REINHOLD ENVIRONMENTAL Ltd.

2018 NOx-Combustion Round Table & Expo Presentation

February 19-20, 2018, in St. Louis, MO / Hosted by Dynegy

Reinhold Environmental 2018 NOx-Combustion Round Table
February 19, 2018

LaCygne Unit 1 and 2 SCR Reactor Design Features and Catalyst Management Comparison

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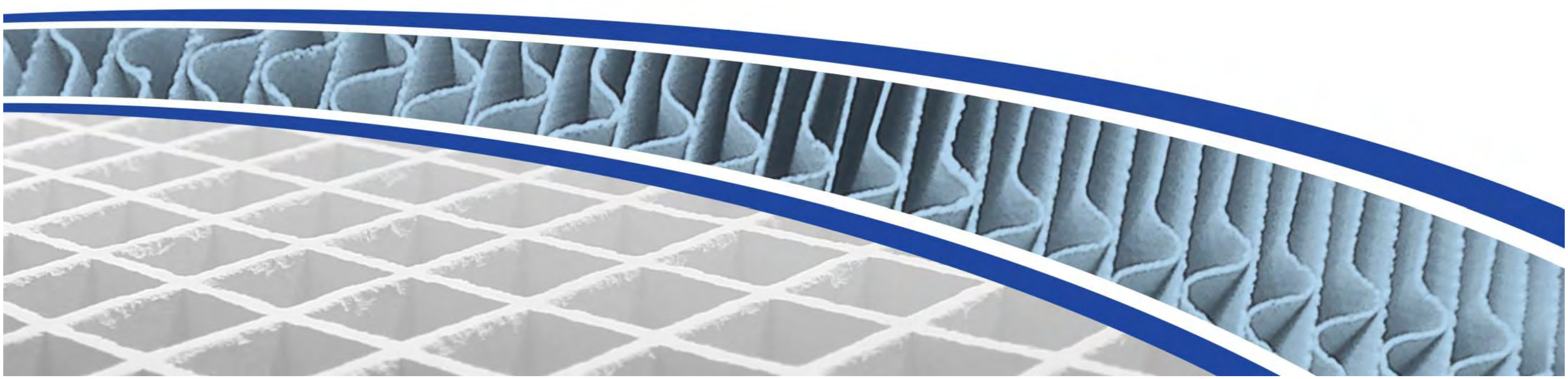


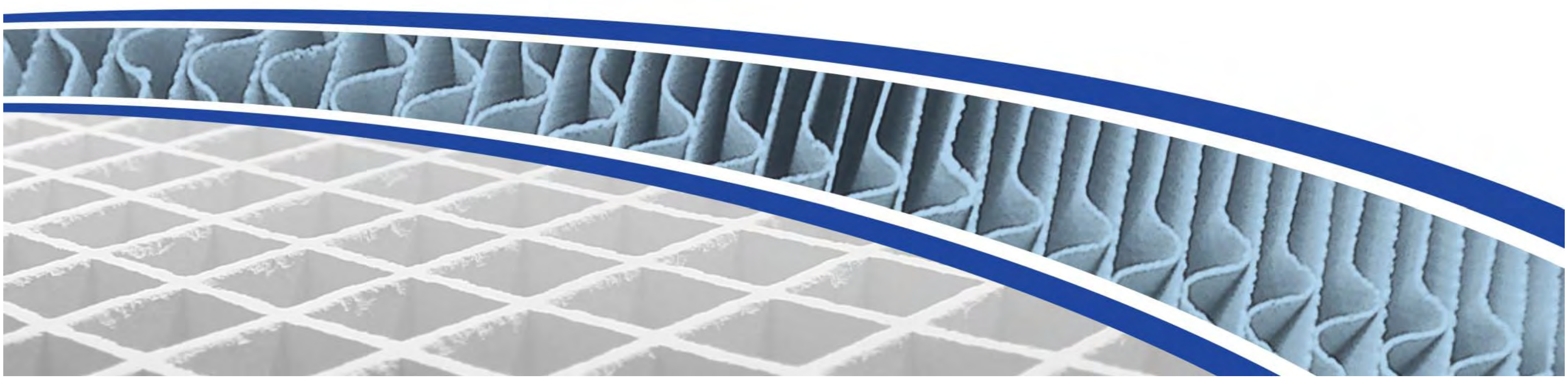
LaCygne SCR Comparison

Design and catalyst management optimization of vastly differing SCR systems:

Minimizing capital and O&M expenses while reducing operating risks.

- Presentation Road Map
  - Introduction
  - Unit Comparison
  - SCR Design Comparison
  - Catalyst Design Comparison
  - Catalyst Management Comparison
  - Conclusion and Questions

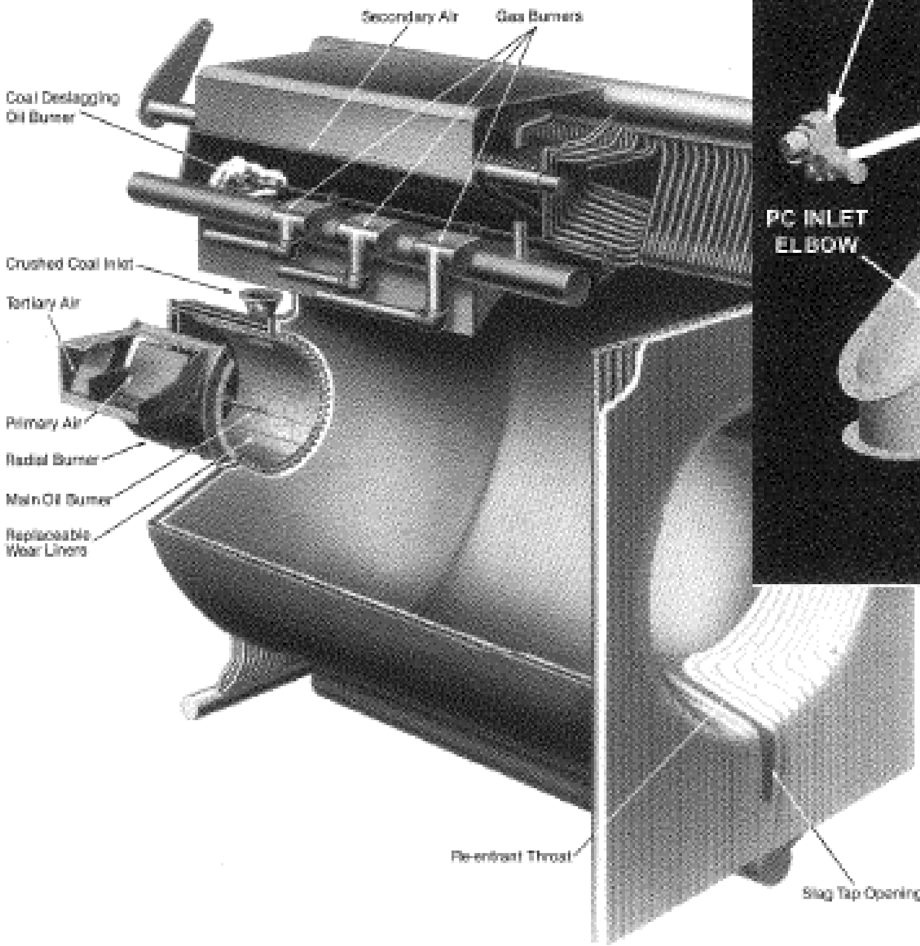
Unit & SCR Design Comparison

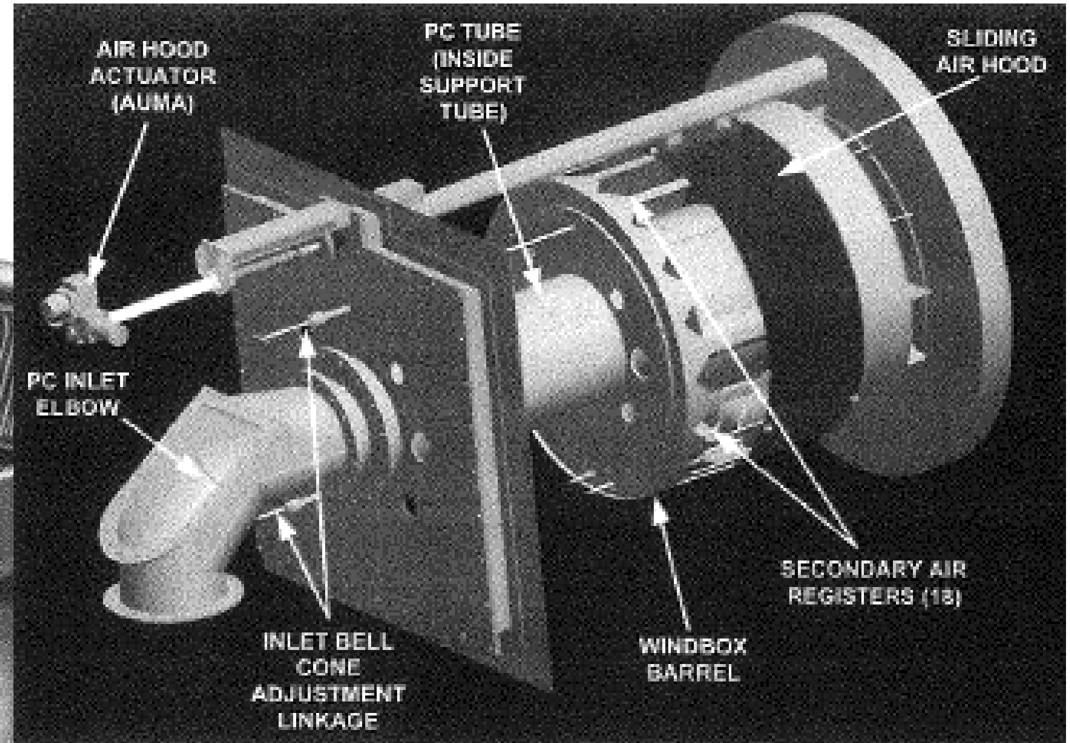


LaCygne Unit Comparison

	LaCygne 1	LaCygne 2
Gross Load	815 MW	715 MW
Boiler Burners	Cyclone	PC LNB
OFA	OFA	OFA
Boiler design NOx	1.0-lb/MBtu	0.22-lb/MBtu
SCR Outlet NOx	0.10-lb/MBtu	0.05-lb/MBtu

LaCygne Unit Comparison - Burners





SCR Design Comparison

	LaCygne 1	LaCygne 2
Catalyst Life Guar	3ppm at 24000 hr	2ppm at 16000 hr
Inlet NOx	0.64-lb/MBtu	0.25-lb/MBtu
Outlet NOx	0.09-lb/MBtu	0.10-lb/MBtu
Face Velocity	5.6 m/s	5.0 m/s
Catalyst Layers	3 + 1	3 + 1
Initial Catalyst Type	7.1 x 842 HC	2 x 6.7 x 700 PL
Catalyst Layout	2 x 8 x 13	2 x 8 x 12

SCR Design Comparison

	LaCygne 1	LaCygne 2
NH3:NOx Distrib	+/-5% Mean	+/-5% Mean
Temp Distribution	+/- 20 F	+/- 20 F
Velocity Distribution	100% in 15% RMS (~30% Mean)	85% in 10% Mean 100% in 15% Mean Phy Model 40 pts
Minimize Flow Recirc in Hood	-	Mutual Agreement
CFD model criteria	Hood = 2M cells	Model all flow obstructions. Hood > 5M cells
Phy model criteria	Model flow device	Model all > 6”

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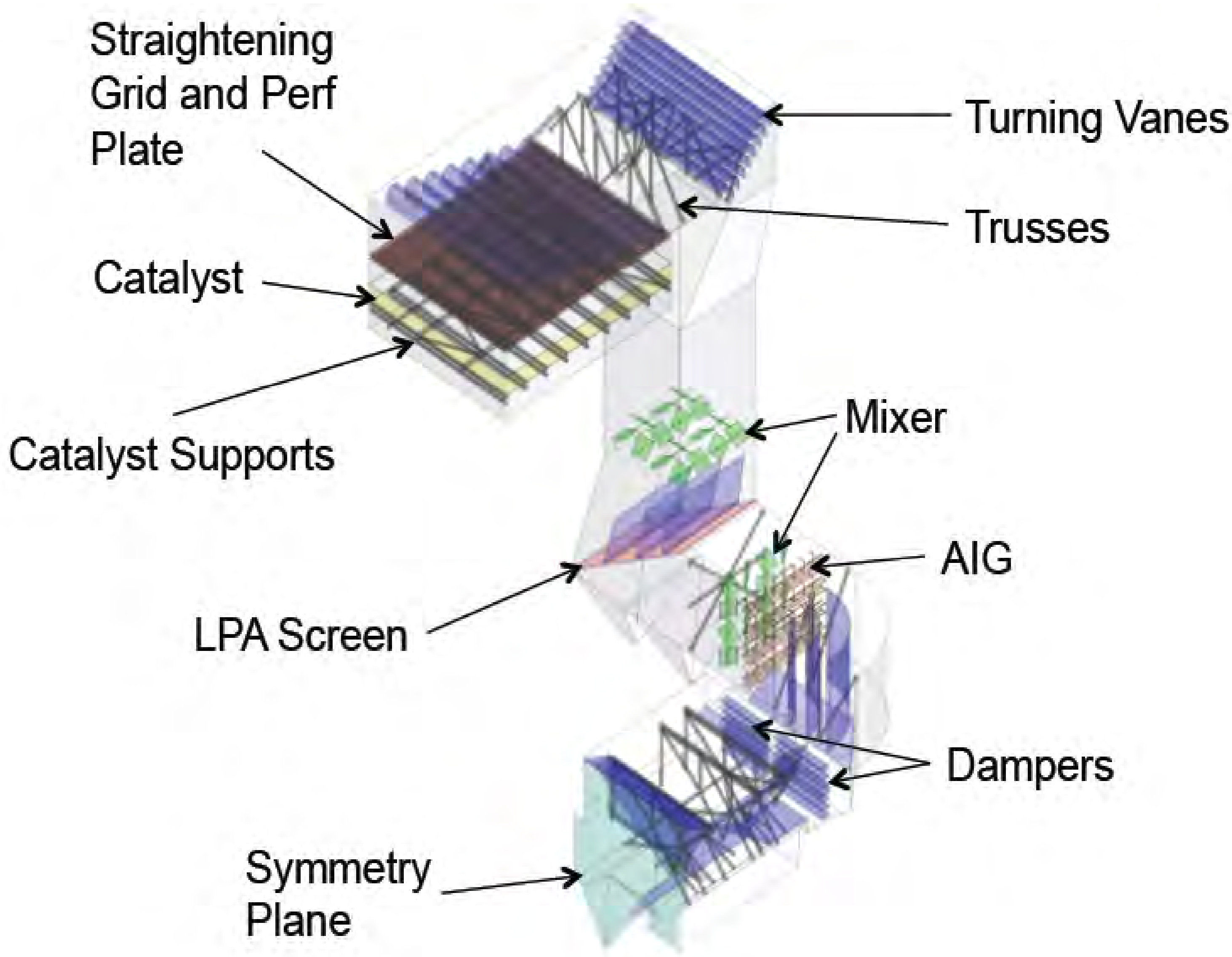
SCR Design Comparison – L1 Layout



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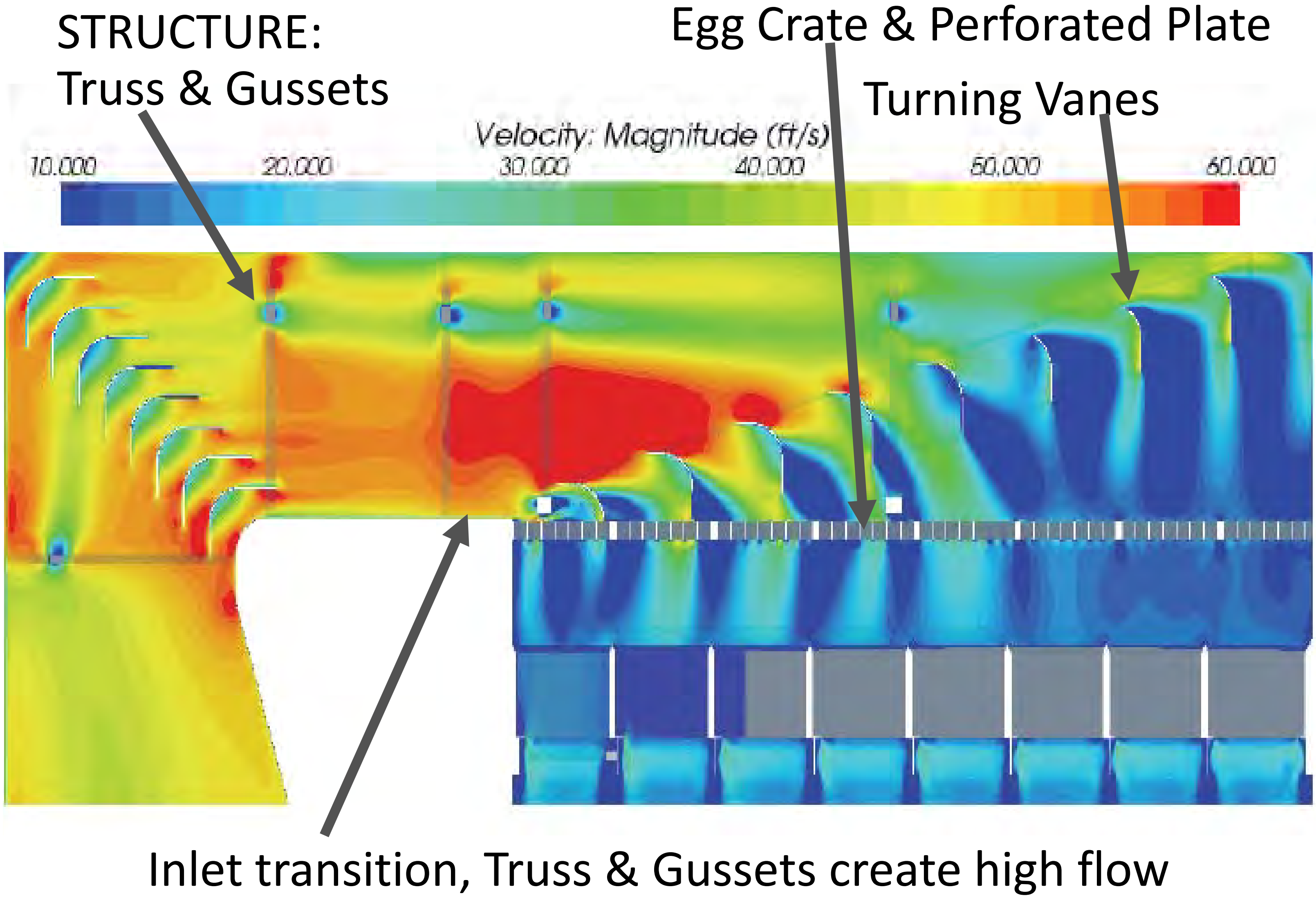
SCR Design Comparison – L1 CFD



SCR Design Comparison – L1 Ash Pluggage

Excess Flyash Pluggage –Layer 2 2nd Seal Strip

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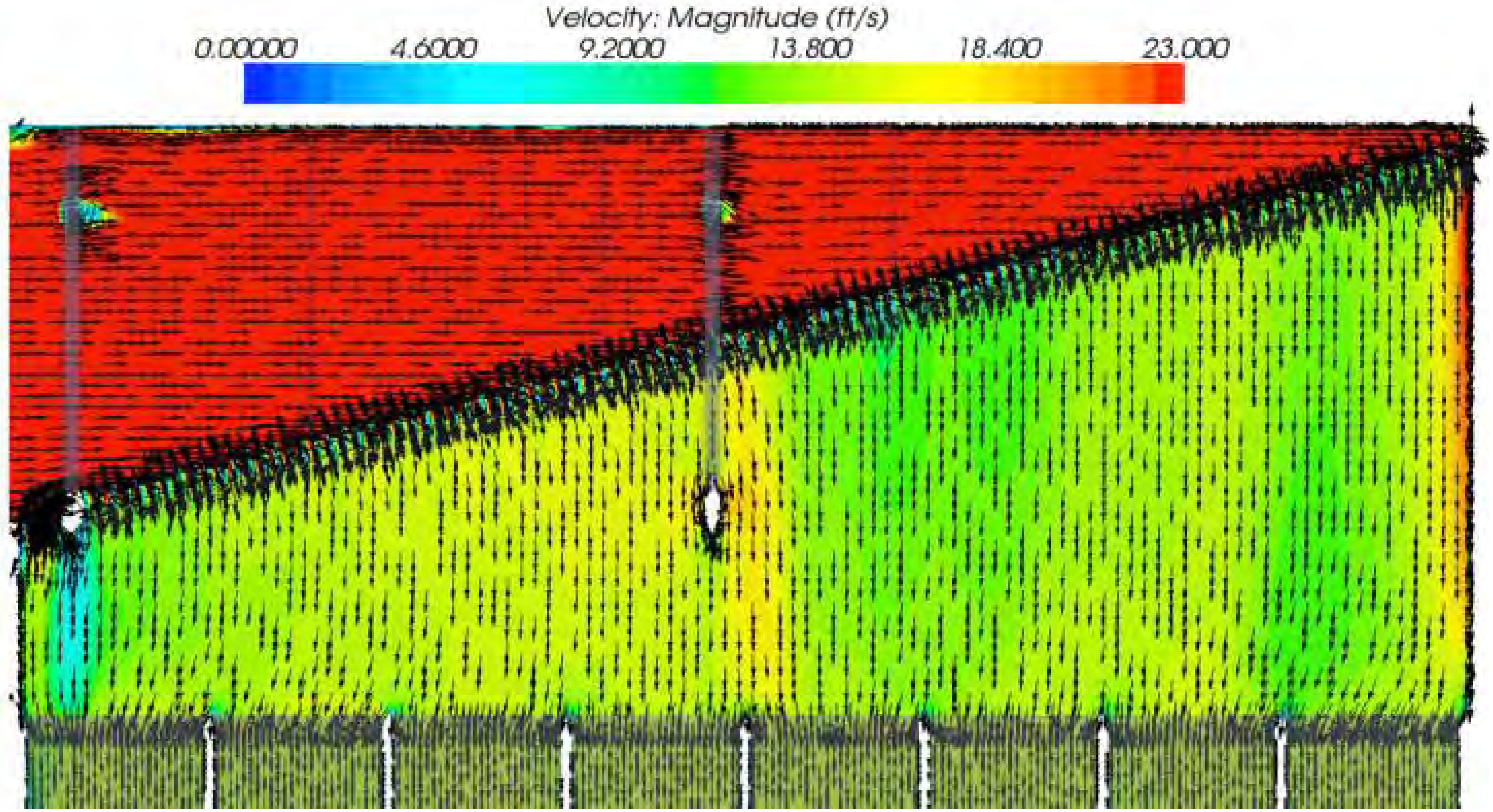
SCR Design Comparison – L1 Hood Mod

Vectors show very good straight flow in the hood.



- Graduated Straightening Grid (GSG) with variable perforated plate - uniform, vertical, non-recirc flow
- Egg Crate structural members removed

SCR Design Comparison – L1 GSG CFD

CFD Flow Modeling Shows GSG Benefits

	Baseline	GSG	Desired
Flow +/- 15%	58%	91%	100%
Flow +/- 30%	94%	99%	Not Used
RMS	17.5%	9.5%	Not Used

SCR Design Comparison – L1 I-Beam Ash Guards

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Regenerated Catalyst Erosion

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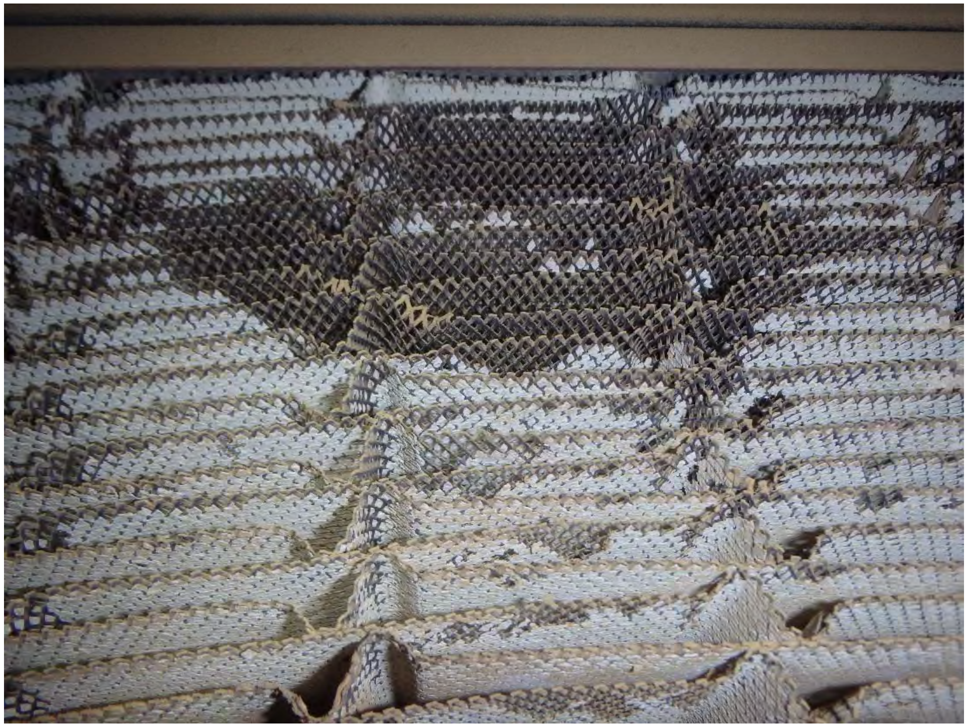
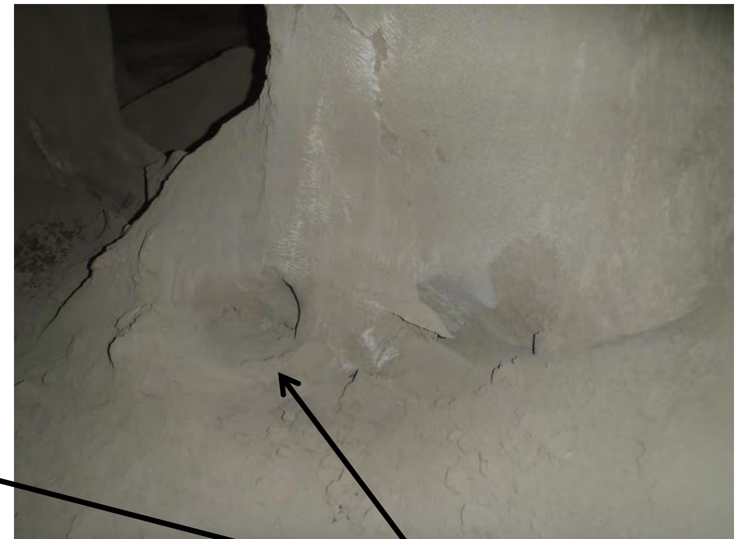
Catalyst Damage from Vacuuming & Dry Ice Blasting



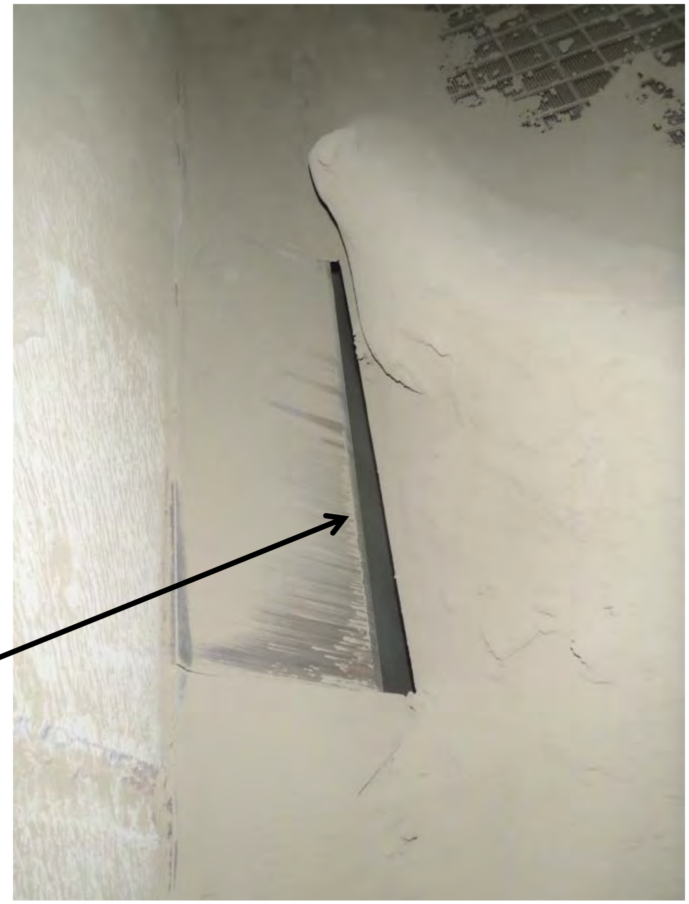
Module Seal Damage Causing Bypass



Flue gas tunneling through ash piles

Module seal gap

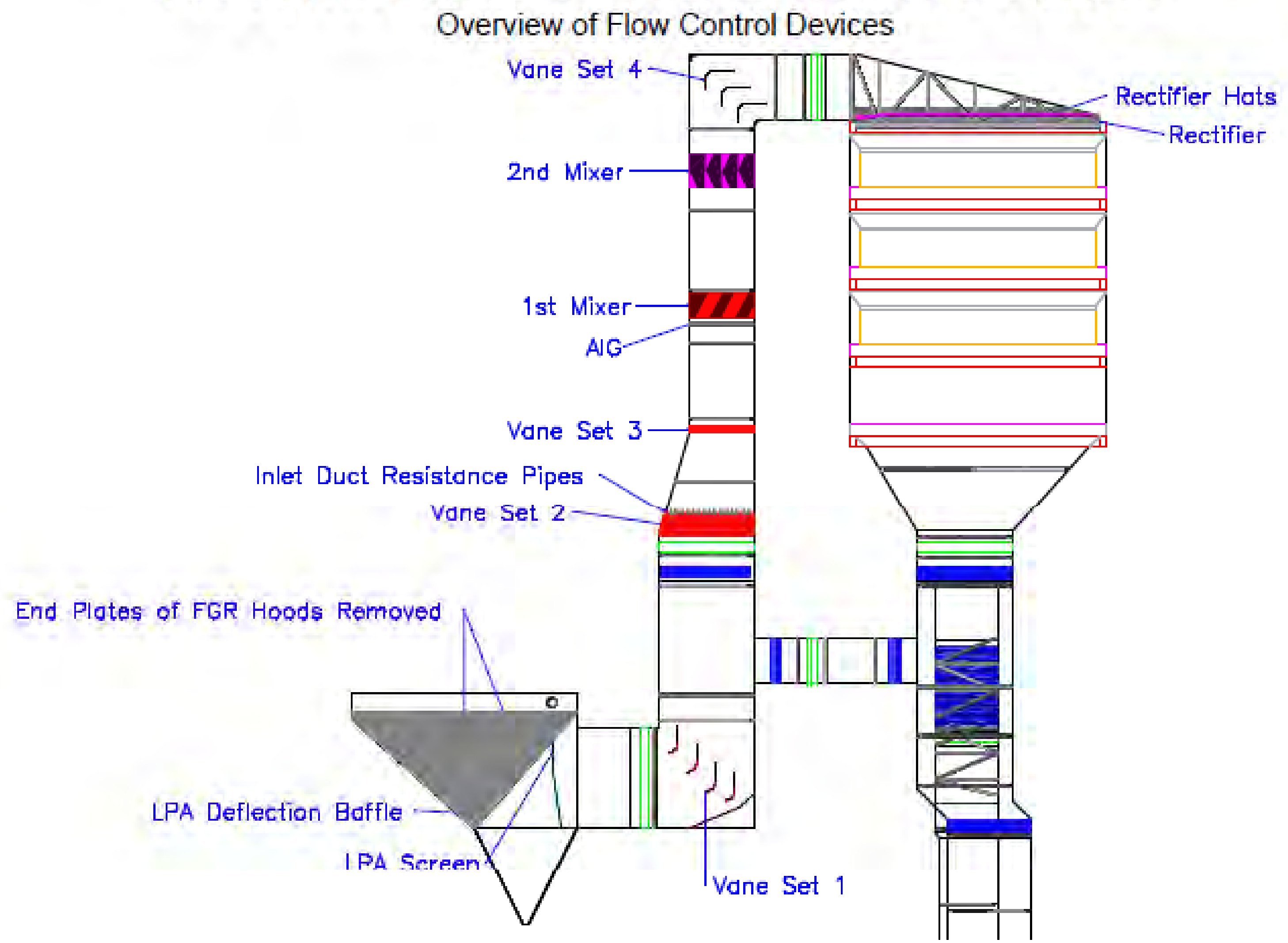
Wall Seal Damage Causing Bypass



Wall seal damage

SCR Design Comparison - L2 Layout

Recommended Flow Control Devices



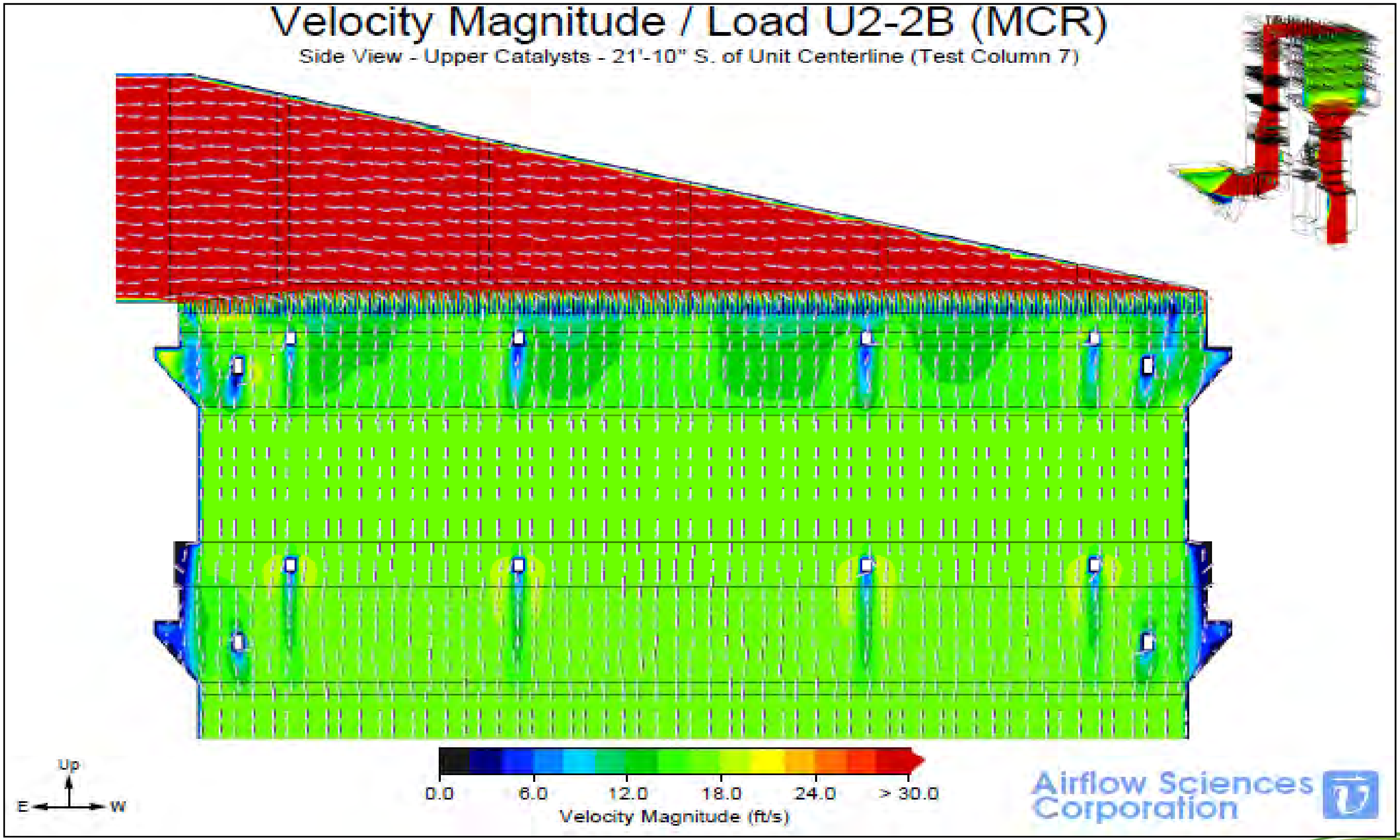
SCR Design Comparison – L2 SCR

	L2 Physical Model	Desired
Flow +/- 10%	**87.5%**	**85%**
Flow +/- 15%	**99%**	**100%**

CFD & Physical SCR Modeling agree

SCR Design Comparison – L2 CFD

Uniform, vertical, non-recirc flow. CFD & Physical Model agree. Model criteria. Ash guards. Outage layup heater.



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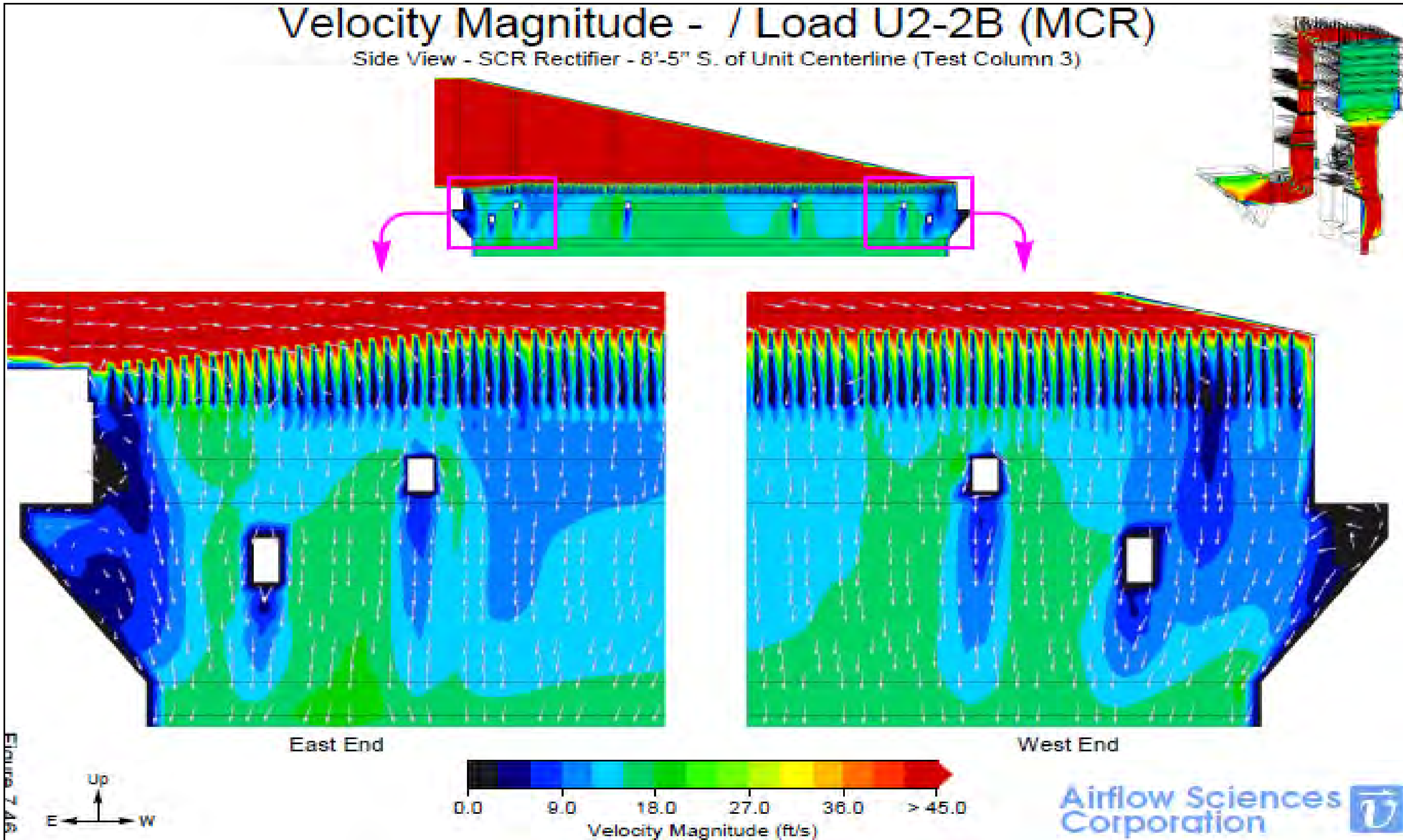
SCR Design Comparison – L2 CFD

Flow recirculation at catalyst wall seals



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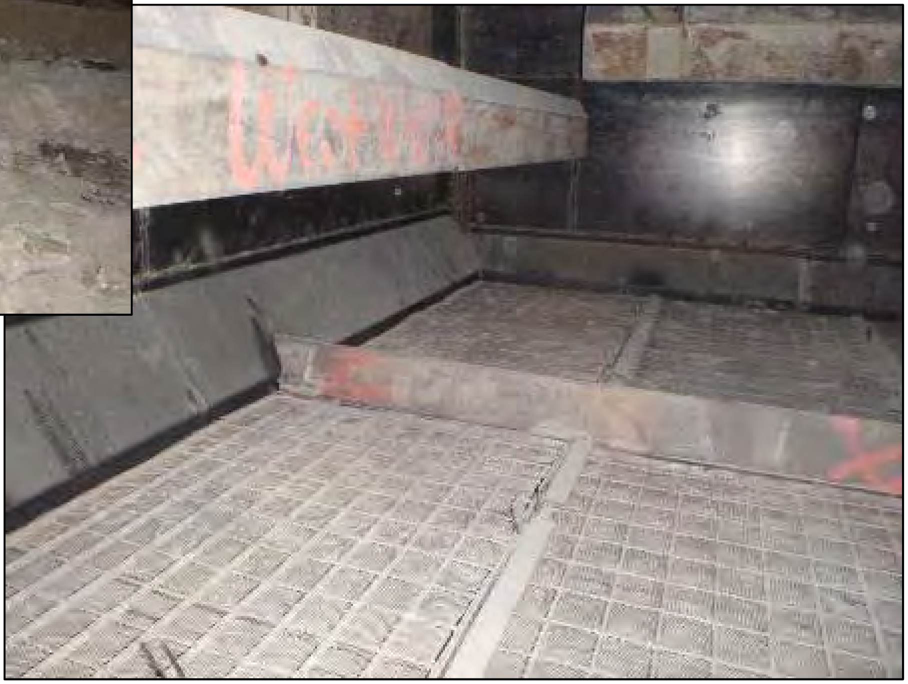
L2 I-Beam Ash Guards

L2 Wall Cavity Shields



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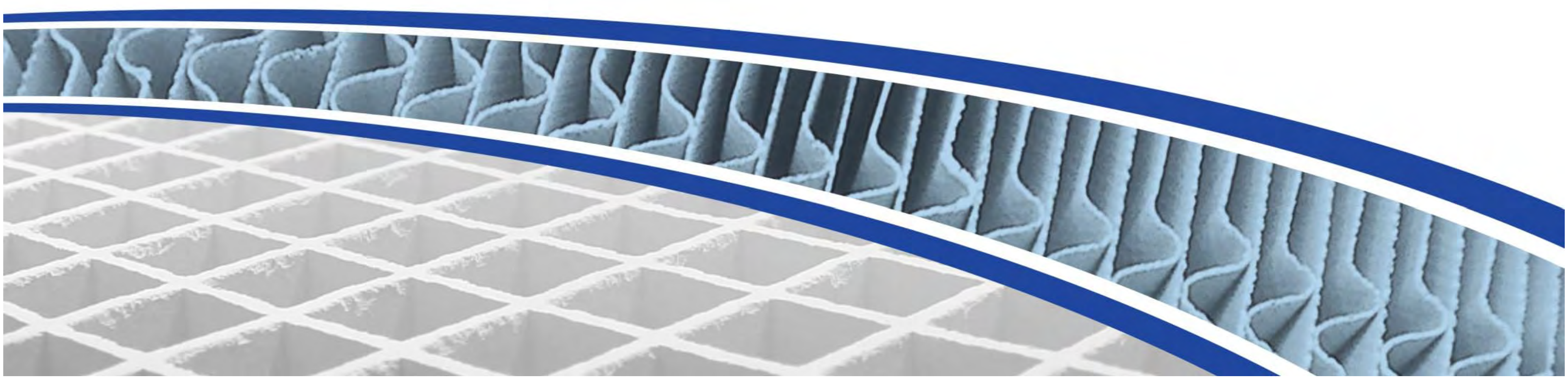
Catalyst Pluggage Due to Seal Design

- Ash accumulation on module edge below seal
- Accounts for 5% pluggage

Catalyst Damage from Vacuuming & Dry Ice Blasting

- Plate misalignment from cleaning and resulting pluggage
- Delamination from ice blasting

Initial Catalyst Design Comparison



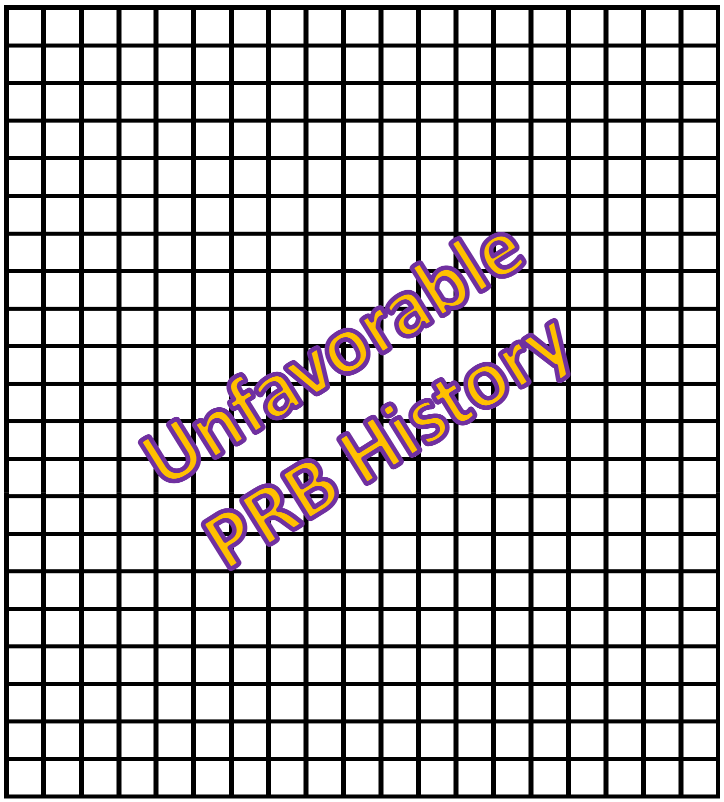
Key Design Considerations

- Catalyst Geometry
  - PRB ash propensity for pluggage
  - Small pitch → reduced volume, competitive price

- Catalyst Deactivation (Sizing Margin)
  - Design K/Ko predicted by catalyst supplier
  - Less design margin → reduced volume, competitive price

Initial Catalyst Geometry

LaCygne Unit 1
7.1 mm Pitch Honeycomb



- 6.4 mm hydraulic opening
- 80% open area
- 500 m^2/m^3 specific SA

LaCygne Unit 2
6.7 mm Pitch Plate

- 11.6 mm hydraulic opening
- 88% open area
- 306 m^2/m^3 specific SA

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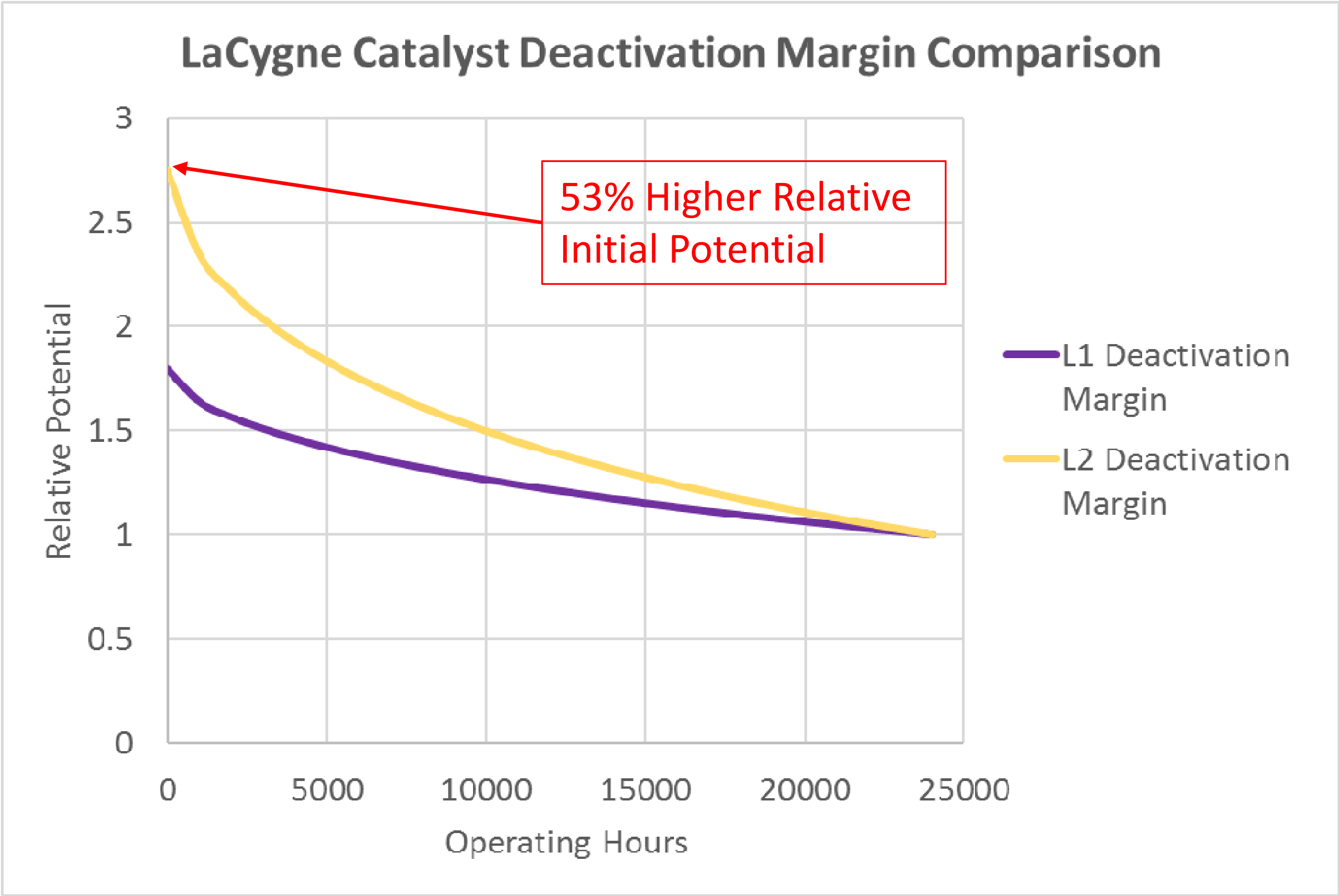
Catalyst Deactivation Margin



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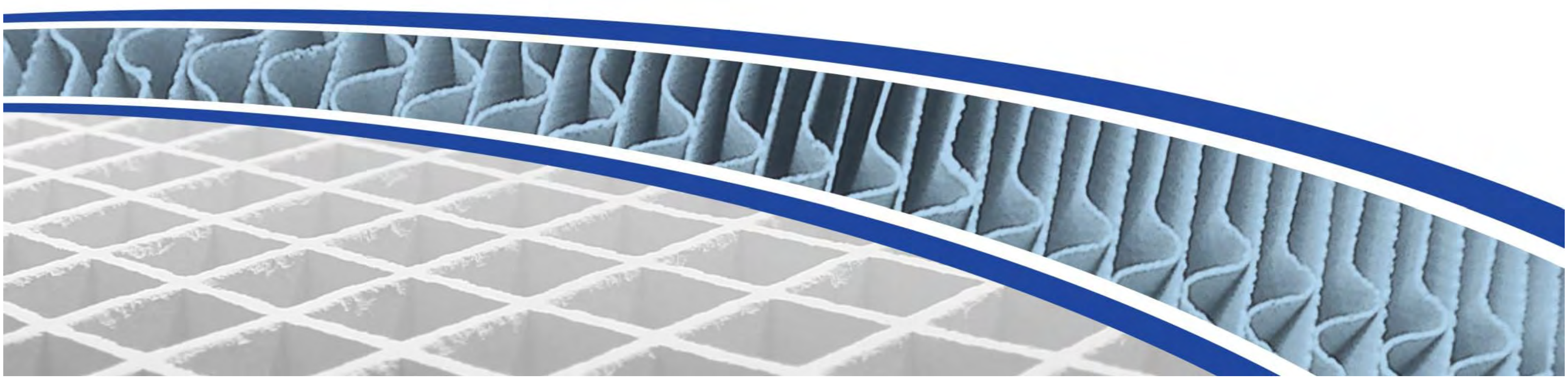
LaCygne U1 Catalyst Layer History

- 2007 original catalyst – Supplier A 7.1 mm HC
- 2009 full replacement – Supplier A 8.2 mm HC
- 2011 – New L1 CERAM 8.2 HC / Rejuv L2 / Vacuum L3
- 2012 full replacement – Regen Supplier B 5.7 mm PL / Regen Supplier A 8.2 mm HC / Regen CERAM 8.2 mm HC
- 2012 SCR hood modification
- 2015 – New CERAM 5.7 mm PL (2015, 2018) / Regen Supplier B 5.7 mm PL (2015)

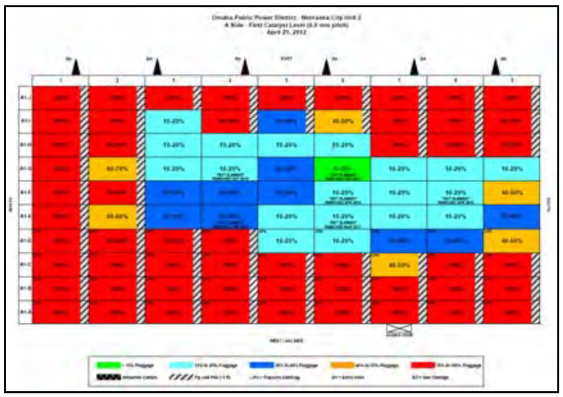
LaCygne U2 Catalyst

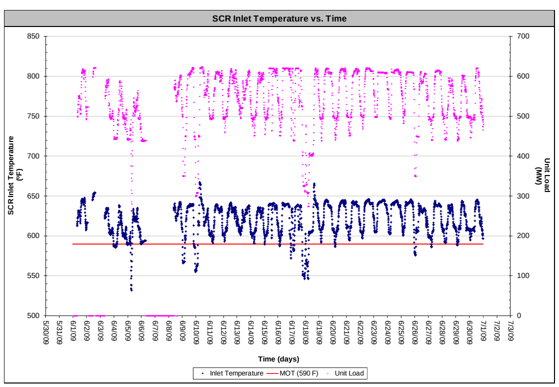
- Supplier C 6.7 mm PL (original catalyst 2014)
- 3+1 layer arrangement
- Full height layers requested by KCP&L
  - Greatly increased catalyst design margin
  - Minimum overall cost impact compared to SCR project

Catalyst Management



Key Aspects of Effective Catalyst Management Planning





- Catalyst Testing:
  - Accuracy and Consistency
  - Benchmarking (Round Robins, 3rd Party)
  - Consider Activity Measurement Bias
    - Low – Premature Catalyst Additions
    - High – Increased Operating Risks/Costs
- Assessment of Mechanical Conditions
  - Pluggage
  - Catalyst Mechanical Condition
  - Others (i.e. Seal Integrity, Flow Correction Dev.)
- Assessment of Operating Conditions
  - DeNOx Demand – SCR Process Requirements
  - Boiler Operations – Affecting "Operating" Reactor Potential

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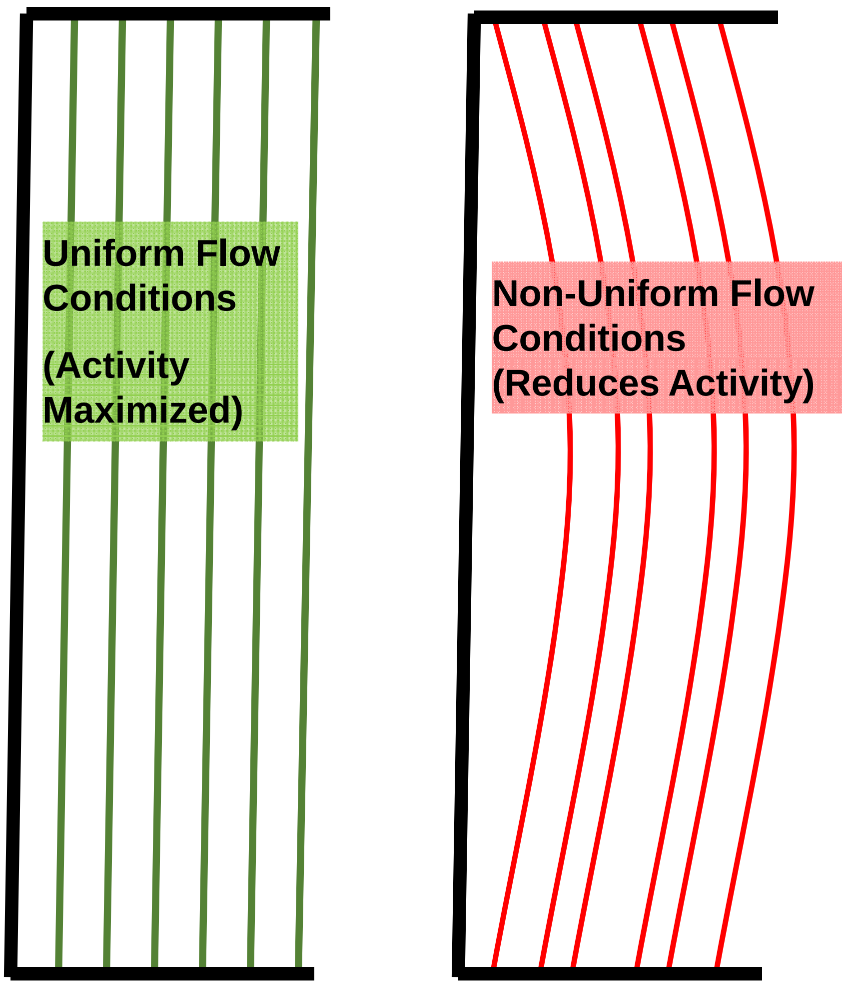
Operating Reactor Potential Affected by Catalyst Mechanical Condition

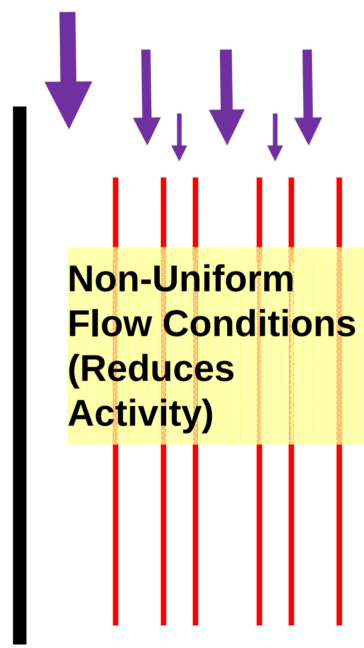


Parallel Plates

Bowing or Touching Plates

Plan View

- Plate Bowing or Touching Reduces Operating Reactor Potential
- Varying Flow Widths and Touching Plates Lead to Non-Uniform Flow
- Non-Uniform Flow Reduces Operating Activity (Reactor Potential)



Elevation View With Bowing or Touching Plates

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Plate Catalyst Activity Measurement Affected by Mechanical Integrity

- In the Laboratory Plate Spacing Can be Nearly Ideal (Maximizing Activity)
- In the Reactor Plate Spacing Can Only be Assured by Maximizing Geometric Uniformity Design
  - Plate Thickness
  - # of Spacers
- Deficient Geometric Uniformity Can Reduce Operating Activity by 4 to 8 Nm^3/m^2h (10 to 20%)

Plate Prepared for Laboratory Testing (forced to ideal spacing!)

Competitor Plate in Reactor

Post Operation

3 Spacers/Plate

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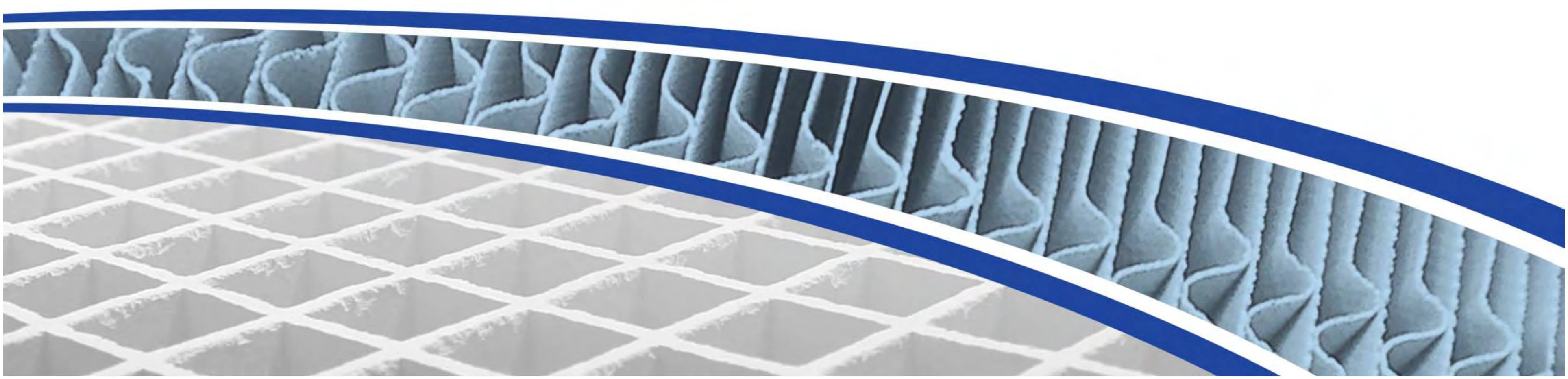
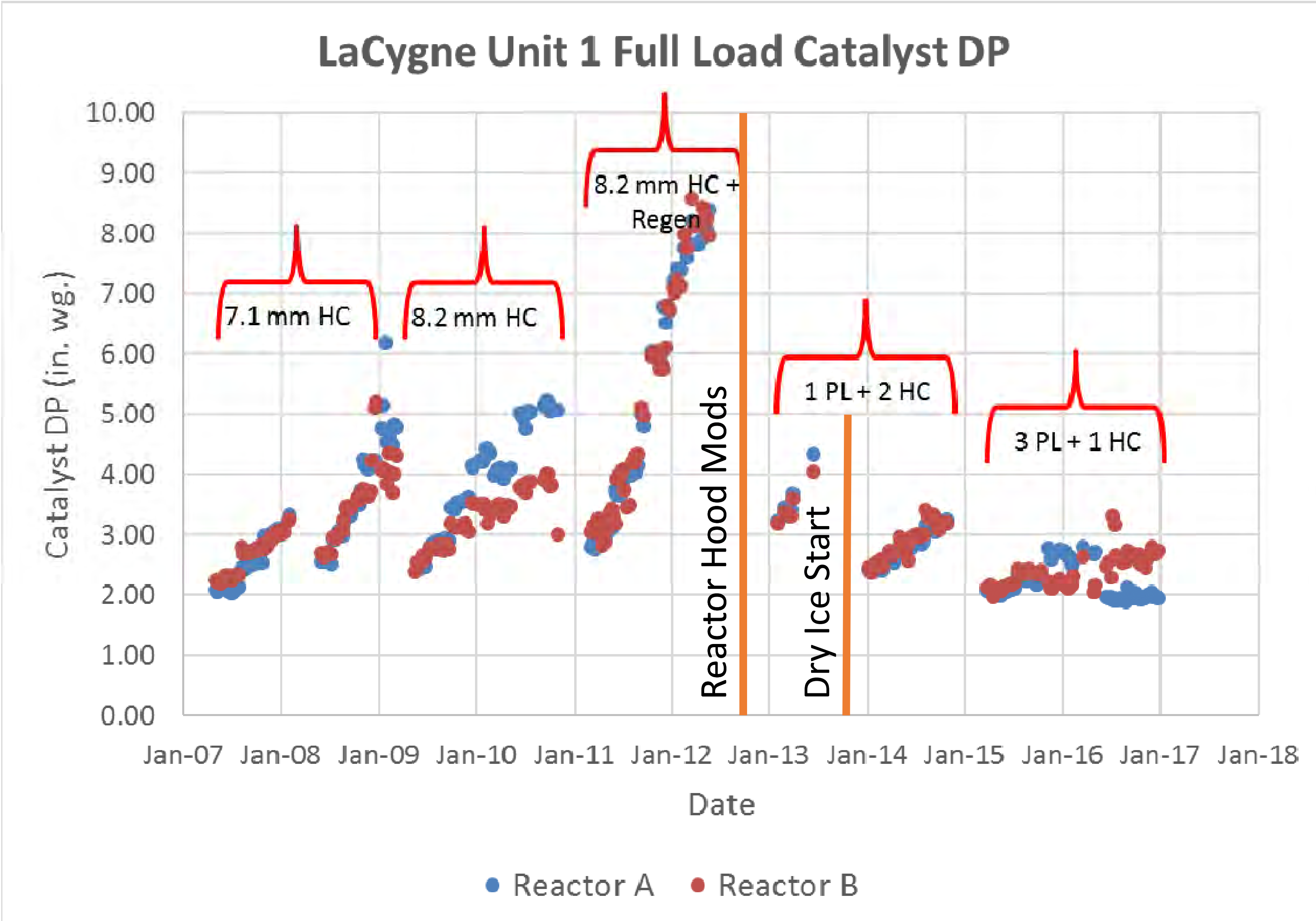
Catalyst Pluggage





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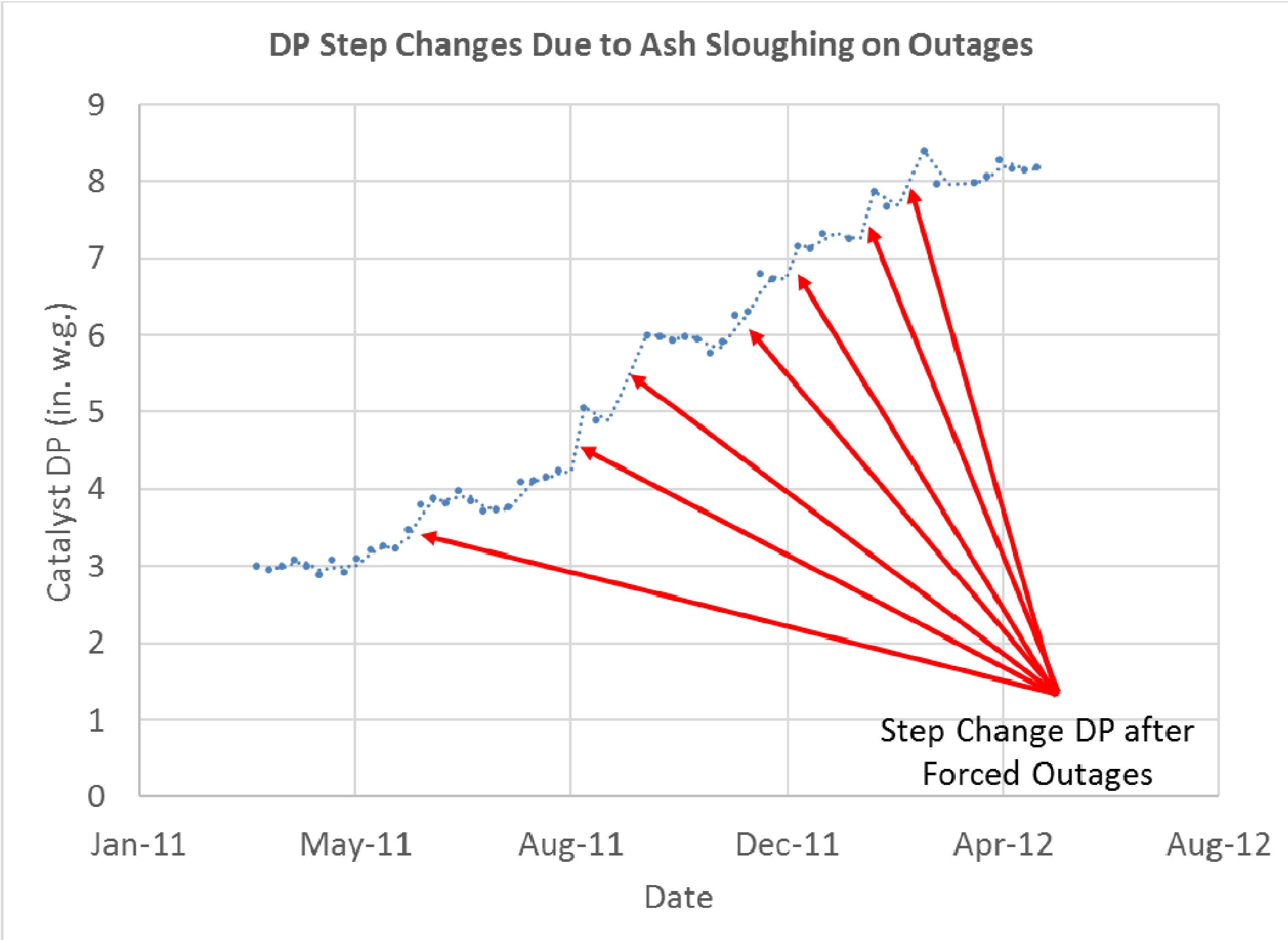
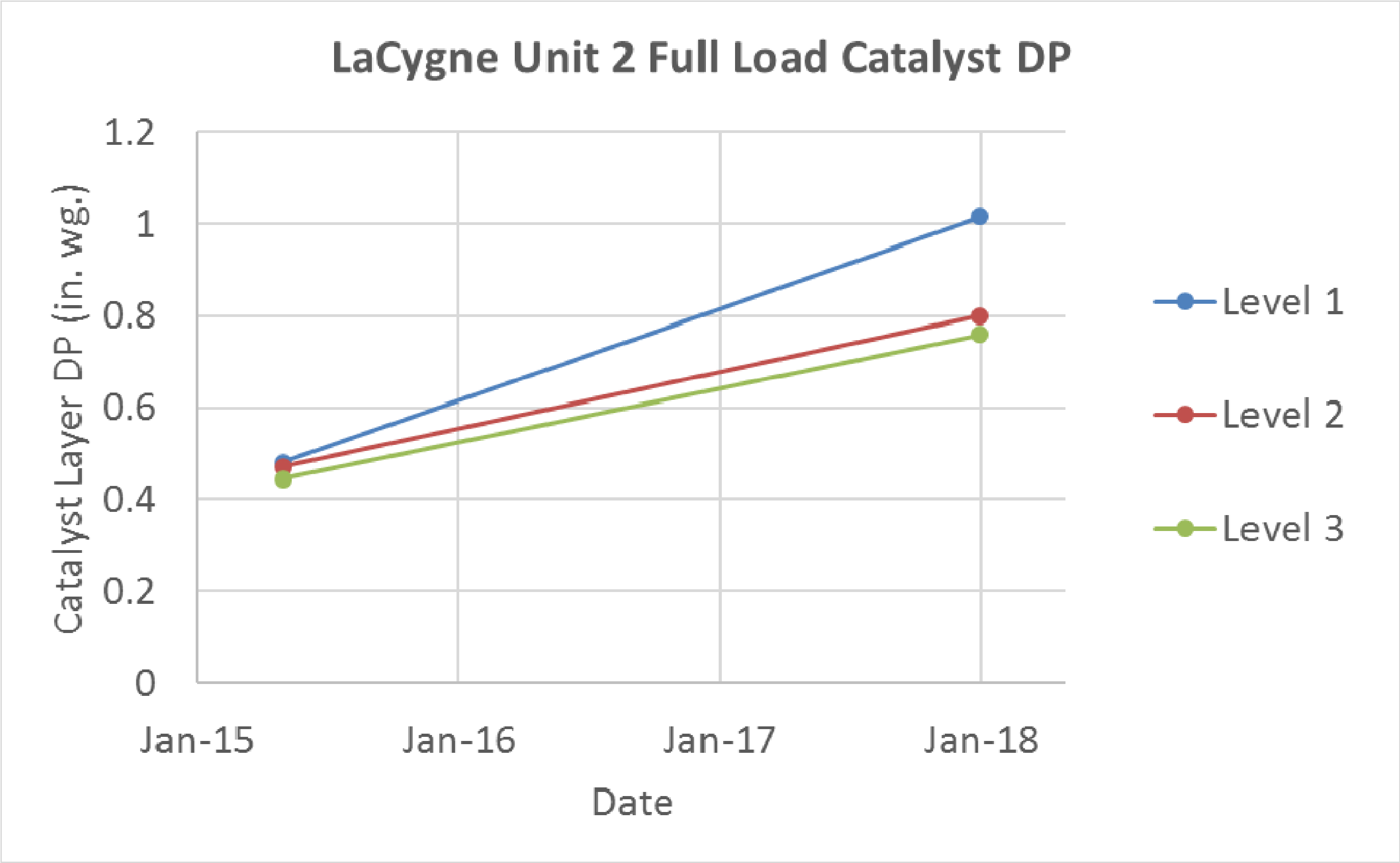
Dry Ice Blasting

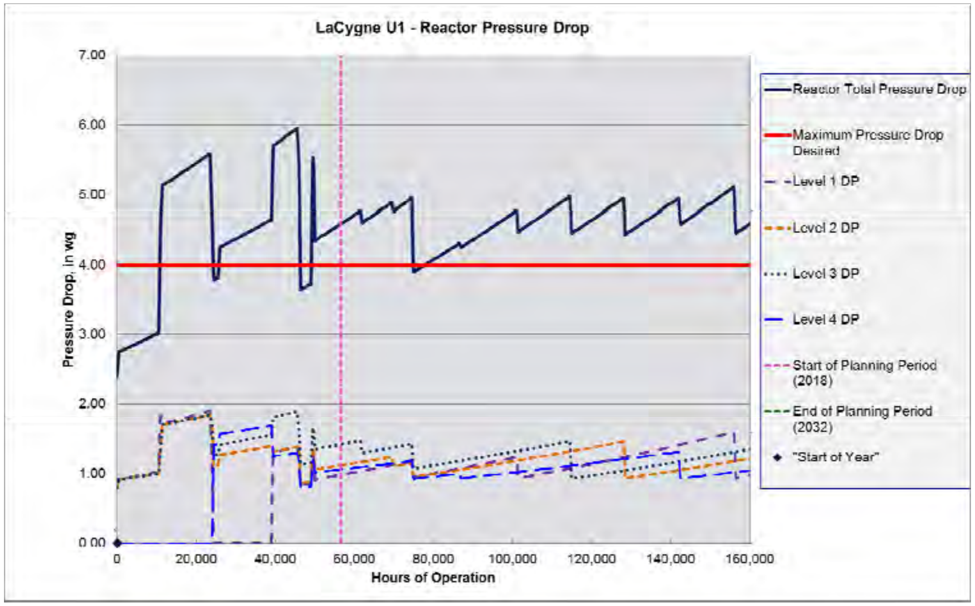
- First Performed in December 2013
- Approximately 45% of modules cleaned
- Reduced average pluggage from 29% to 9%
- Used again in future outages on modules >20% plugged

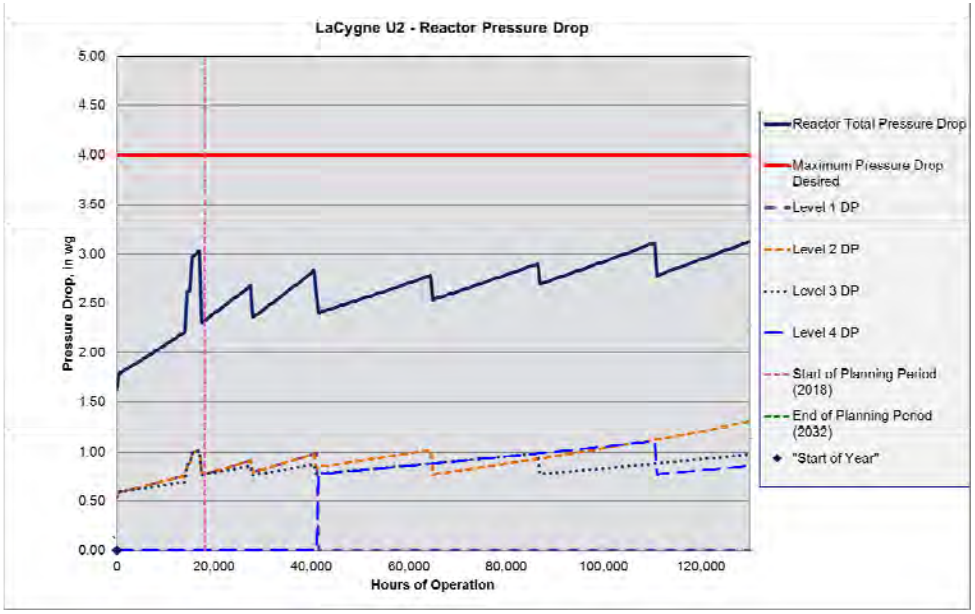

DP Step Changes Due to Ash Sloughing on Outages
Catalyst DP (in. w.g.)
0
1
2
3
4
5
6
7
8
9
Jan-11
May-11
Aug-11
Dec-11
Apr-12
Aug-12
Date
Step Change DP after Forced Outages



Average 22% pluggage after 30 months

Model Catalyst DP Trends





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Catalyst Testing

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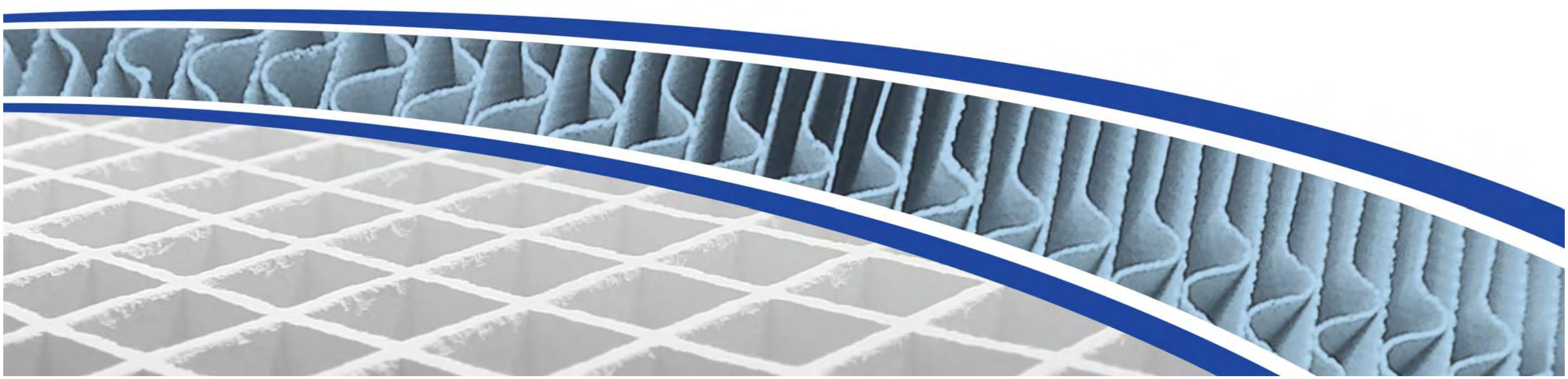
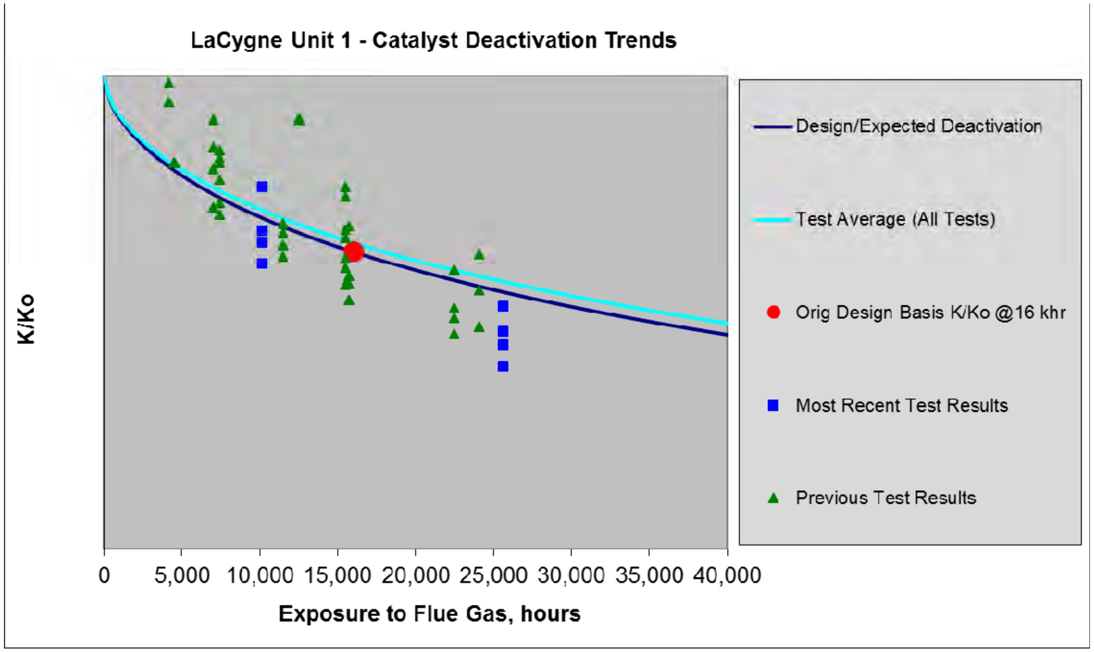
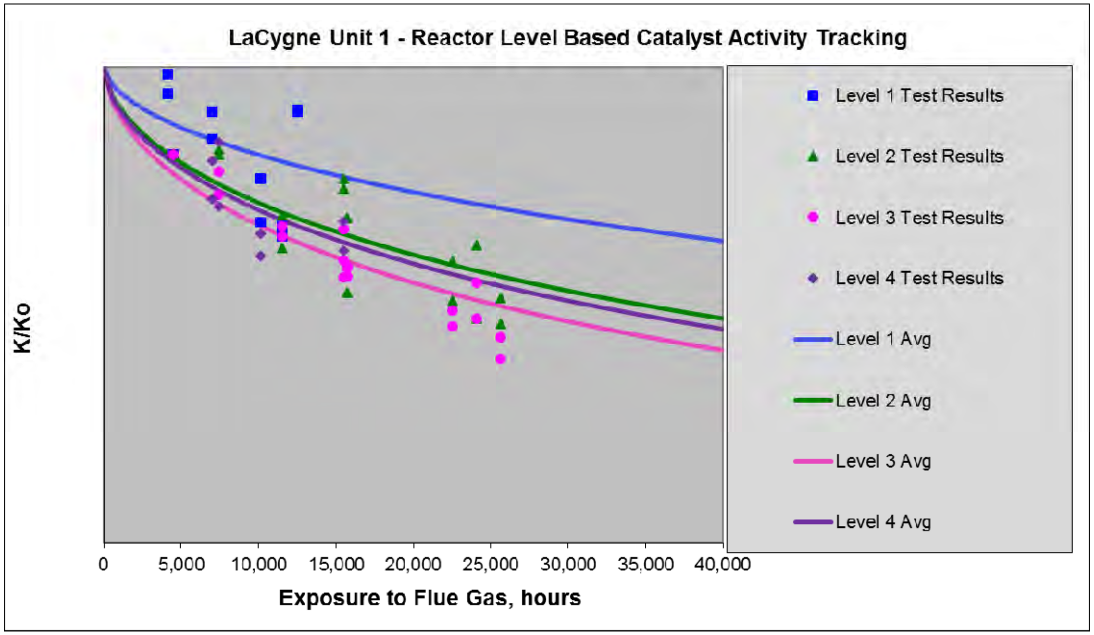
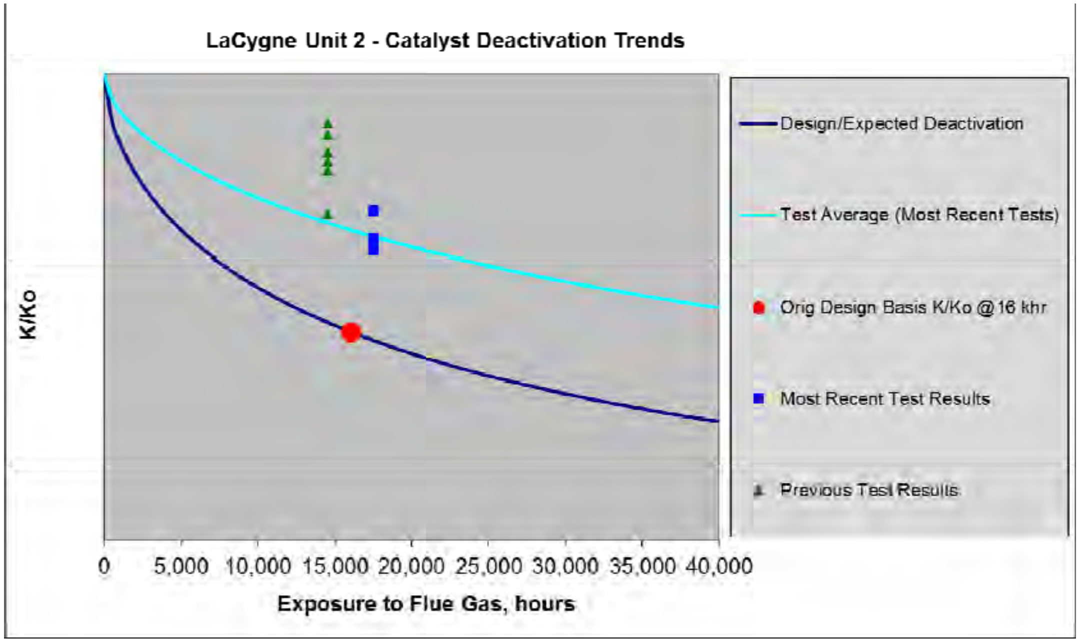


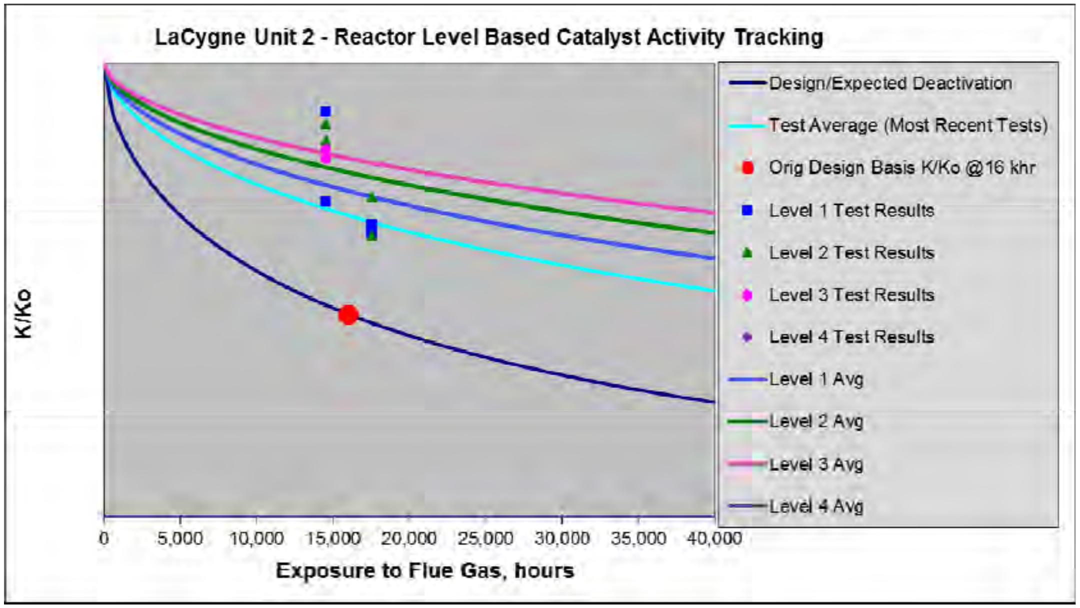
LaCygne Unit 1 Catalyst Test History





LaCygne Unit 2 Catalyst Test History





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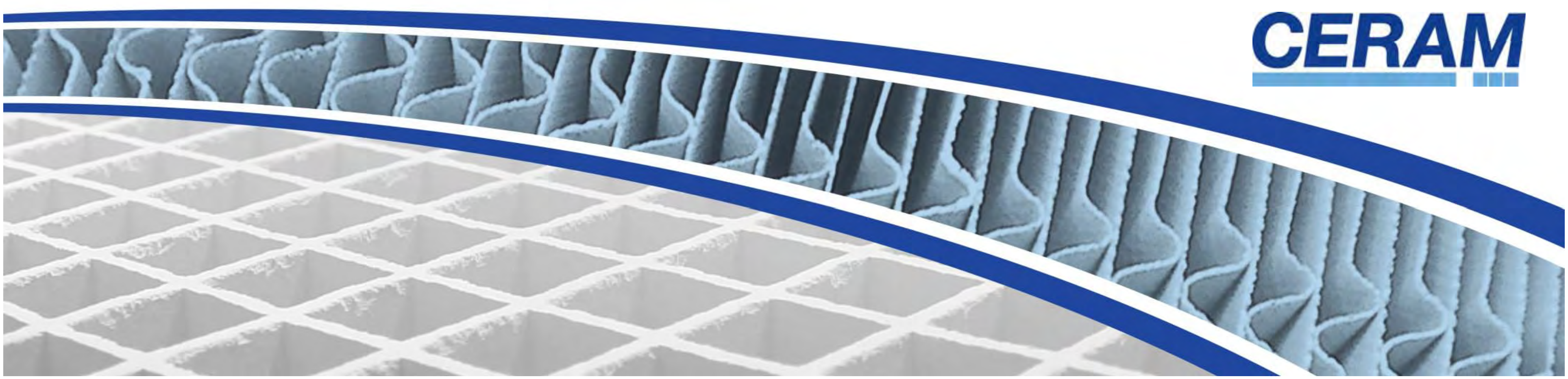
LaCygne Unit 1
Catalyst Management Plan



LaCygne U1 SCR Operating Cases

Unit or Fuel Case Description	Units of Input	Original Design Basis	Post LNB Operations
Inlet NOx	lb/MBtu	1.000	0.643
Inlet NOx, ppmvd @3%O2	ppmvd@3%O2	725.0	490.0
Outlet NOx	lb/MBtu	0.080	0.085
Ammonia Slip ppmvd @3%O2	ppmvd@3%O2	2.0	5.0
Fuel Burn Rate, MBtu/hr	MBtu/h	8,100	7,877
DeNOx Gas Temp, F	F	700	706
Oxidation Gas Temp, F	F	700	706
Economizer Outlet Flow @DeNOx Gas T	acfm	4,000,000	3,895,229
Economizer Outlet Gas Pressure	in wg	-14.5	-14.0
Economizer Outlet Flow	Nm3/h wet	2,785,722	2,750,200
Relative Potential Required		1.00	0.71
Gas Analysis at SCR Inlet:			
Oxygen, wet %	%	2.10	2.31
Moisture, %	%	14.00	13.46
Carbon Dioxide, % wet	%	13.85	14.32

Operating case developed from 3 Months of 10-minute data analysis

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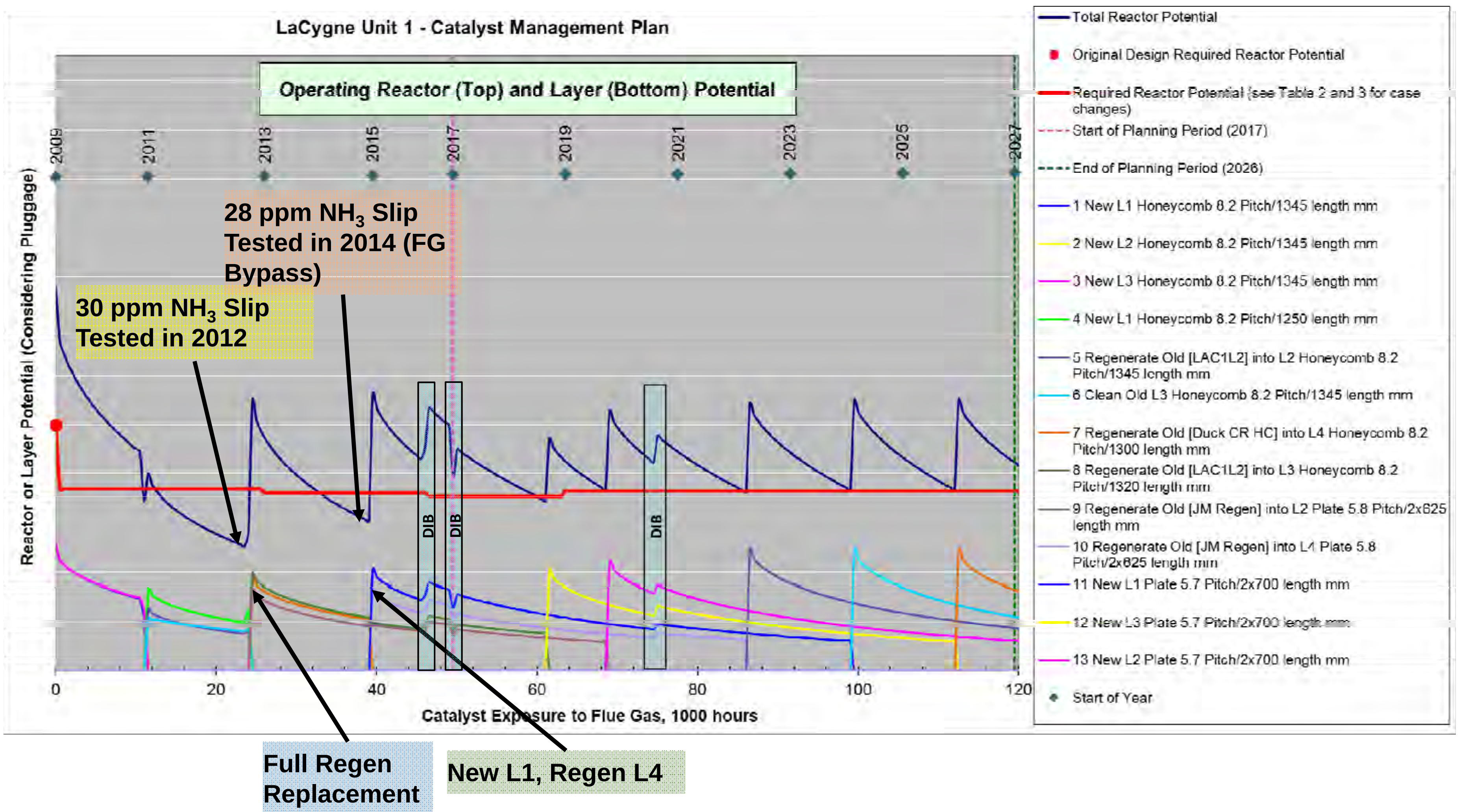
LaCygne Unit 1 CMP



8 Catalyst Layers Installed 2007 thru 2012 Mods

5 Catalyst Layers Installed 2012 thru 2017

3 Catalyst Layers Planned 2017 thru 2022

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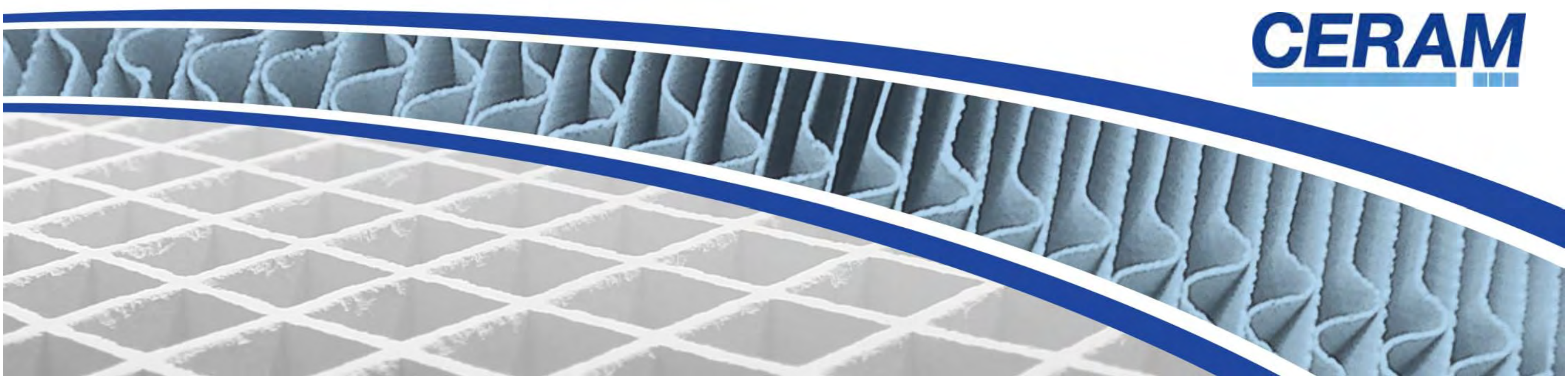
LaCygne Unit 2
Catalyst Management Plan



LaCygne U2 SCR Operating Cases

Unit or Fuel Case Description	Units of Input	Original Design	Actual Operations
Inlet NOx	lb/MBtu	0.220	0.250
Inlet NOx, ppmvd @3%O2	ppmvd@3%O2	167.0	186.0
Outlet NOx	lb/MBtu	0.050	0.100
Ammonia Slip ppmvd @3%O2	ppmvd@3%O2	2.0	5.0
Fuel Burn Rate, MBtu/hr	MBtu/h	6,982	7,120
DeNOx Gas Temp, F	F	772	738
Oxidation Gas Temp, F	F	772	738
Economizer Outlet Flow @DeNOx Gas T	acfm	3,466,000	3,643,507
Economizer Outlet Gas Pressure	in wg	-6.0	-6.0
Economizer Outlet Flow	Nm3/h wet	2,245,407	2,503,306
Relative Potential Required		1.00	0.80
Gas Analysis at SCR Inlet:			
Oxygen, wet %	%	2.00	2.31
Moisture, %	%	13.00	14.16
Carbon Dioxide, % wet	%	13.00	14.36

Operating case developed from 3 Months of 10-minute data analysis

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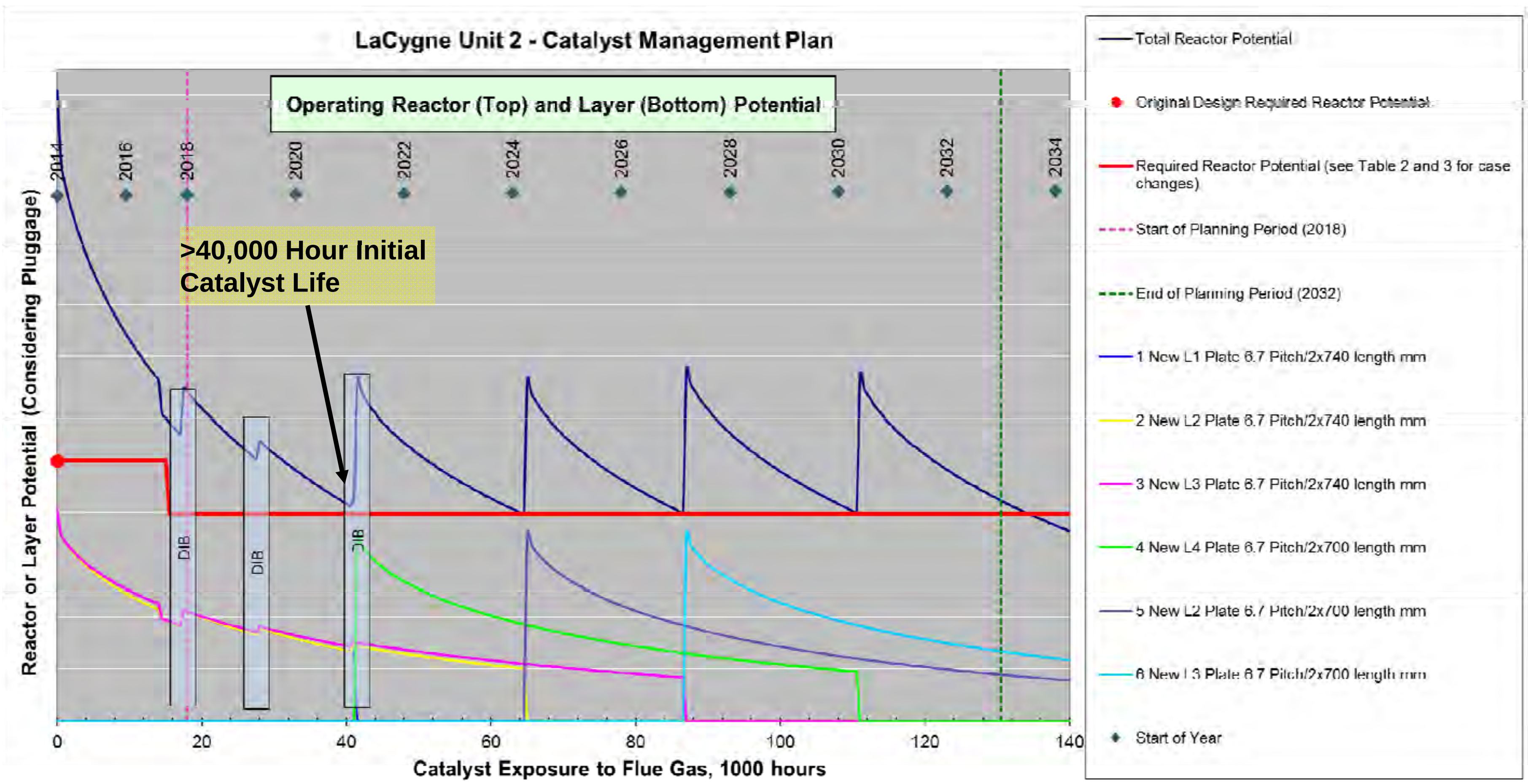
LaCygne Unit 2 CMP



CMP Economic Analysis 2018 - 2032

15 Year Net Present Value Analysis		
	Unit 1	Unit 2
Number of Catalyst Layers	8 Layers	4 Layers
Catalyst Related Expenditures	$ 11,208,000	$ 5,903,000
Fan Energy Costs for Reactor Pressure Drop	$ 5,835,000	$ 3,414,000
DeNOx System Ammonia Cost	$ 29,932,000	$ 7,316,000
Total Net Present Value of Plan (2018 to 2032)	$ 46,975,000	$ 16,633,000
NPV NOx Removal Cost of Plan (2018 to 2032)	$223 per Ton	$325 per Ton

- Unit 1 twice the number of catalyst layers
- Unit 1 4X ammonia consumption (cyclone vs. PC)
- Unit 2 higher cost per ton of NOx

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The Goal:

-Manage Operating Risk

-Minimize Capital & O&M $$$

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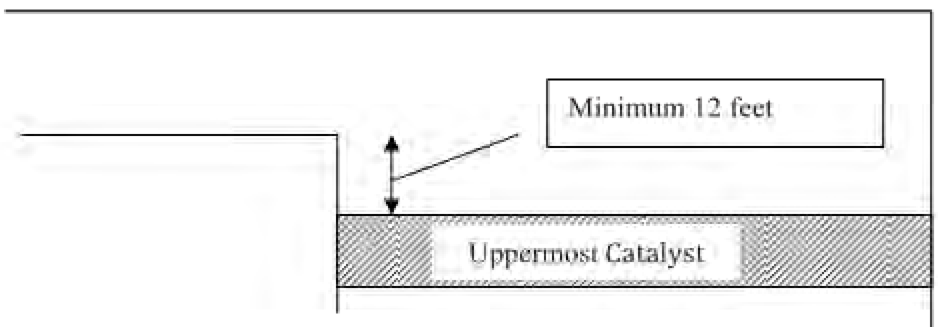

Figure 4 – Minimum Distance to First Catalyst Layer

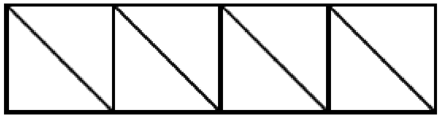

Figure 5 - Type 1 Internal Bracing Configuration - not allowed when oriented perpendicular to the direction of gas flow, but can be used in parallel to gas flow.

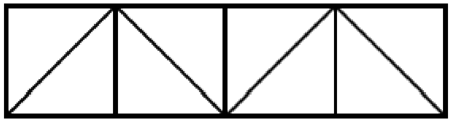

Figure 6 - Type 2 beam structure – not allowed within 1.5 hydraulic diameter of SCR reactor inlet plane when oriented perpendicular to the direction of gas flow, but can be used in parallel to gas flow.

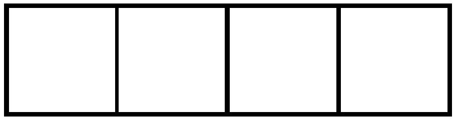

Figure 7 - Pipe structure – allowed when oriented perpendicular to the direction of gas flow.

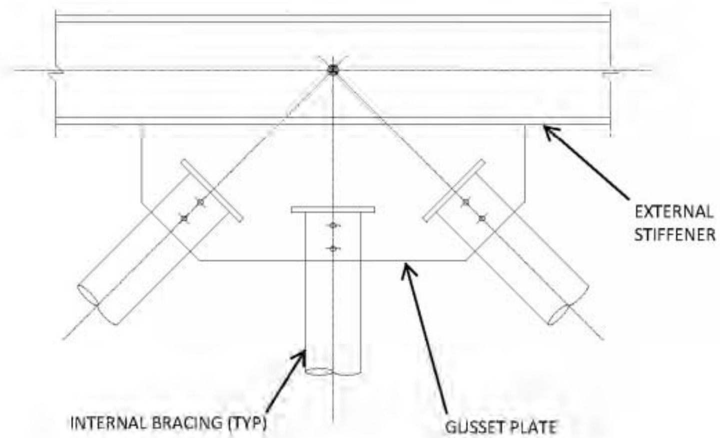

Figure 8 - Example of unacceptable gusset plate design

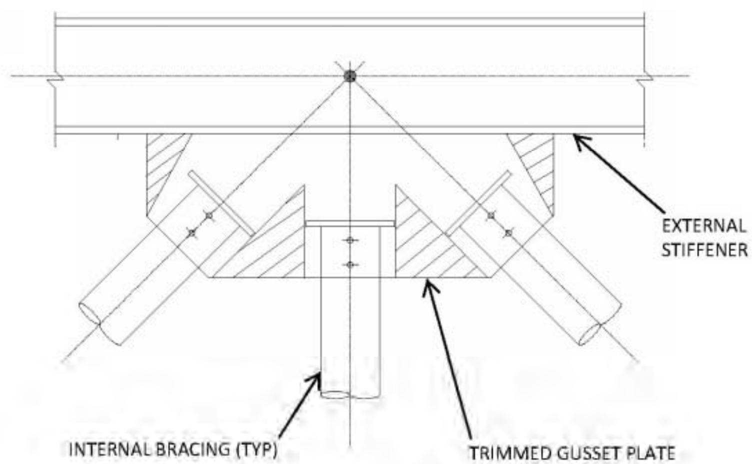

Figure 9 - Example of acceptable gusset plate design. A maximum 2" stress radius can be added to the cutouts, if required by the Contractor's design.

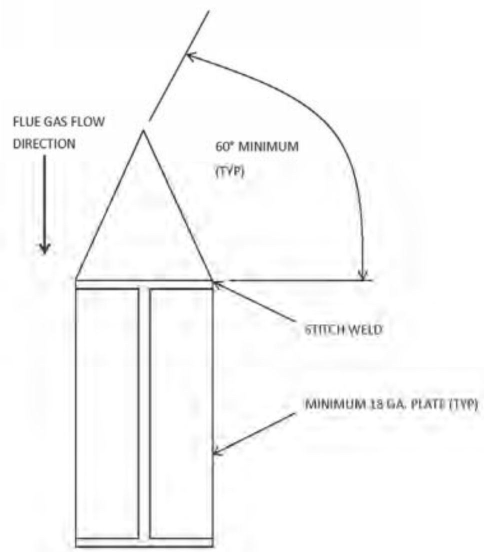

Figure 10- Example of deflector plate design for structural members parallel to gas flow (Type 1 – totally enclosed beam).

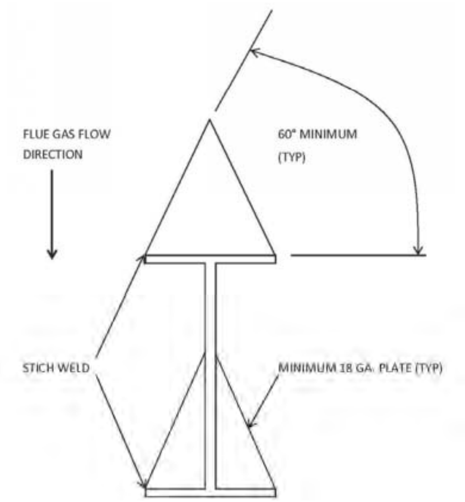

Figure 11 - Example of deflector plate design for structural members parallel to gas flow (Type 2 – partially enclosed beam).