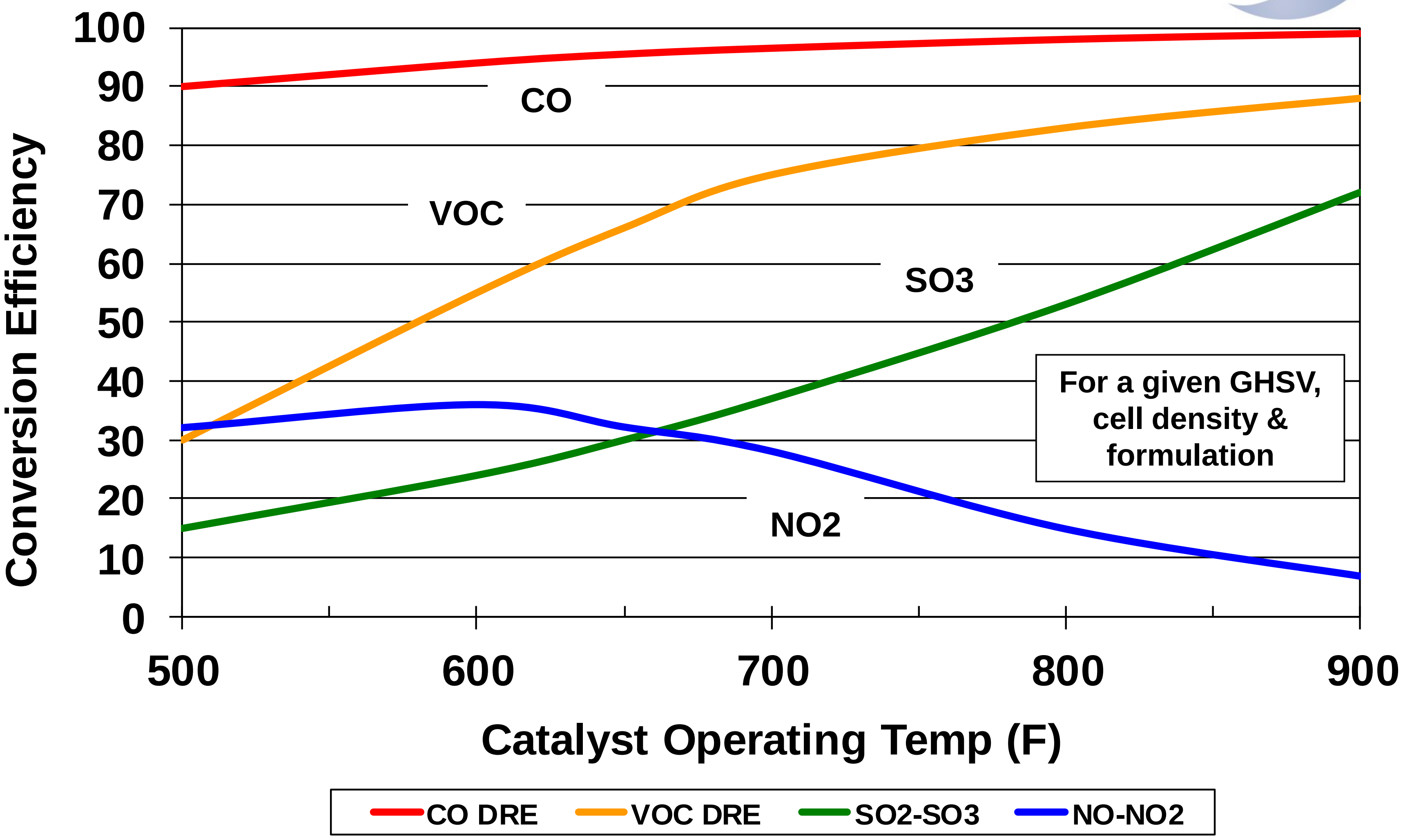
Performance as a Function of Precious Metal Loading



Simultaneous Collateral Reactions

- NO-NO_2 Oxidation
  - Favors NO_2 at low temps; NO at high temps
  - Effects SCR reactions, NH_3 consumption
  - Destroys sulfur bound carbon nanoparticles
- SO_2-SO_3 Oxidation
  - Increases with temperature
  - Precursor to particulate matter
  - Ammonia slip reacts to form bi-sulfate particulate after SCR
- Catalyst formulations can suppress these

Overall Effect of Operating Temp on Catalyst Reactions



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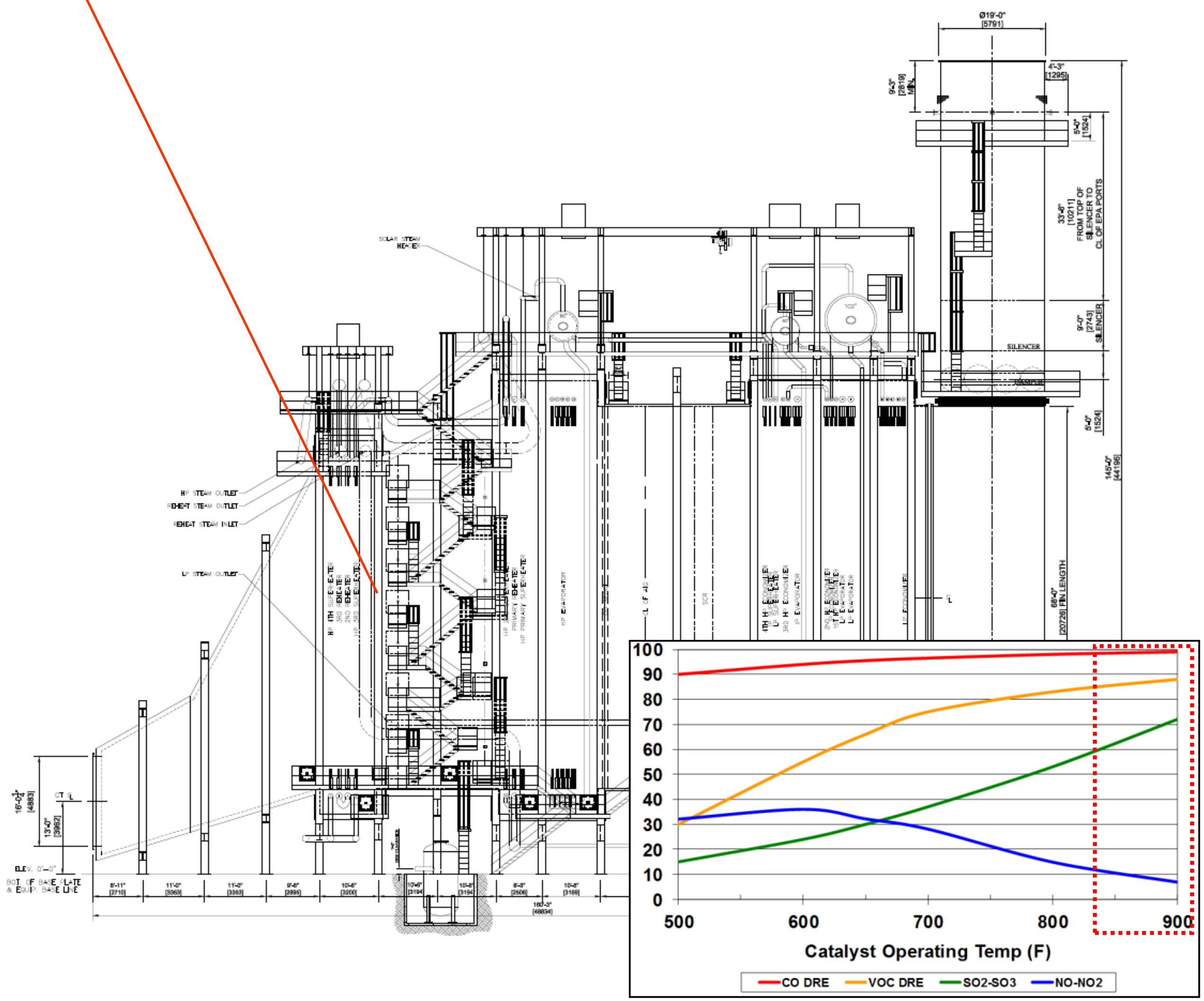
Putting it all together…

How does HRSG temperature effect catalyst design and price?

Effect of HRSG Temperature Zone on Oxidation Catalyst Performance

~1000ºF

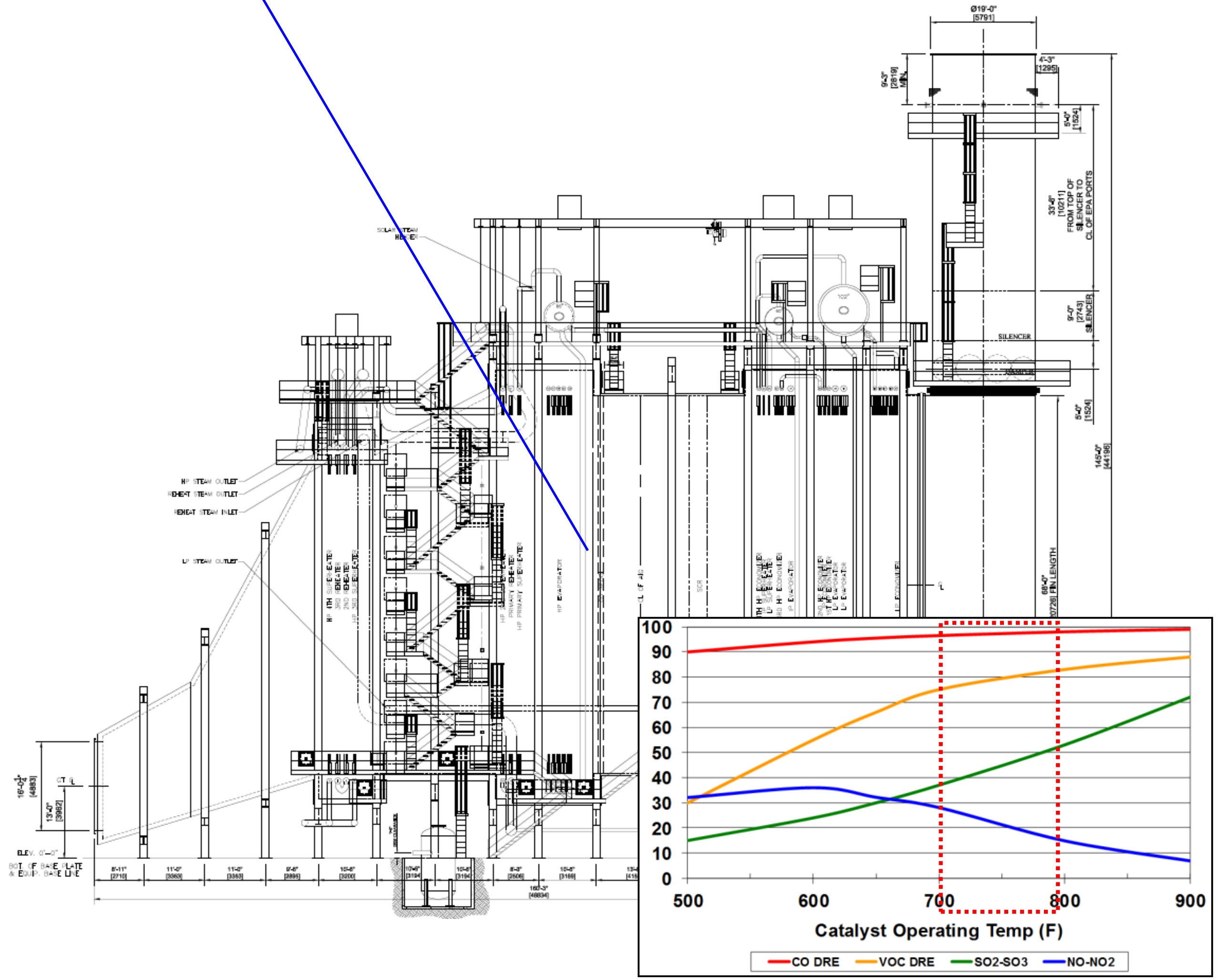
- **Hi CO performance**
- **Hi VOC performance**
- **Lowest catalyst volume**
- **Lo NO to NO_2 conversion**
- **Hi SO_2 to SO_3 conversion**
- **Lower Pt**
- **Lowest cost catalyst**



Effect of HRSG Temperature Zone on Oxidation Catalyst Performance

~750ºF

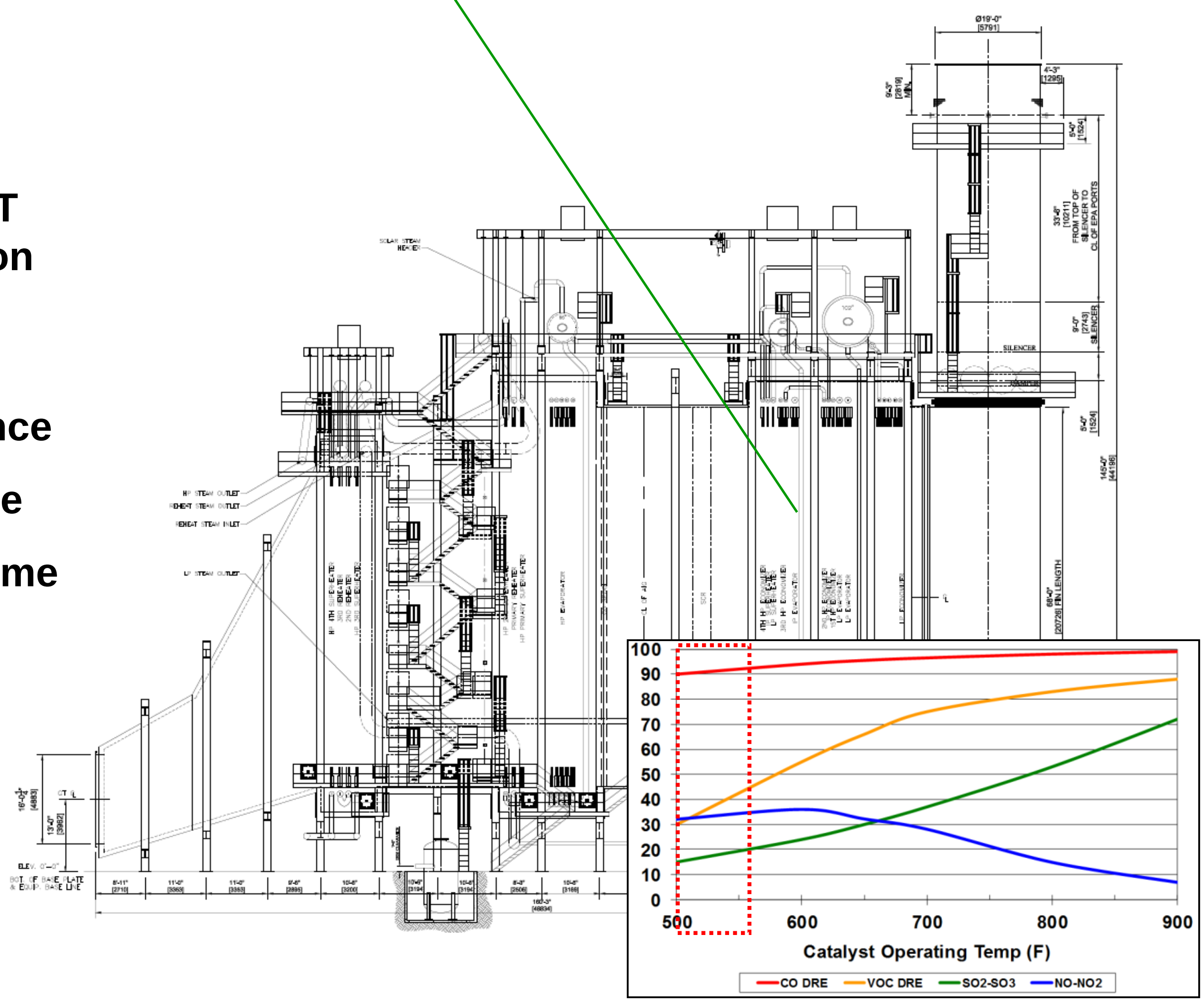
- **Hi CO performance**
- **Good VOC performance**
- **Moderate catalyst volume**
- **Moderate NO to NO_2 conversion**
- **Moderate SO_2 to SO_3 conversion**
- **Economical Pt-loading**



Effect of HRSG Temperature Zone on Oxidation Catalyst Performance

500-550ºF

- **Risk of sulfur accumulation with decreased life**
- **Increase Pt for low-T lightoff and protection from masking & poisoning**
- **Good CO performance**
- **Lo VOC performance**
- **Larger catalyst volume**
- **High NO to NO_2 conversion**
- **Low SO_2 to SO_3 conversion**
- **Highest catalyst $$**

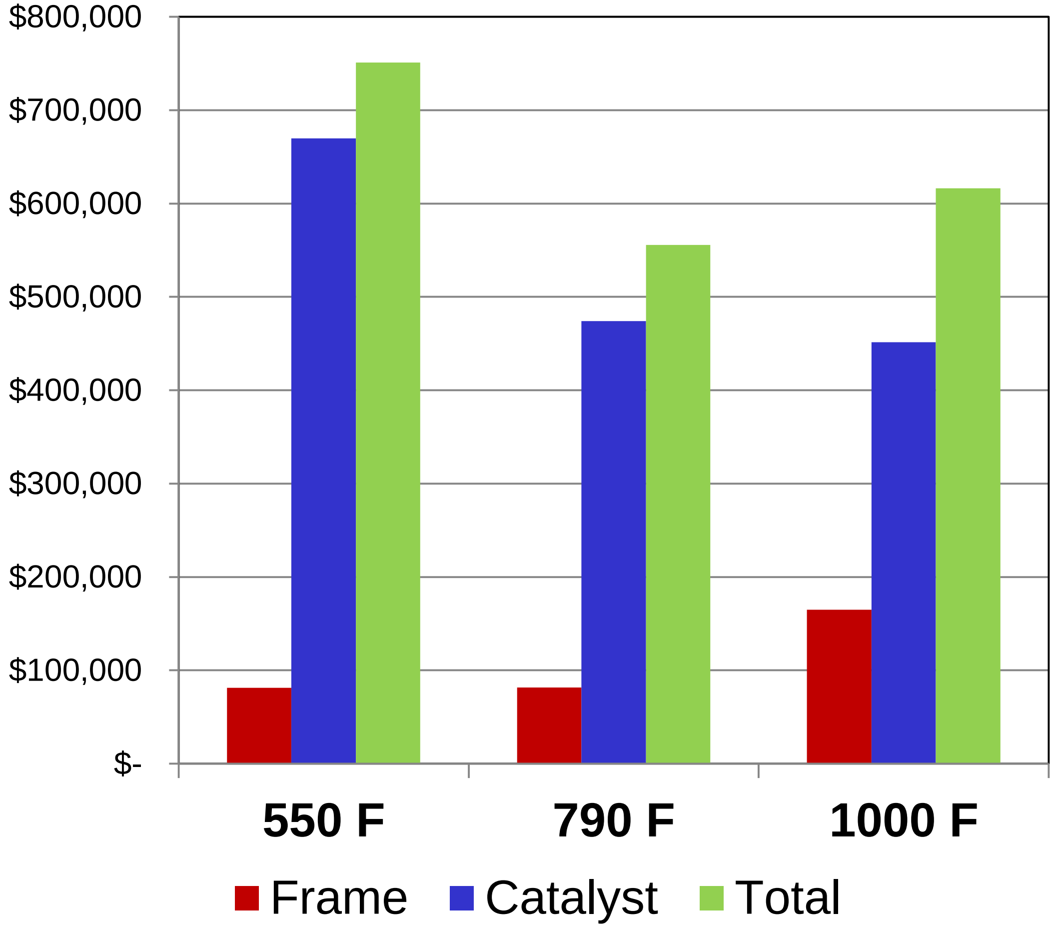


Effect of HRSG Temperature Zone on Catalyst System Price

	550 F	790 F	1000 F
Catalyst GHSV*	175,000	200,000	215,000
Catalyst Volume	310 ft3 most catalyst due to lower activity	270 ft3	250 ft3 least catalyst due to high activity
Platinum Loading	~1.5X more Pt due to likely accumulation of contaminants	X	X
Frame Material	carbon steel	carbon steel	stainless steel

** Catalyst GHSV is approximate for illustration only, based upon a given cell density and formulation.*

Effect of HRSG Temperature Zone on Catalyst System Price



Catalyst and frame prices are approximate for illustration only, based upon a given exhaust characteristic, catalyst design, gas path and Pt price.

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Evaluate all operating cases
(temp, flow, performance)

PARAMETER	Units	DESIGN BASIS	100	102	111	112	126	129
CASE DESCRIPTION								
GENERAL INFORMATION								
GT Load		0.50035542	100%	50%	50%	100%	50%	50%
GT Fuel Type		Natural Gas	Natural Gas	Natural Gas	Natural Gas	Natural Gas	Natural Gas	Natural Gas
Ambient Temp	ºF	20	60	60	100	0	80	100
Temp at Catalyst	ºF	832	835	824	955	845	958	977
EXHAUST CHARACTERISTICS FROM GT								
GT Flow with Tempering Air	lb/hr	647,792	866,129	629,703	522,225	874,486	517,015	492,086
Gas Composition	% vol							
O_2		14.55	13.75	14.79	13.47	14.06	13.81	13.66
H_2O		5.94	8.76	6.72	9.85	6.26	8.42	9.19
N_2		75.65	73.54	74.87	72.70	75.58	73.81	73.20
CO_2		2.95	3.07	2.72	3.09	3.19	3.07	3.07
Ar		0.91	0.89	0.90	0.87	0.90	0.88	0.88
Total		100.00	100.00	100.00	99.99	99.99	99.99	99.99
MW	lb/lb-mole	28.57	28.27	28.46	28.15	28.55	28.31	28.22
Flow Rate (wet)	scfh	8,593,971	11,610,925	8,384,926	7,030,717	11,607,285	6,922,442	6,608,366
Flow Rate (dry)	scfh	8,083,203	10,594,153	7,821,332	6,337,931	10,880,855	6,339,469	6,001,203
O_2 Concentration Dry	%	15.47	15.07	15.85	14.95	15.00	15.08	15.04
CO AT CATALYST INLET								
CO as ppmvd at 15% O_2		70.10	25.02	70.20	69.99	24.99	69.99	69.99
CO Flow	lb/hr	38.6	19.4	34.7	33.1	20.1	32.3	30.8
CO AT CATALYST OUTLET								
CO as ppmvd at 15% O_2		5.5	5.5	5.5	5.5	5.5	5.5	5.5
CO Destruction Required	%	92.2	78.0	92.2	92.1	78.0	92.1	92.1
VOC AT CATALYST INLET								
VOC as ppmvd at 15% O_2		8.41	3.00	8.42	8.40	3.00	8.40	8.40
VOC AT CATALYST OUTLET								
VOC as ppmvd at 15% O_2		2.00	2.00	2.00	2.00	2.00	2.00	2.00
VOC Destruction Required	%	76.2	33.4	76.3	76.2	33.3	76.2	76.2
ADDITIONAL DATA								
Required Pressure Drop	"H_2O	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Expected Pressure Drop	"H_2O	0.7	1.0	0.7	0.7	1.0	0.7	0.7

DETERMINE "GHSV" FOR EACH FLOW RATE AND TEMPERATURE TO ACHIEVE REQUIRED CO & VOC PERFORMANCE

Determine "GHSV" for each flow rate & temp to achieve CO & VOC performance

PARAMETER	Units	DESIGN BASIS	100	102	111	112	126	129
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GENERAL INFORMATION								
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CO as ppmvd at 15% O2		5.5	5.5	5.5	5.5	5.5	5.5	5.5
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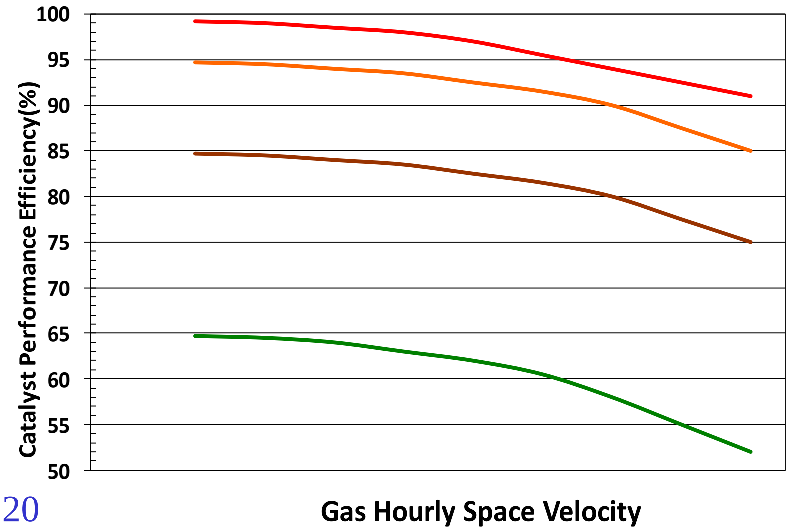

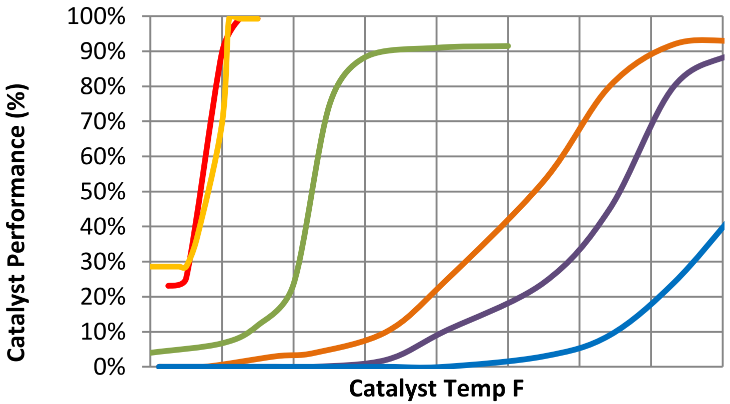

Convert GHSV into catalyst volume

- GHSV varies by
  - performance level
  - compound
  - temperature
  - formulation and loading of precious metals
  - formulation of wash coating
- catalyst volume (*cubic feet)* calculated by dividing volumetric gas flow rate *(s-ft³/hr)* by GHSV *(1/hr)*

$$\frac{8{,}593{,}971 \text{ scfh}}{165{,}000 \text{ hr}^{-1}} = 52.1 \text{ ft}^3$$

Calculate the required catalyst volume for each case

PARAMETER	Units	DESIGN BASIS	100	102	111	112	126	129
CASE DESCRIPTION		117	With Dilution/Tempering Air Injection			Without Dilution/Tempering		
GENERAL INFORMATION								
GT Load		0.50035542	100%	50%	50%	100%	50%	50%
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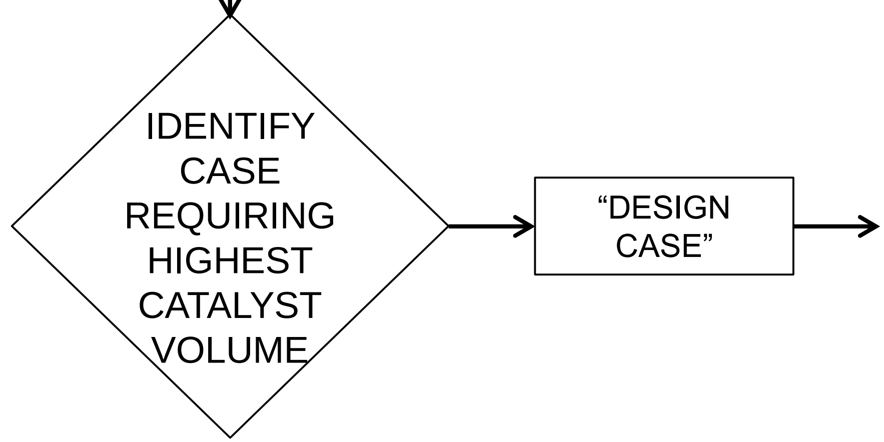
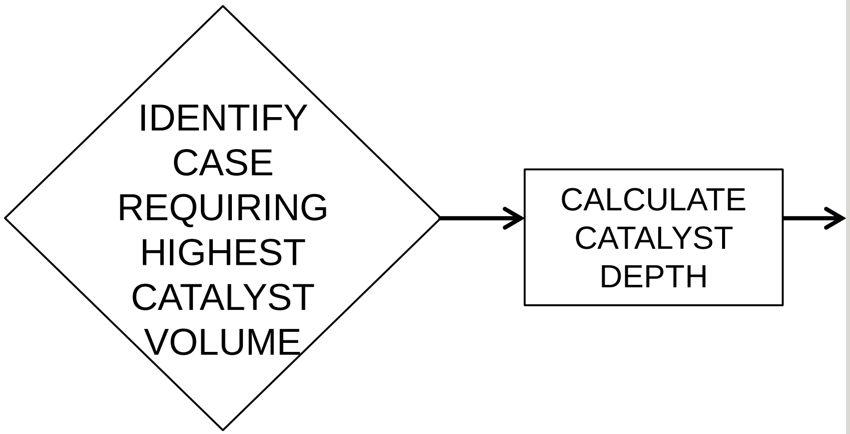
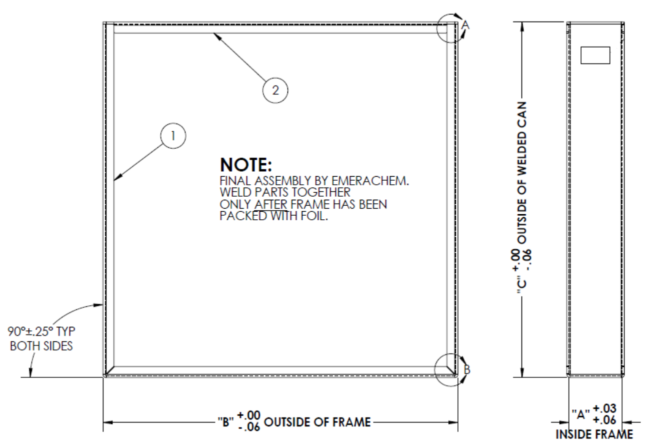
Expected Pressure Drop	"H_2O	0.7	1.0	0.7	0.7	1.0	0.7	0.7

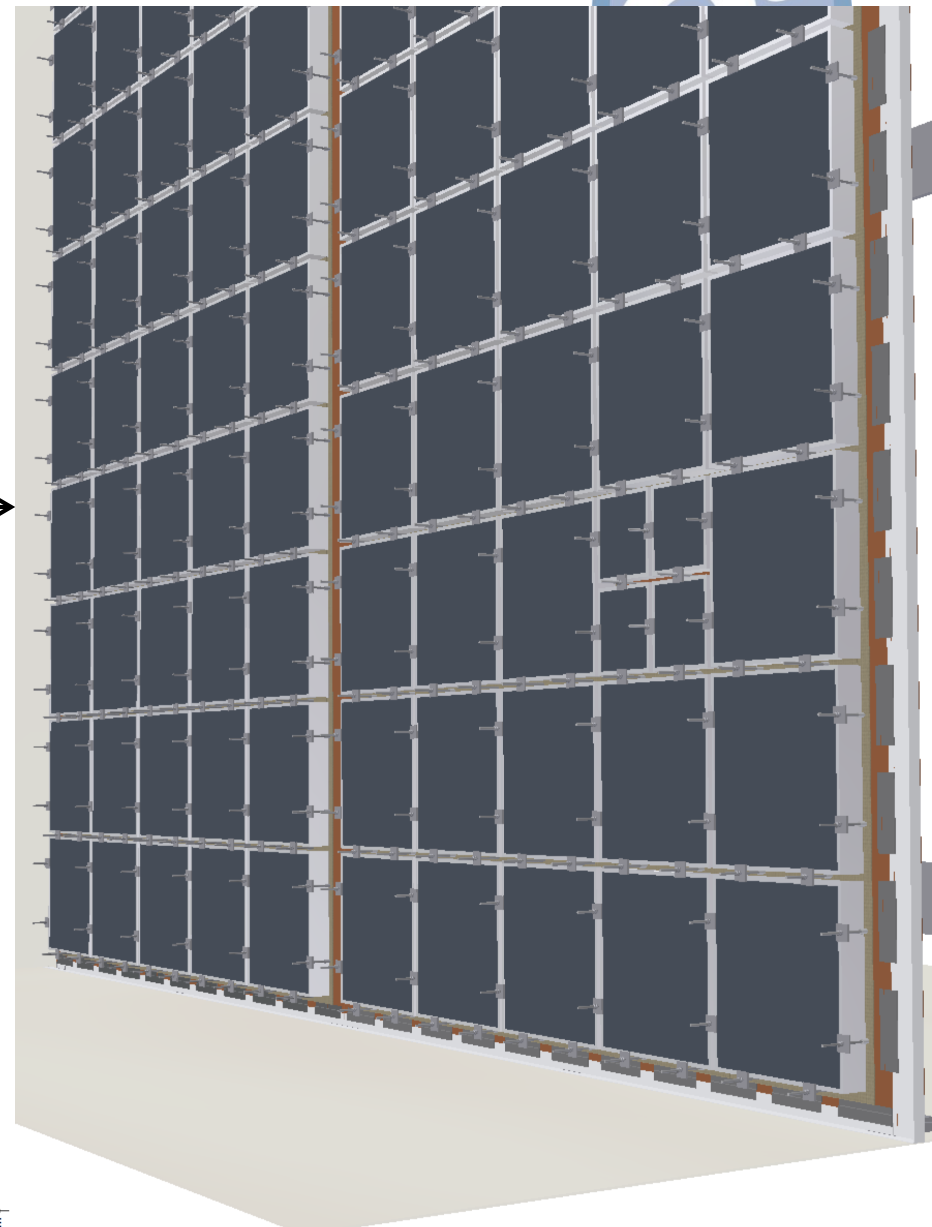
$$\frac{8{,}593{,}971\,\text{scfh}}{165{,}000\,\text{hr}^{-1}} = 52.1\,\text{ft}^3$$



Calculate catalyst depth



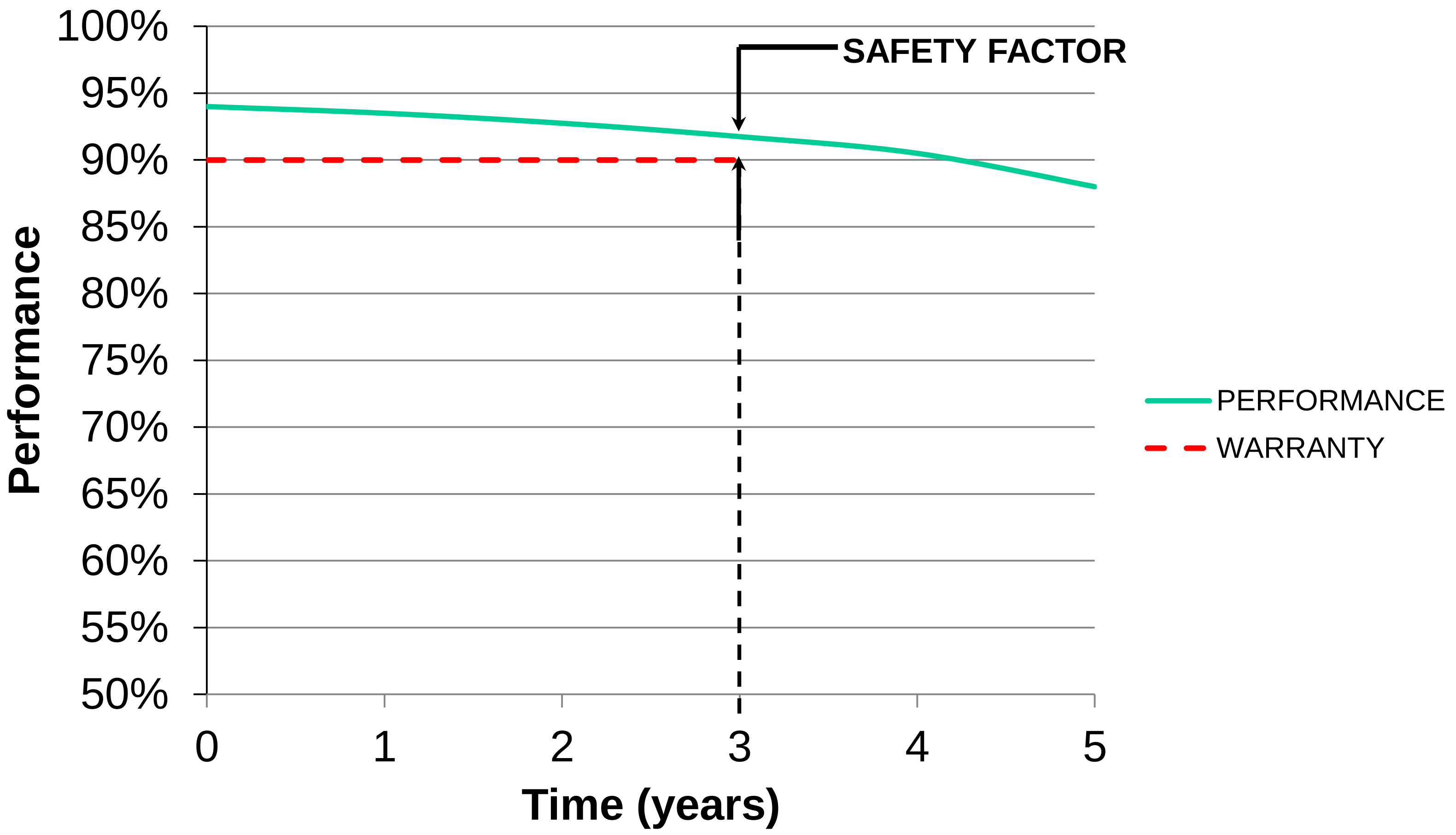




Remember…

- Catalyst performance dictates catalyst volume
  - (for a given cell density, Pt loading, wash coat, etc)
- Once catalyst volume is determined
  - Changing duct size results in thicker or thinner catalyst (to maintain volume)
  - Large frontal area and thin vs. small area and thick
- However, 100 ft^3 of catalyst in 100 modules costs less than 100 ft^3 in 120 modules
- There is a practical *minimum* thickness

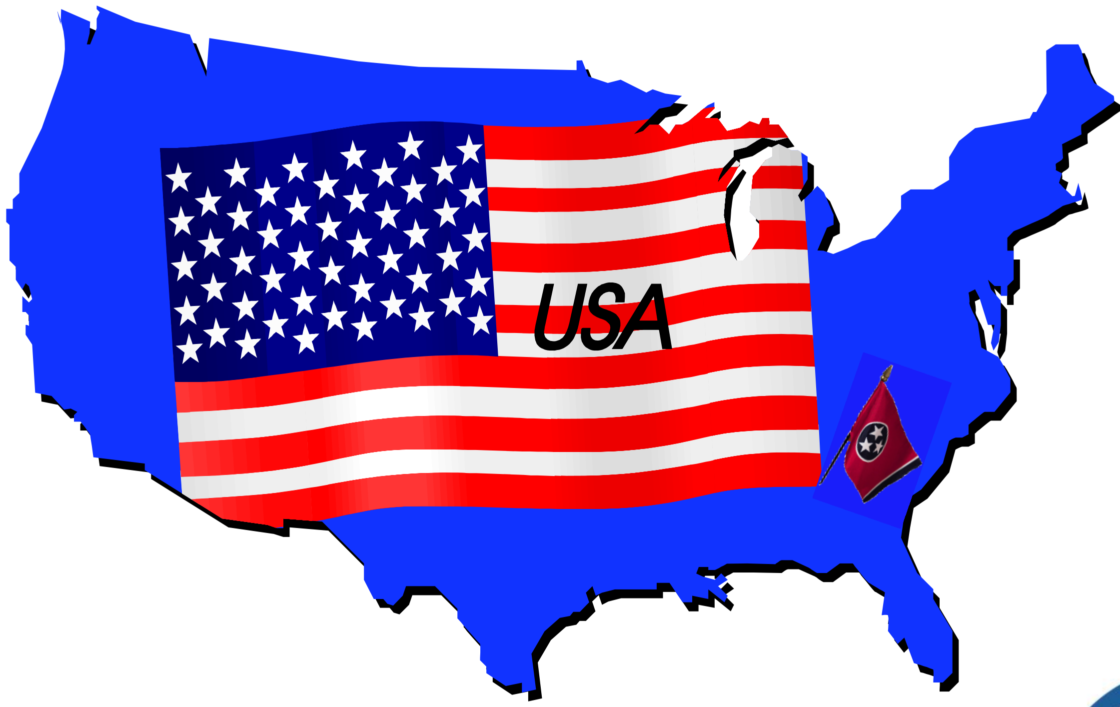
Performance Over Time



Origin of “Safety Factor”

- Emission performance over time is a function of system variables
  - type of combustion turbine
  - start-up profiles (no. starts/stops/yr.)
  - water injection & evap cooling
  - exhaust gas temperature
  - engine fuel composition – particularly **Sulfur**
  - seals, leakage and bypass
  - contaminants present in engine exhaust
  - effect of engine lube oil on catalyst
- Owners don’t report data over time for every combination

Thank you from EmeraChem



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