REINHOLD ENVIRONMENTAL ®

2023 Reinhold/PCUG Round Table Presentation

Cohosted by Duke Energy and Vistra in The Westin Hotel,
Cincinnati, OH on June 26-27, 2023

2023 Reinhold Environmental Round Table

Media Cleaning SCR Catalyst for High Dust Applications: Industry Observations and Best Practices

Presented by
Elizabeth Danielson (OPPD) & Noel Rosha (CERAM)
June 26, 2023

Introduction

Media cleaning (dry ice, sponge, etc.) can help reduce SCR catalyst pluggage, but understanding the benefits and limitations of media cleaning is important in the determination of cost-effectiveness.

In this presentation, OPPD and CERAM will discuss their experiences and observations of media cleaning SCR catalyst.

- Presentation Road Map
  - OPPD & CERAM Media Cleaning Background
  - Catalyst Cleaning Basics
  - Realistic Expectations and Catalyst Management Model Analysis
  - Case Studies
- Questions and Answers

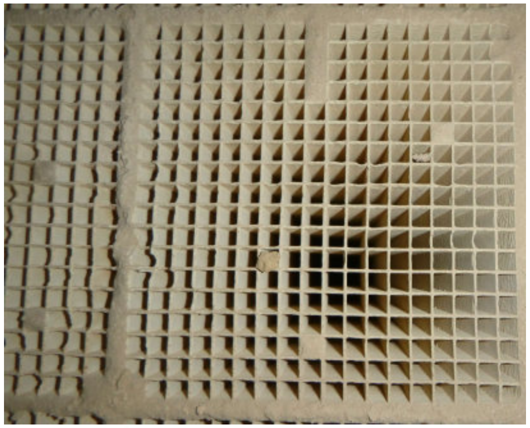
OPPD & CERAM Media Cleaning Background

- CERAM Manufacturers Catalyst (since 1985) and Provides Catalyst Management Services (since 2001)
- Referring to Media Cleaning as Compressed Air and Grit Media (dry ice, sponge, silica grit, etc.)
- CERAM Does Not Perform Media Cleaning
- CERAM Performs Dozens of Catalyst Inspections per Year, pre and post media cleaning
  - Direct experience on 18 SCR systems
- CERAM Performs Catalyst Management Modeling on Numerous Units Utilizing Media Cleaning

CERAM is neutral on whether dry ice or sponge media are used for catalyst cleaning. The use of media cleaning can be situationally advantageous but is not a cure-all.

OPPD & CERAM Media Cleaning Background

- OPPD Nebraska City Unit 2 dry ice cleaning since 2017
- Dry ice cleaning performed at most major outages
  - 2-Year interval typical
- Positive results with media cleaning until 2021
  - Excessive damage in one catalyst layer

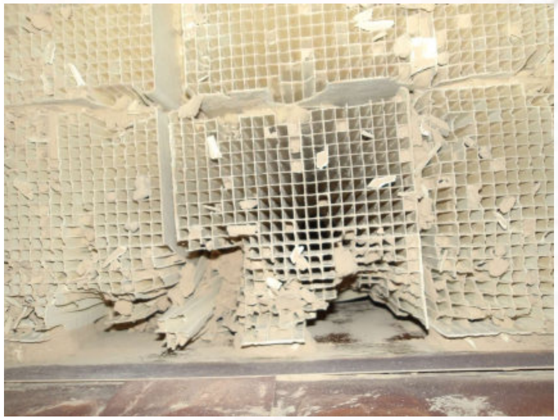


First Step – Vacuuming

- Vacuum thoroughly prior to media cleaning!
- Most common of the cleaning techniques
- Pluggage improvement a function of the ash deposits
  - Ash type and time functions
- Start at top and work down
- Include flow rectifier, turning vanes, structural beams
- Remove cover grates
- Vacuum down to catalyst inlet face
- Vacuum catalyst outlet face

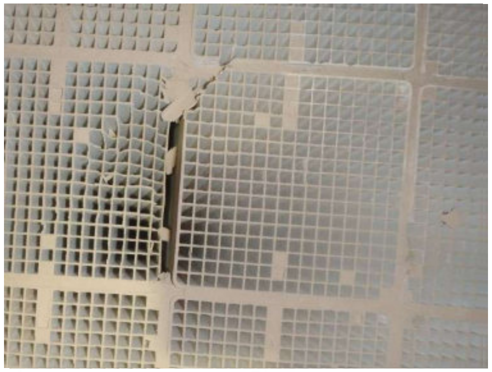
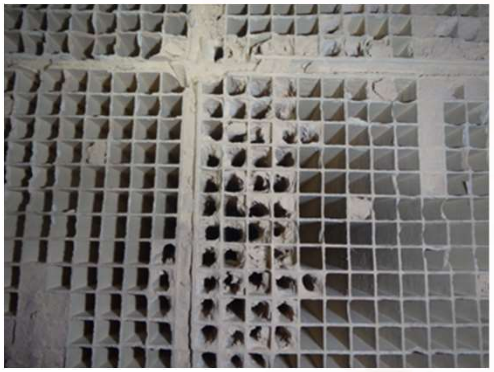
SCR Catalyst Cleaning Basics

- Avoid moisture (clean soon after shutdown)
- Avoid damaging catalyst (stepping on catalyst, breaking or bending the catalyst face)
  - Damage propagates pluggage
- Cleaning lance flow should be directly vertical
- Catalyst must be cleaned across entire depth to be effective
- More "recent" catalyst pluggage is more removable
  - Friable ash that has not had the chance to set up
  - Old, heavily plugged modules are less than optimal candidates



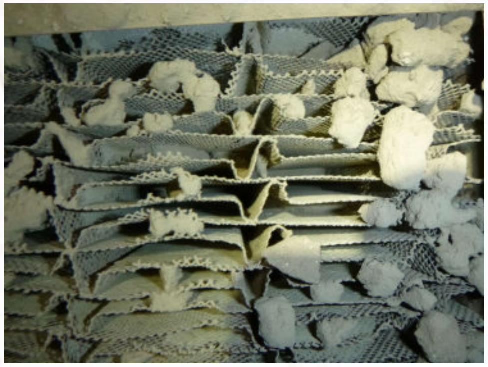
SCR Catalyst Media Cleaning Basics

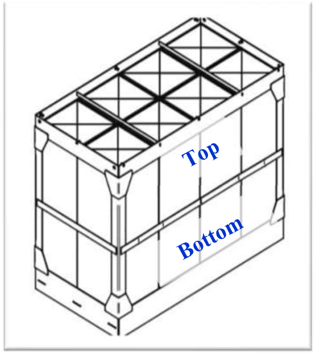
- Clean from top and bottom (as possible)
- Cleaning results may look great initially, but pluggage is frequently ‘pushed’ down into catalyst cells.
  - Honeycomb pluggage is frequently pushed downward several inches or catalyst channels may have a crust around the perimeter of the channel opening (ratholing)

SCR Catalyst Media Cleaning Basics

- Plate pluggage can be pushed downwards and/or deposited at the interface between catalyst subblocks
  - Uniform plate spacing, parallel plate designs, and a single sublayer design can help make cleaning more effective





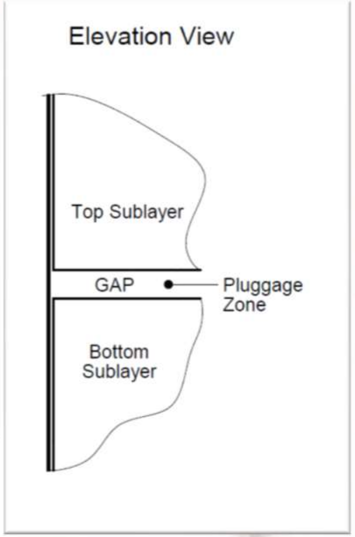
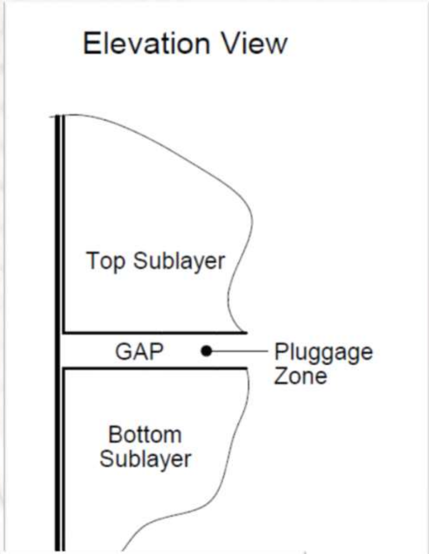
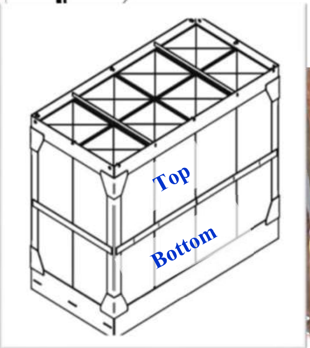


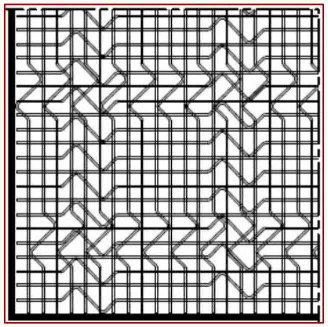
Plate vs. Honeycomb Media Cleaning

- Both Honeycomb and Plate Catalyst can be Effectively Cleaned via Media Cleaning
- Plate catalyst is more forgiving
  - Plates can flex slightly during the cleaning process
  - The steel substrate of plate catalyst will remain intact under intense cleaning
- Honeycomb can be more susceptible to off-axis flow damage

Parallel Subblock Design Reduces Pluggage

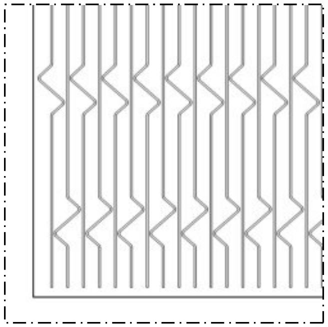






Perpendicular Sublayer Orientation Plan View

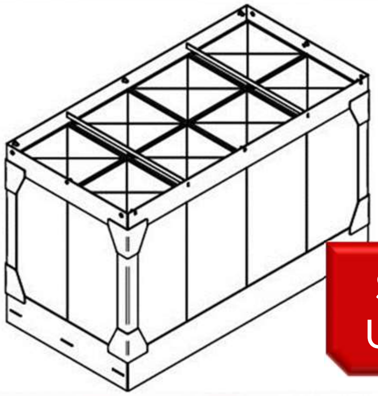
- 90° Orientation from Top to Bottom Sublayer
- Increases Pluggage Risk



Parallel Plate Sublayer Orientation Plan View

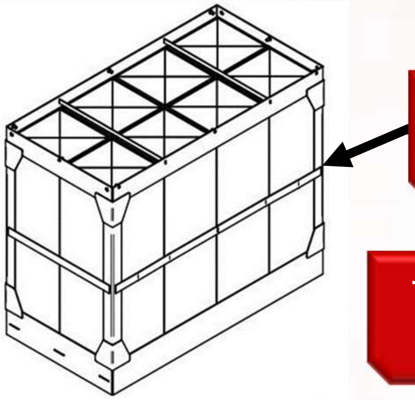
- Parallel Orientation
- Reduces Risk of Pluggage Between Sublayers
- Equivalent Chemical Performance

Single Layer Plate Design Minimizing Pluggage Potential and Pressure Drop



Single Sublayer
Up To 1000 mm

- Single Length of Catalyst Top to Bottom
- Conservative Design
- Cleaning Energy Reaches Top to Bottom
- Eliminates Sublayer Pluggage
- Easier to Pass Large Particle Ash (LPA)
- Lowest Pluggage and Minimal Long Term Pressure Drop



Gap Between
Sublayers

Two Sublayer
Design

- Two Sublayers With Gap Between
- Cleaning Energy Dissipates in Gap
- LPA Can Lodge in Sublayer
- Pluggage Potentially Builds in Sublayer
- Less Certain Long Term Pressure Drop
- More Susceptible to Non-Uniform Flow Conditions

Pluggage Reduction Varies

- Results vary on case by case basis
  - How long has catalyst been plugged?
  - Nature of pluggage (friable ash, LPA, unburned carbon)
  - Mechanical condition of the catalyst
  - Experience of crews performing work
  - Owner oversight

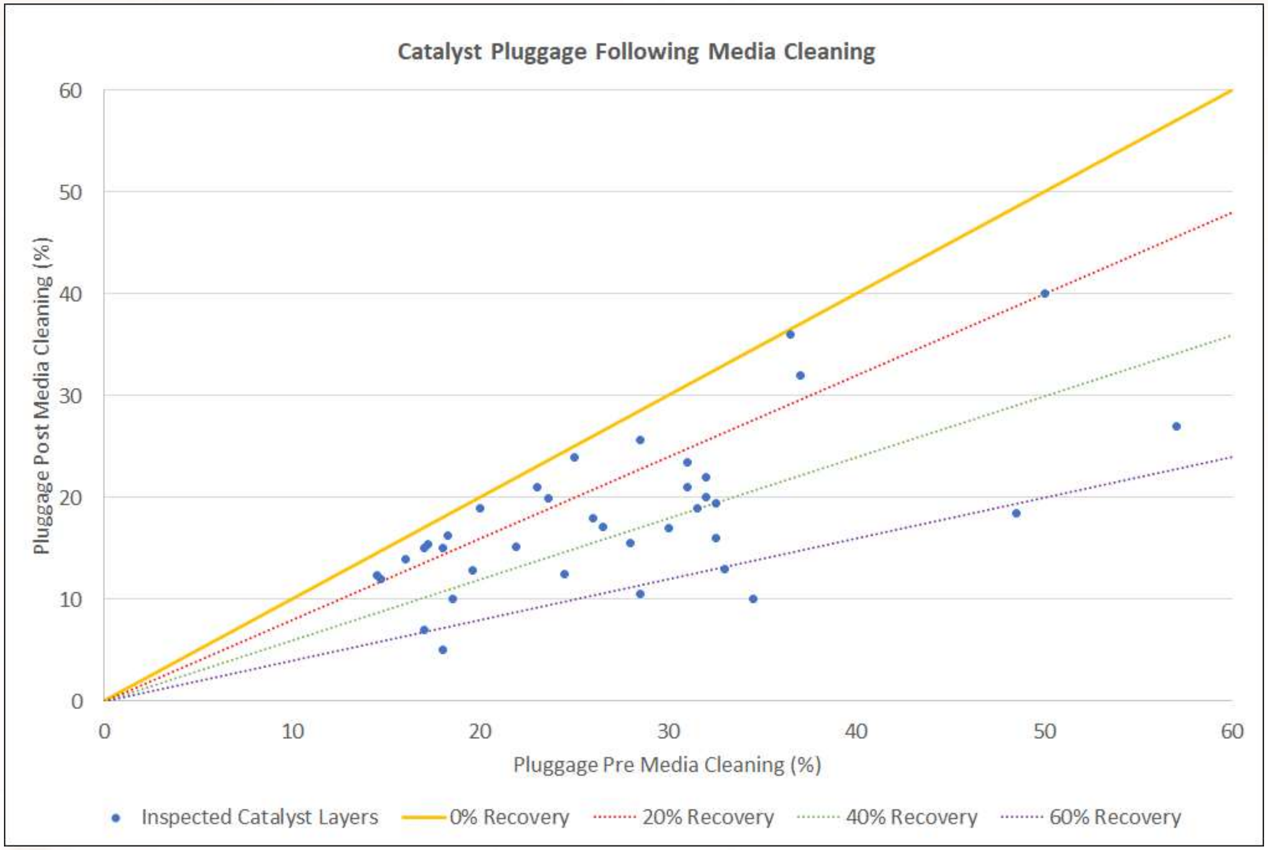
A detailed pre- and post-cleaning pluggage assessment is necessary to confirm pluggage improvement

Verify with Pressure Drop Trends!

Realistic Expectations

- A thorough cleaning can reduce pluggage by approximately 30% to 40%
  - i.e. a 20% plugged layer may be 12% to 14% following cleaning
- Modules > 80% or < 10% plugged may not be effective use of time
  - Too ‘set-up’
  - More risk of damaging the catalyst than potential pluggage gains
  - 20% to 60% modules seem to have best improvement
  - Cost vs. Benefit/Risk

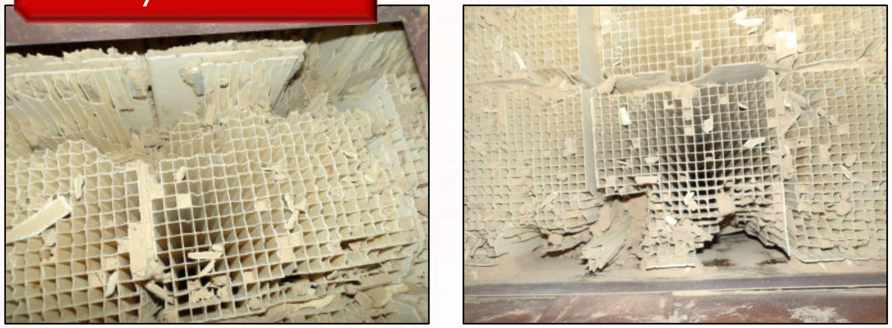
Media Cleaning Recovery Data



Do the Benefits Outweigh Costs & Risks?

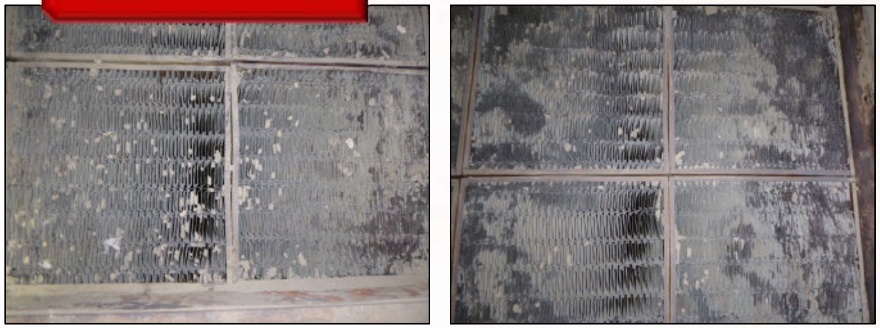
Media Cleaning has Obvious Benefits but is no Panacea

Honeycomb Case



- 7.4 mm Pitch HC Layer
- ~40,000 hours of operation, very set-up ash
- Equal cleaning time on all catalyst (regardless of condition)
- Minimal Pluggage Reduction, from 28% to 26%
- Significant damage to catalyst <10% plugged *initially*

Plate Case

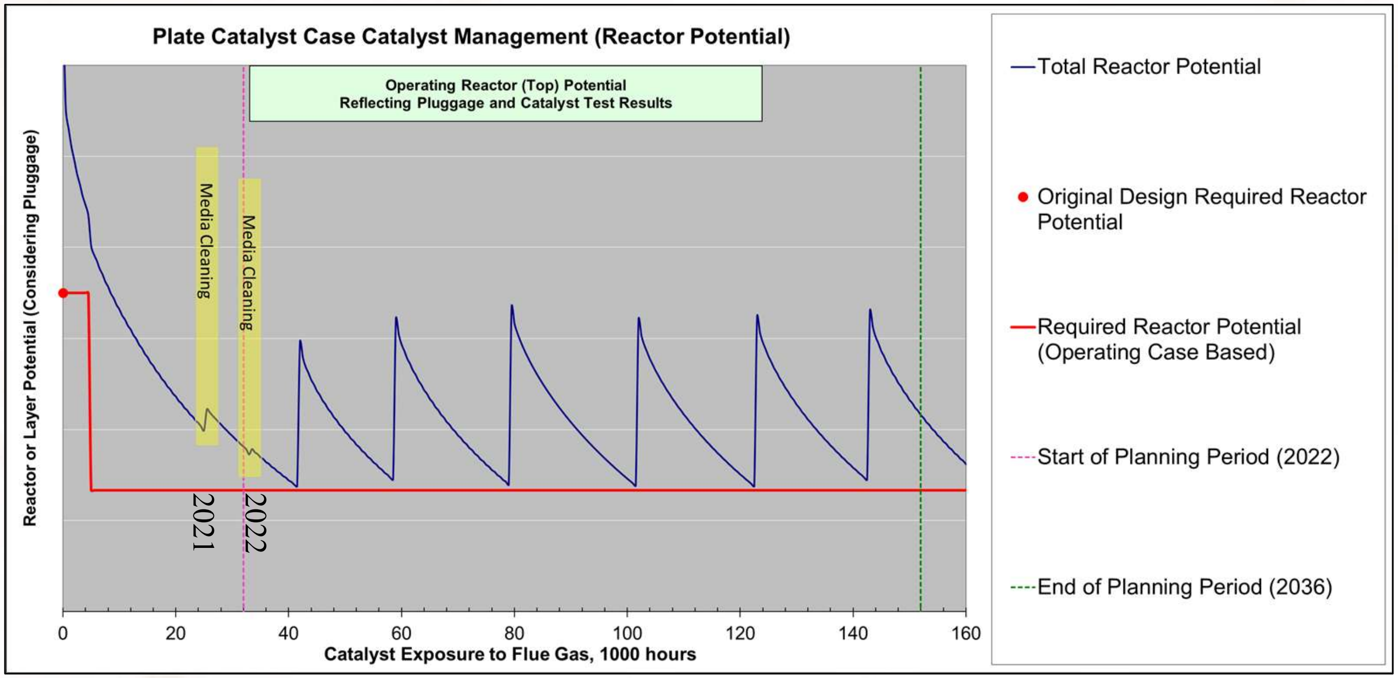


- 7 mm Pitch 2 x 625 mm Plate
- 2021 Cleaning Reduced Pluggage from 23% to 15%
  - Pushed Material into Sublayer Gap
  - Minor Catalyst Damage
- 2022 Cleaning Reduced 20% to 17%

Do the Benefits Outweigh Costs & Risks?

Plate Case (from previous slide)

- 7 mm Pitch 2 x 625 mm Plate
- 2021 Media Cleaning Reduced Pluggage from 23% to 15%
- 2022 Media Cleaning Reduced 20% to 17%



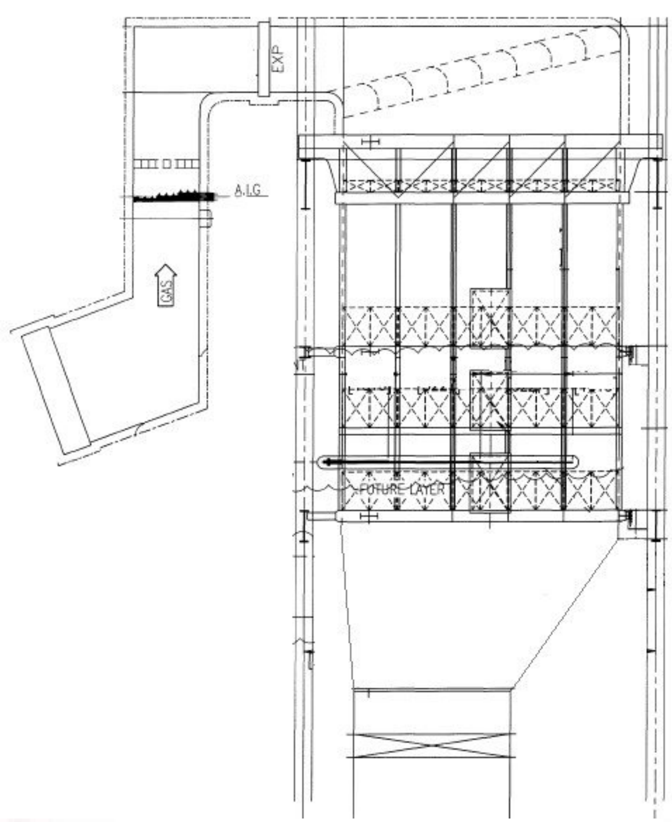
2021 Media Cleaning Improved the CMP

2022 Media Cleaning had Negligible Impact

Nebraska City Unit 2 Case Example

- 740 MW Commercial Operation 2009
- 100% PRB Coal Fired
- PC Boiler
- Low NOx Burners
- SCR
- Spray Dry Absorber/Fabric Filter
- Powder Activated Carbon-Injection

Nebraska City Unit 2 SCR Design



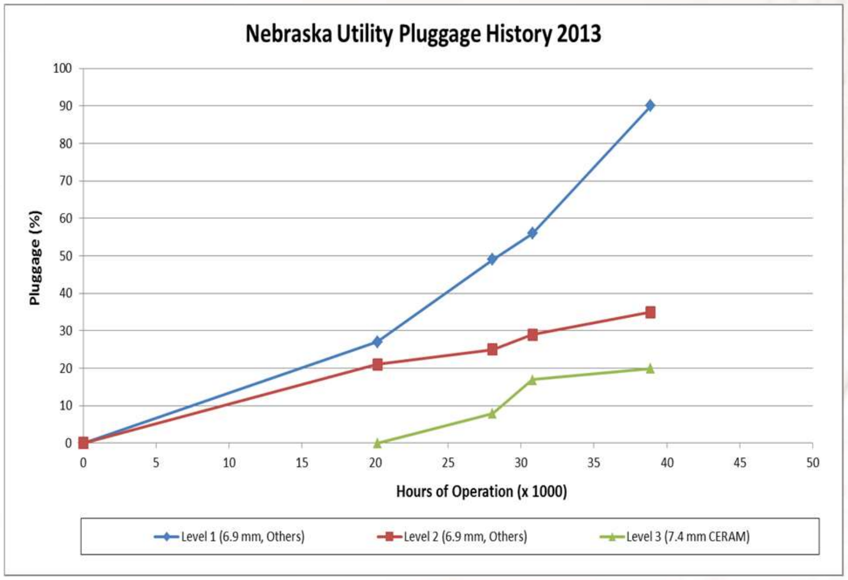
- High Dust
- 2+1 Layer Arrangement
- 2 Reactors
- Square Hood

Nebraska City SCR

Initial Operation: What Went Wrong?

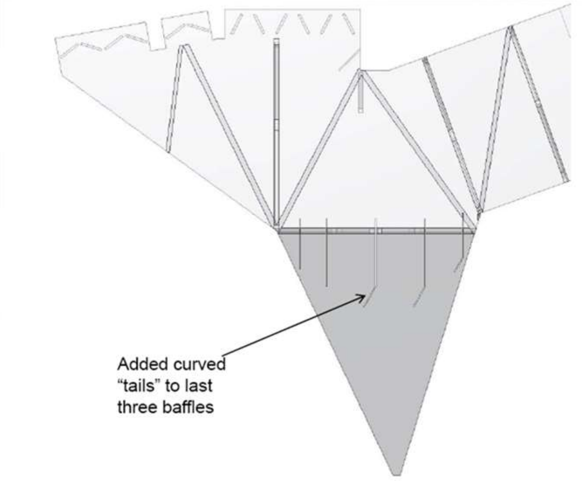
1) Poor flow Distribution Through the Reactor, LPA Accumulation on Covergrates
2) Aggressive Catalyst Design by Other Honeycomb Supplier
   - 6.9 mm Pitch Catalyst (Aggressive for PRB)
3) Thin Wall Catalyst (0.6 mm), Pluggage, and Erosion did not Allow for Regeneration
4) Steep Catalyst Deactivation Rates
5) 2 Initial Catalyst Layers (2+1 Reactor)
   - Operated as 3+0 with Frequent Change Outs

Result is Very High Ammonia Slip and Frequent Catalyst Change Outs


Nebraska Utility Pluggage History 2013

CERAM Working with Nebraska City to Optimize CMP

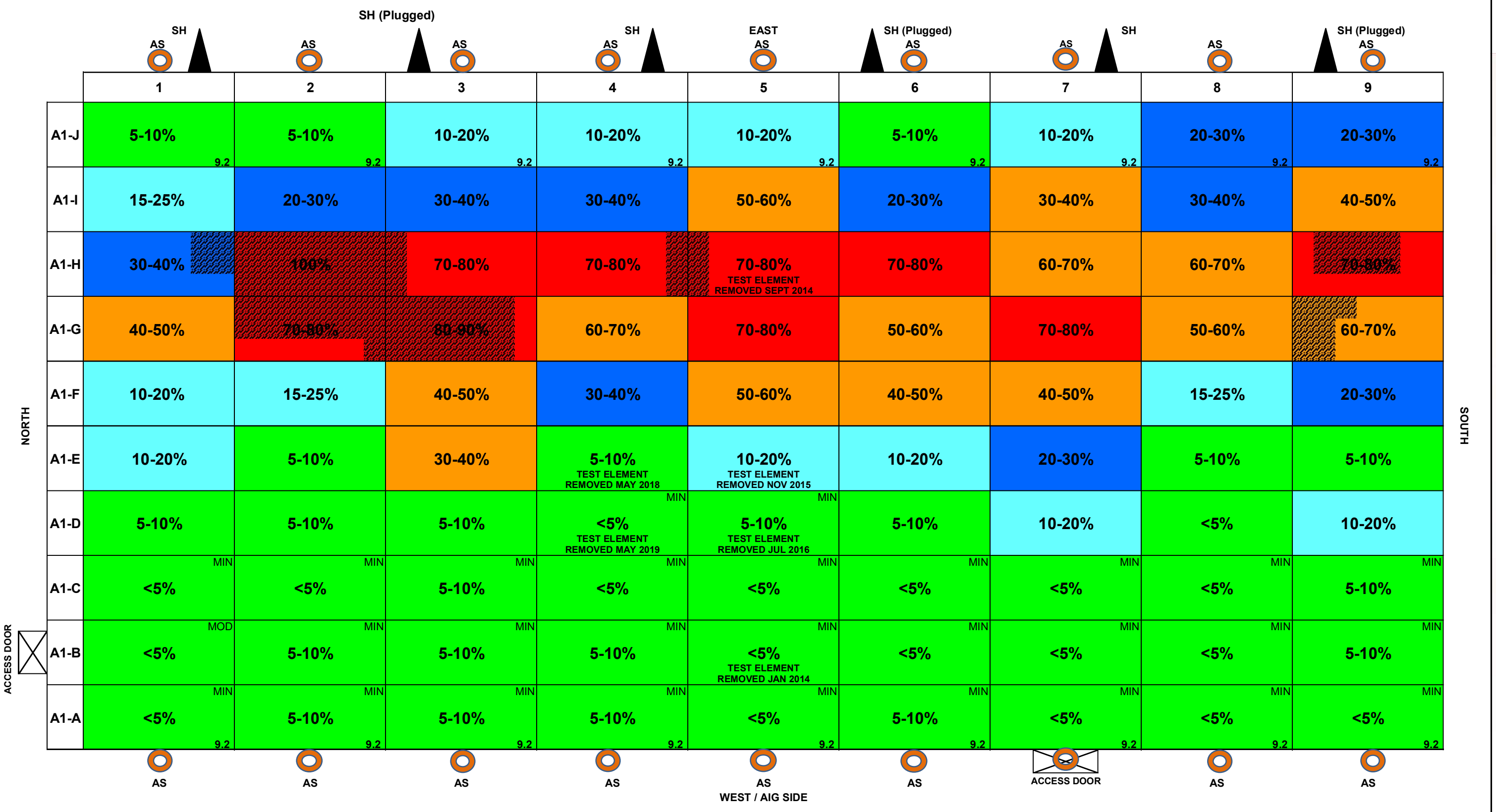
- Develop Catalyst Management Plan to fit Desired Outage Schedule
  - Replace One Layer Every 2 Years
- Transition to Larger Catalyst Pitch (7.4 to 8.2 mm HC)
  - Reduced specific surface area → longer length required
- Improve catalyst cleanliness
  - Flow modeling to improve LPA capture/flow conditions
  - Added air cannons to first layer far wall and near wall
- Future 2 Year Replacement Cycle is Achievable
  - BUT…catalyst pluggage rates critical to maintaining low NH3 Slip



2021 Cleaning Issues

- Severe damage done to North top layer honeycomb catalyst
- ID fan OFF due to large DCS upgrade
- Inexperienced crew - foreman had experience
- Low visibility due to ID Fans being off
- Cleaning wand angled, not perpendicular
- Damage noticed prior to starting south top layer

Omaha Public Power District - Nebraska City Unit 2
A Side - First Catalyst Level (8.2/9.2 mm pitch)
May 2, 2019



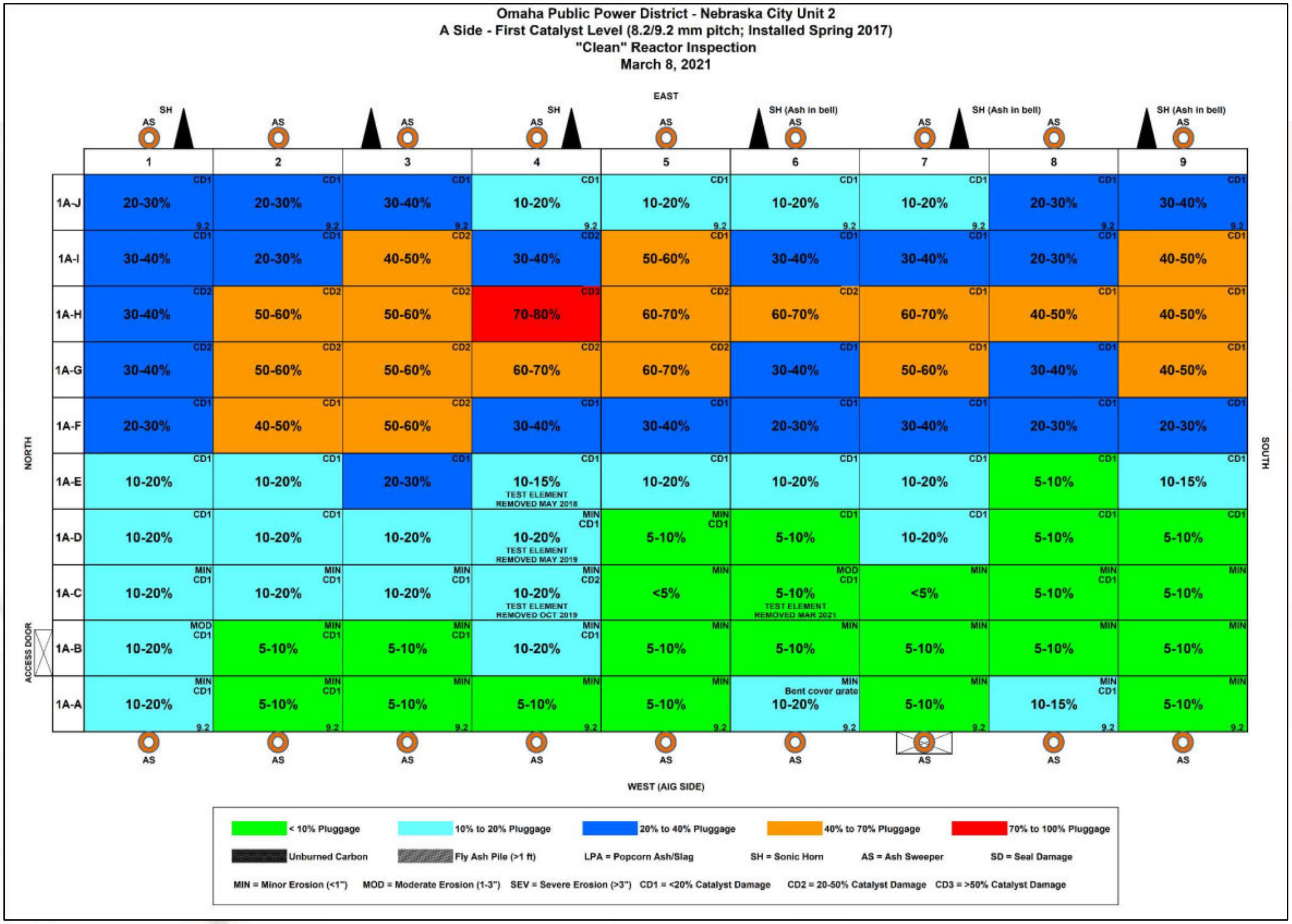
	1	2	3	4	5	6	7	8	9
A1-J	5-10% 9.2	5-10% 9.2	10-20% 9.2	10-20% 9.2	10-20% 9.2	5-10% 9.2	10-20% 9.2	20-30% 9.2	20-30% 9.2
A1-I	15-25%	20-30%	30-40%	30-40%	50-60%	20-30%	30-40%	30-40%	40-50%
A1-H	30-40%	100%	70-80%	70-80%	70-80% TEST ELEMENT REMOVED SEPT 2014	70-80%	60-70%	60-70%	70-80%
A1-G	40-50%	70-80%	80-90%	60-70%	70-80%	50-60%	70-80%	50-60%	60-70%
A1-F	10-20%	15-25%	40-50%	30-40%	50-60%	40-50%	40-50%	15-25%	20-30%
A1-E	10-20%	5-10%	30-40%	5-10% TEST ELEMENT REMOVED MAY 2018	10-20% TEST ELEMENT REMOVED NOV 2015	10-20%	20-30%	5-10%	5-10%
A1-D	5-10%	5-10%	5-10%	MIN <5% TEST ELEMENT REMOVED MAY 2019	MIN 5-10% TEST ELEMENT REMOVED JUL 2016	5-10%	10-20%	<5%	10-20%
A1-C	MIN <5%	MIN <5%	MIN 5-10%	MIN <5%	MIN <5%	MIN <5%	MIN <5%	MIN <5%	MIN 5-10%
A1-B	MOD <5%	MIN 5-10%	MIN 5-10%	MIN 5-10%	MIN <5% TEST ELEMENT REMOVED JAN 2014	MIN <5%	MIN <5%	MIN <5%	MIN 5-10%
A1-A	MIN <5% 9.2	MIN 5-10% 9.2	MIN 5-10% 9.2	MIN 5-10% 9.2	MIN <5% 9.2	MIN 5-10% 9.2	MIN <5% 9.2	MIN <5% 9.2	MIN <5% 9.2

🟩 < 10% Pluggage
🟦 10% to 20% Pluggage
🟦 20% to 40% Pluggage
🟧 40% to 70% Pluggage
🟥 70% to 100% Pluggage
▩ Unburned Carbon
▨ Fly Ash Pile (>1 ft)
LPA = Popcorn Ash/Slag
SH = Sonic Horn
AS = Ash Sweeper
SD = Seal Damage
MIN = Minor Erosion
MOD = Moderate Erosion

Your Energy Partner®

Omaha Public Power District

26%
Plugged



Omaha Public Power District - Nebraska City Unit 2
A Side - First Catalyst Level (8.2/9.2 mm pitch; Installed Spring 2017)
"Clean" Reactor Inspection
March 8, 2021

	1	2	3	4	5	6	7	8	9
1A-J	CD1 20-30% 9.2	CD1 20-30% 9.2	CD1 30-40% 9.2	CD1 10-20% 9.2	CD1 10-20% 9.2	CD1 10-20% 9.2	CD1 10-20% 9.2	CD1 20-30% 9.2	CD1 30-40% 9.2
1A-I	CD1 30-40%	CD1 20-30%	CD2 40-50%	CD2 30-40%	CD1 50-60%	CD1 30-40%	CD1 30-40%	CD1 20-30%	CD1 40-50%
1A-H	CD2 30-40%	CD2 50-60%	CD2 50-60%	CD3 70-80%	CD2 60-70%	CD2 60-70%	CD1 60-70%	CD1 40-50%	CD1 40-50%
1A-G	CD2 30-40%	CD2 50-60%	CD2 50-60%	CD2 60-70%	CD2 60-70%	CD1 30-40%	CD1 50-60%	CD1 30-40%	CD1 40-50%
1A-F	CD1 20-30%	CD1 40-50%	CD2 50-60%	CD1 30-40%	CD1 30-40%	CD1 20-30%	CD1 30-40%	CD1 20-30%	CD1 20-30%
1A-E	CD1 10-20%	CD1 10-20%	CD1 20-30%	CD1 10-15% TEST ELEMENT REMOVED MAY 2018	CD1 10-20%	CD1 10-20%	CD1 10-20%	CD1 5-10%	CD1 10-15%
1A-D	CD1 10-20%	CD1 10-20%	10-20%	MIN CD1 10-20% TEST ELEMENT REMOVED MAY 2019	MIN CD1 5-10%	CD1 5-10%	CD1 10-20%	CD1 5-10%	CD1 5-10%
1A-C	MIN CD1 10-20%	MIN CD1 10-20%	MIN CD1 10-20%	MIN CD2 10-20% TEST ELEMENT REMOVED OCT 2019	MIN <5%	MOD CD1 5-10% TEST ELEMENT REMOVED MAR 2021	MIN <5%	MIN CD1 5-10%	MIN 5-10%
1A-B	MOD CD1 10-20%	MIN CD1 5-10%	MIN CD1 5-10%	MIN CD1 10-20%	MIN 5-10%	MIN 5-10%	MIN 5-10%	MIN 5-10%	MIN 5-10%
1A-A	MIN CD1 10-20% 9.2	MIN CD1 5-10% 9.2	MIN 5-10% 9.2	MIN 5-10% 9.2	MIN 5-10% 9.2	MIN Bent cover grate 10-20% 9.2	MIN 5-10% 9.2	MIN CD1 10-15% 9.2	MIN 5-10% 9.2
	AS	AS	AS	AS	AS	AS	AS	AS	AS

🟩 < 10% Pluggage
🟦 10% to 20% Pluggage
🟦 20% to 40% Pluggage
🟧 40% to 70% Pluggage
🟥 70% to 100% Pluggage
⬛ Unburned Carbon
▨ Fly Ash Pile (>1 ft)
LPA = Popcorn Ash/Slag
SH = Sonic Horn
AS = Ash Sweeper
SD = Seal Damage
MIN = Minor Erosion (<1")
MOD = Moderate Erosion (1-3")
SEV = Severe Erosion (>3")
CD1 = <20% Catalyst Damage
CD2 = 20-50% Catalyst Damage
CD3 = >50% Catalyst Damage

ceram USA

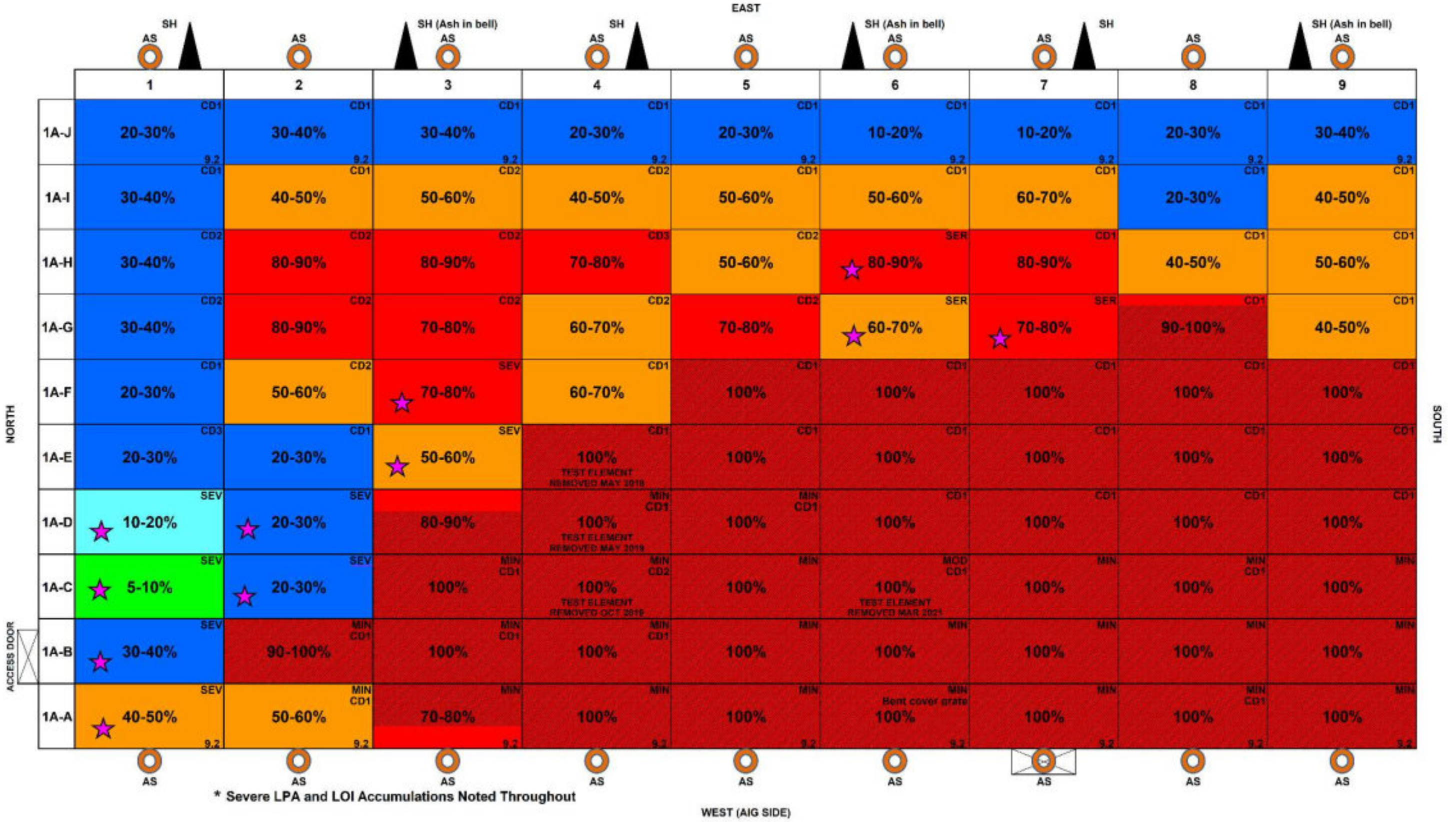
Your Energy Partner®
OPPD
Omaha Public Power District

26% Plugged

75 of 90 Modules had Moderate to Severe Damage from Media Cleaning

Layer no longer good candidate for Regeneration

Omaha Public Power District - Nebraska City Unit 2
A Side - First Catalyst Level (8.2/9.2 mm pitch; Installed Spring 2017)
"Dirty" Reactor Inspection
November 2, 2021



	1	2	3	4	5	6	7	8	9
1A-J	CD1 20-30% 9.2	CD1 30-40% 9.2	CD1 30-40% 9.2	CD1 20-30% 9.2	CD1 20-30% 9.2	CD1 10-20% 9.2	CD1 10-20% 9.2	CD1 20-30% 9.2	CD1 30-40% 9.2
1A-I	CD1 30-40%	CD1 40-50%	CD2 50-60%	CD2 40-50%	CD1 50-60%	CD1 50-60%	CD1 60-70%	CD1 20-30%	CD1 40-50%
1A-H	CD2 30-40%	CD2 80-90%	CD2 80-90%	CD3 70-80%	CD2 50-60%	SER ★ 80-90%	CD1 80-90%	CD1 40-50%	CD1 50-60%
1A-G	CD2 30-40%	CD2 80-90%	CD2 70-80%	CD2 60-70%	CD2 70-80%	SER ★ 60-70%	SER ★ 70-80%	CD1 90-100%	CD1 40-50%
1A-F	CD1 20-30%	CD2 50-60%	SEV ★ 70-80%	CD1 60-70%	CD1 100%	CD1 100%	CD1 100%	CD1 100%	CD1 100%
1A-E	CD3 20-30%	CD1 20-30%	SEV ★ 50-60%	CD1 100% TEST ELEMENT REMOVED MAY 2018	CD1 100%	CD1 100%	CD1 100%	CD1 100%	CD1 100%
1A-D	SEV ★ 10-20%	SEV ★ 20-30%	80-90%	MIN CD1 100% TEST ELEMENT REMOVED MAY 2019	MIN CD1 100%	CD1 100%	CD1 100%	CD1 100%	CD1 100%
1A-C	SEV ★ 5-10%	SEV ★ 20-30%	MIN CD1 100%	MIN CD2 100% TEST ELEMENT REMOVED OCT 2019	MIN 100%	MOD CD1 100% TEST ELEMENT REMOVED MAR 2021	MIN 100%	MIN CD1 100%	MIN 100%
1A-B	SEV ★ 30-40%	MIN CD1 90-100%	MIN CD1 100%	MIN CD1 100%	MIN 100%	MIN 100%	MIN 100%	MIN 100%	MIN 100%
1A-A	SEV ★ 40-50% 9.2	MIN CD1 50-60% 9.2	MIN 70-80% 9.2	MIN 100% 9.2	MIN 100% 9.2	MIN Bent cover grate 100% 9.2	MIN 100% 9.2	MIN CD1 100% 9.2	MIN 100% 9.2

* Severe LPA and LOI Accumulations Noted Throughout

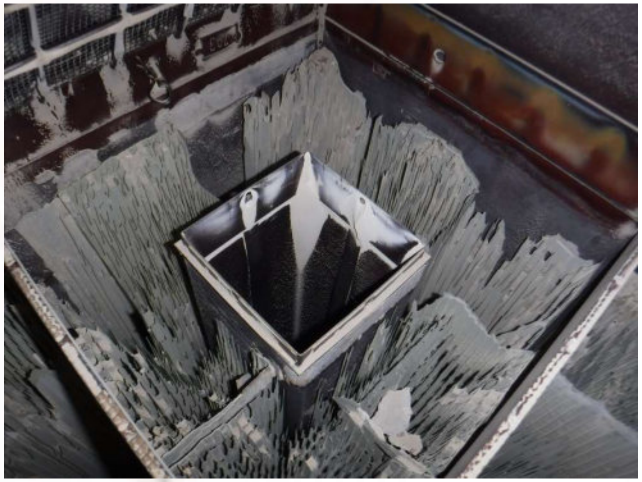
🟩 < 10% Pluggage
🟦 10% to 20% Pluggage
🟦 20% to 40% Pluggage
🟧 40% to 70% Pluggage
🟥 70% to 100% Pluggage

★ Requires Perf Plate
▨ Fly Ash Pile (>1 ft)
SH = Sonic Horn
AS = Ash Sweeper
SD = Seal Damage

MIN = Minor Erosion (<1")
MOD = Moderate Erosion (1-3")
SEV = Severe Erosion (>3")
CD1 = <20% Catalyst Damage
CD2 = 20-50% Catalyst Damage
CD3 = >50% Catalyst Damage

71%
Plugged

Popcorn ash accumulation event due to plugged economizer hopper

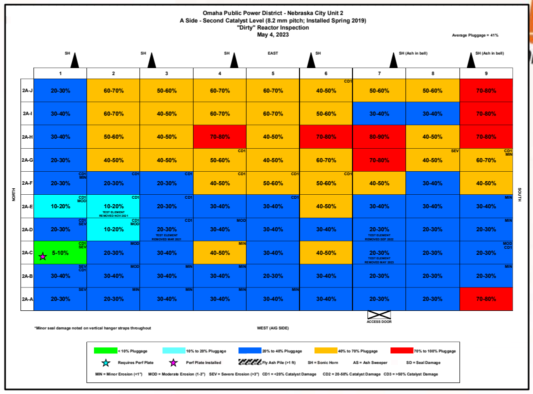


2023 Outage Media Cleaning

- DON'T REPEAT 2021
- Original SCR Cleaning Plan:
    - Dates: 5/17 – 5/19
    - Previously used company from 2021
    - ID Fans ON for draft to help with visibility
- Actual SCR Cleaning:
    - Dates: 5/31 – 6/2
    - New company, first contacted on 5/12
    - ID fans OFF due to SDA coating project
    - 40,000 CFM Mobile baghouse with 20" Flex duct inserted on top of APH
    - Results: visually good, no data to verify yet

2023 Outage Media Cleaning Conclusions

- Media Cleaning Contractor Experience
  - Supervision and Laborer/Craft
  - Site specific technique/settings
- Condition of ash is important
- Focus on low risk/high reward areas
  - Avoid erosion, use pluggage map for guidance
- Seeing the work ensures quality work
  - Third-party mobile baghouse
- Can be a useful means of managing pluggage



Omaha Public Power District - Nebraska City Unit 2
A Side - Second Catalyst Level (8.2 mm pitch; Installed Spring 2019)
"Dirty" Reactor Inspection
May 4, 2023

Average Pluggage = 41%

SH SH SH EAST SH SH (Ash in bell) SH (Ash in bell)

NORTH

	1	2	3	4	5	6	7	8	9
2A-J	20-30%	60-70%	50-60%	60-70%	60-70%	CD1 40-50%	50-60%	50-60%	70-80%
2A-I	30-40%	60-70%	40-50%	60-70%	60-70%	50-60%	30-40%	30-40%	70-80%
2A-H	30-40%	50-60%	40-50%	70-80%	40-50%	70-80%	80-90%	40-50%	70-80%
2A-G	20-30%	40-50%	40-50%	CD1 50-60%	40-50%	60-70%	70-80%	SEV 40-50%	CD1 MIN 60-70%
2A-F	CD1 MIN 20-30%	CD1 20-30%	CD1 20-30%	CD1 40-50%	CD1 50-60%	CD1 50-60%	40-50%	30-40%	40-50%
2A-E	CD1 MOD 10-20%	CD1 10-20% TEST ELEMENT REMOVED NOV 2021	CD1 20-30%	30-40%	CD1 30-40%	40-50%	30-40%	30-40%	MIN 30-40%
2A-D	CD1 SEV 20-30%	CD1 MOD 10-20%	CD1 20-30% TEST ELEMENT REMOVED MAR 2021	MOD 30-40%	30-40%	30-40%	20-30% TEST ELEMENT REMOVED SEP 2022	20-30%	MIN 20-30%
2A-C	CD1 SEV ★ 5-10%	MOD 20-30%	30-40%	MIN 40-50%	30-40%	40-50%	20-30% TEST ELEMENT REMOVED MAY 2023	20-30%	MOD CD1 20-30%
2A-B	SEV CD1 30-40%	MOD 30-40%	MIN 30-40%	MIN 30-40%	20-30%	30-40%	20-30%	20-30%	MIN 20-30%
2A-A	SEV 20-30%	MIN 20-30%	MIN 30-40%	MIN 30-40%	MIN 30-40%	30-40%	20-30%	20-30%	70-80%

SOUTH

ACCESS DOOR

*Minor seal damage noted on vertical hanger straps throughout

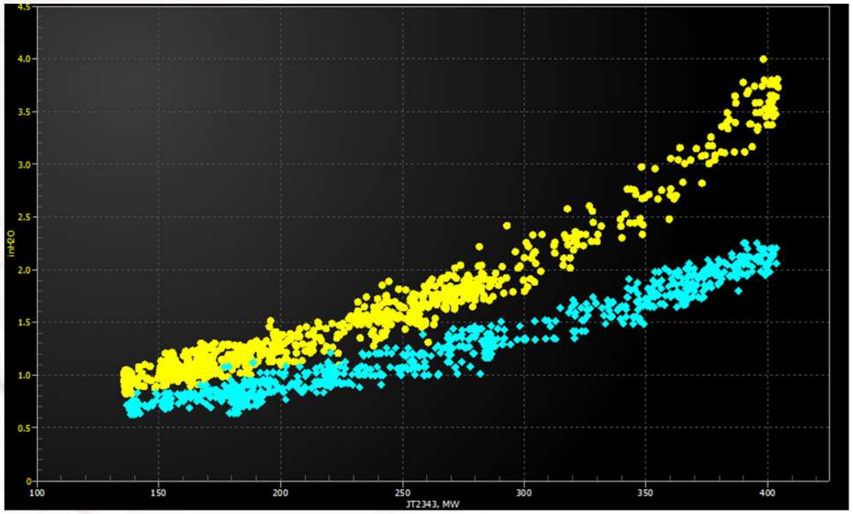
WEST (AIG SIDE)

🟩 < 10% Pluggage
🟦 10% to 20% Pluggage
🟦 20% to 40% Pluggage
🟨 40% to 70% Pluggage
🟥 70% to 100% Pluggage

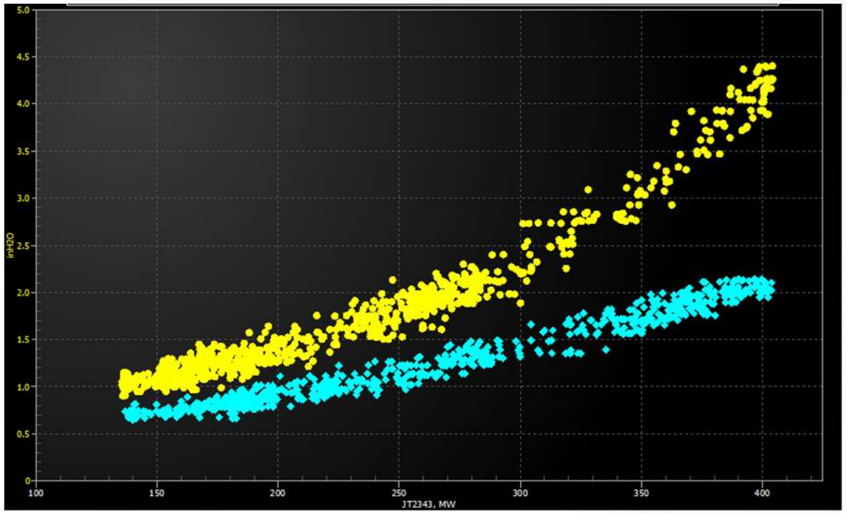
☆ Requires Perf Plate
★ Perf Plate Installed
▨ Fly Ash Pile (>1 ft)
SH = Sonic Horn
AS = Ash Sweeper
SD = Seal Damage

MIN = Minor Erosion (<1") MOD = Moderate Erosion (1-3") SEV = Severe Erosion (>3") CD1 = <20% Catalyst Damage CD2 = 20-50% Catalyst Damage CD3 = >50% Catalyst Damage

Track Improvement with DP Trends



Load vs. DP



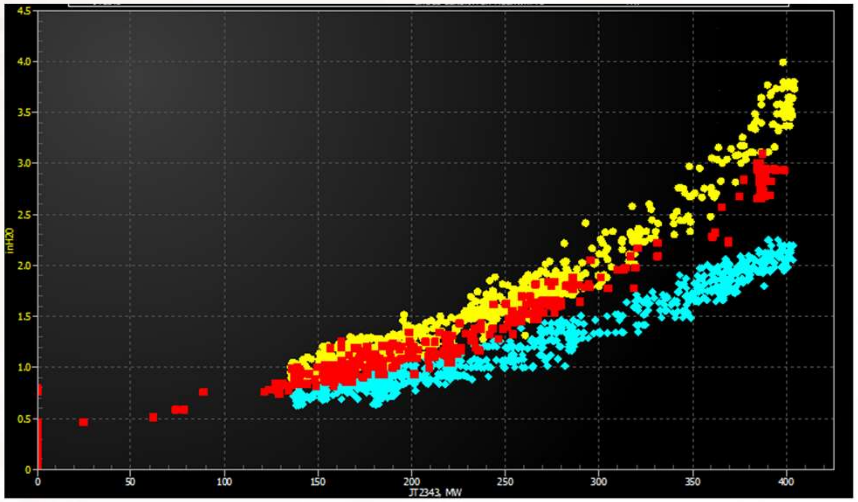
Load vs. DP

Yellow: Pre-Clean

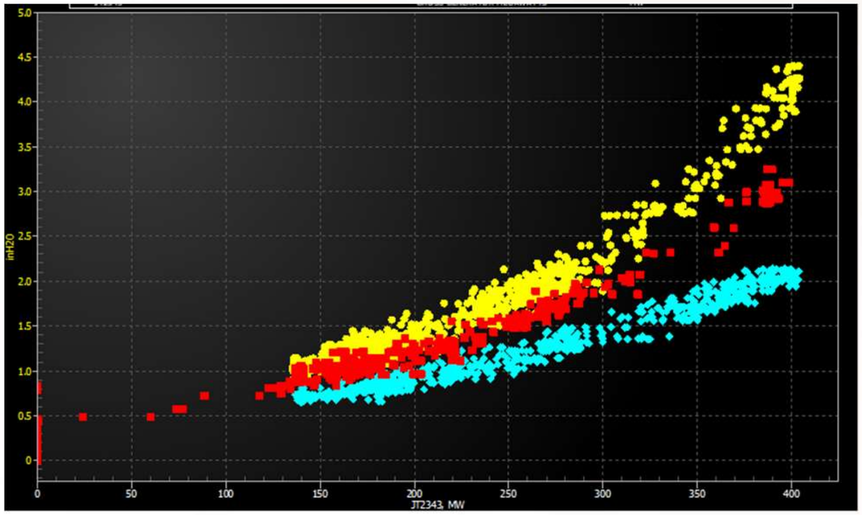
Teal: Post Clean

Continue to Track

Load vs. DP



Load vs. DP

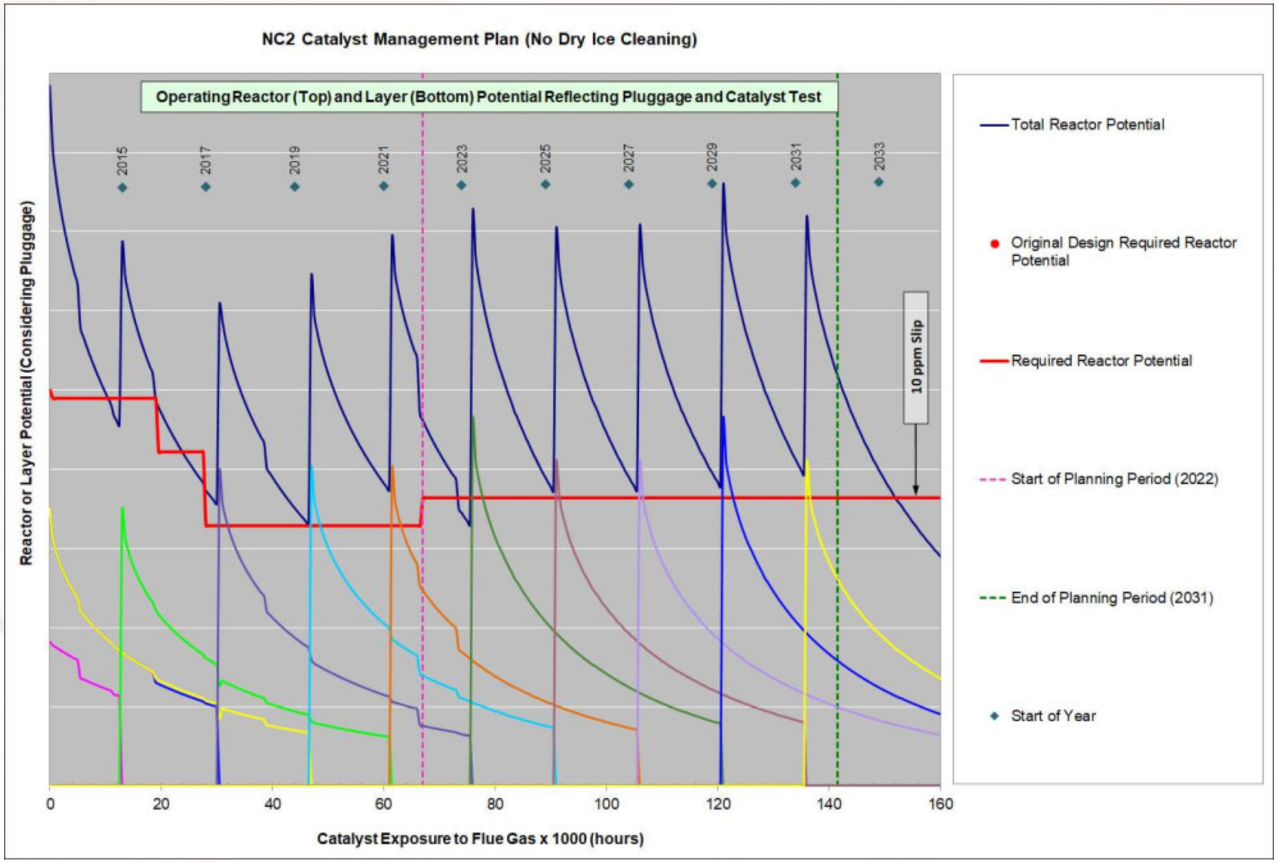


Yellow: Pre-Clean

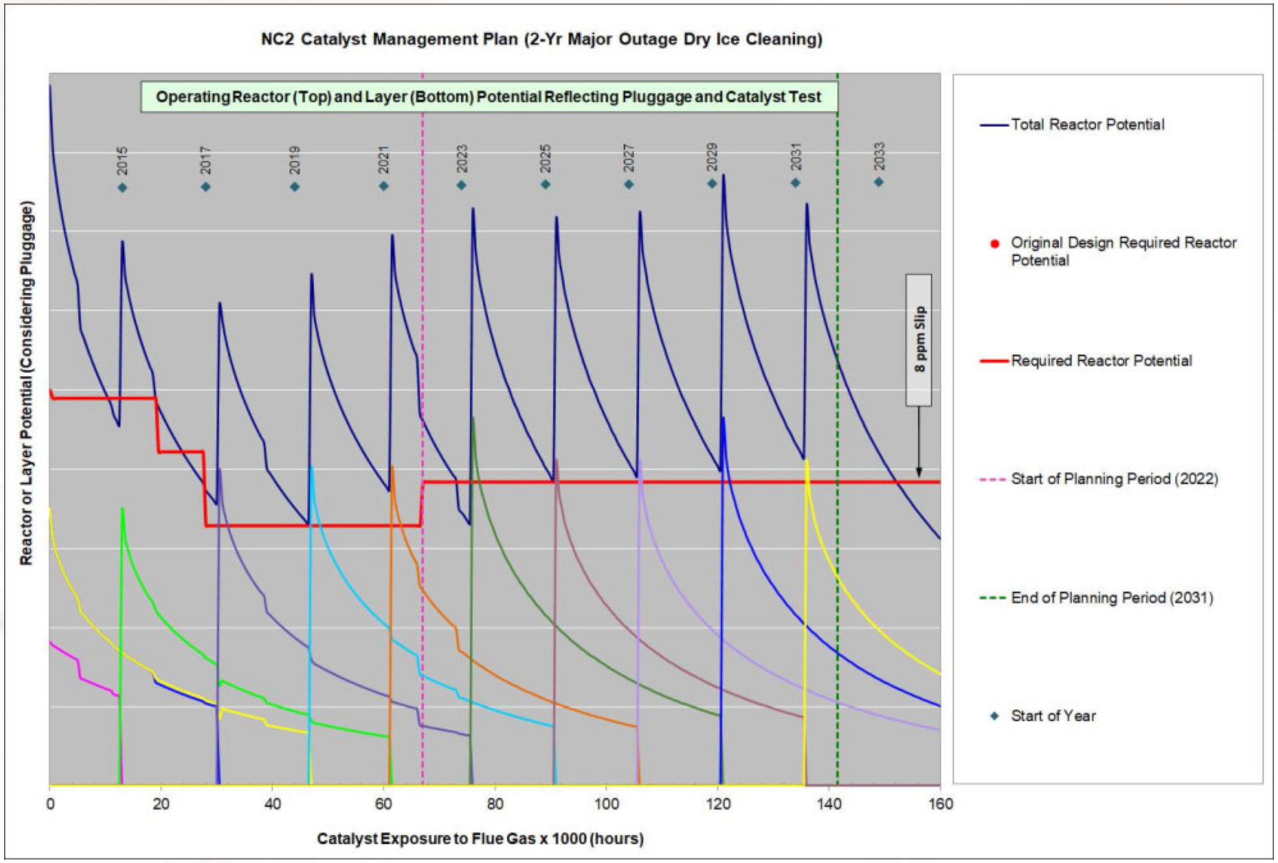
Teal: Post Clean

Red: After 2 Months

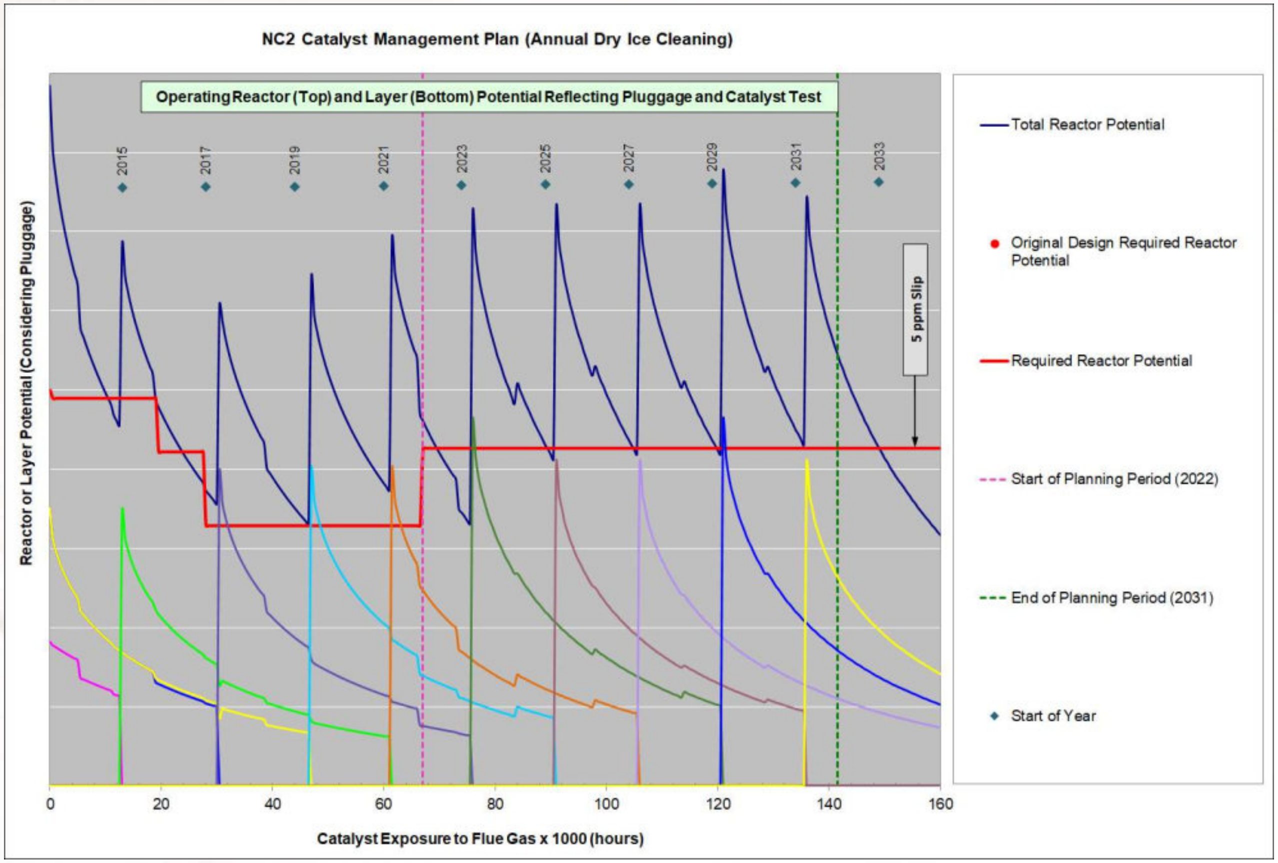
CMP – No Dry Ice Cleaning



CMP – Major Outage (2-Yr) Dry Ice Cleaning



CMP – Annual Dry Ice Cleaning



Cost/Risk Analysis – Over 10-Years

Ammonia and Fan Energy	**No DIB (10 ppm NH3 Slip)**	**2-Yr DIB (8 ppm NH3 Slip)**	**Annual DIB (5 ppm NH3 Slip)**
Ammonia Usage (tons)	16,990	16,701	16,268
Ammonia Cost ($)	$6,873,000	$6,757,000	$6,581,000
Ammonia Savings ($)	$0	$116,000	$292,000
Fan Energy Savings ($)	$0	$78,000	$174,000
Total Savings ($)	$0	$194,000	$466,000

- Reduced operational risk with lower NH_3 Slip
  - Air heater, Ammonia in Ash (ash sales), NH3 Odors
- Significant increase in margin for error
  - Unforeseen events (ash pluggage, LPA, combustion NOx, etc.)

Conclusions

- Media cleaning can be an effective tool for removal of catalyst pluggage
- Results depend on key factors
  - The crews performing the work
  - The nature of the pluggage
- Consider realistic expectations when making decisions
  - Confirm actual results on case by case basis
- Incorporate all cleaning methods into the long-term catalyst management plan – Does it make sense?

Your Energy Partner®
OPPD
Omaha Public Power District

Thank you!

Questions???

ceram
usa