Considerations for Catalyst Deactivation and Regeneration When Firing Biomass

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Presenters

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Presentation Topics

- Biomass Defined
- Biomass Market
- Effects on SCR Design
- Plant Examples
- Rejuvenation/Regeneration
- Considerations When Firing Coal/Biomass Blends
- Summary

Define Biomass


Wood Waste

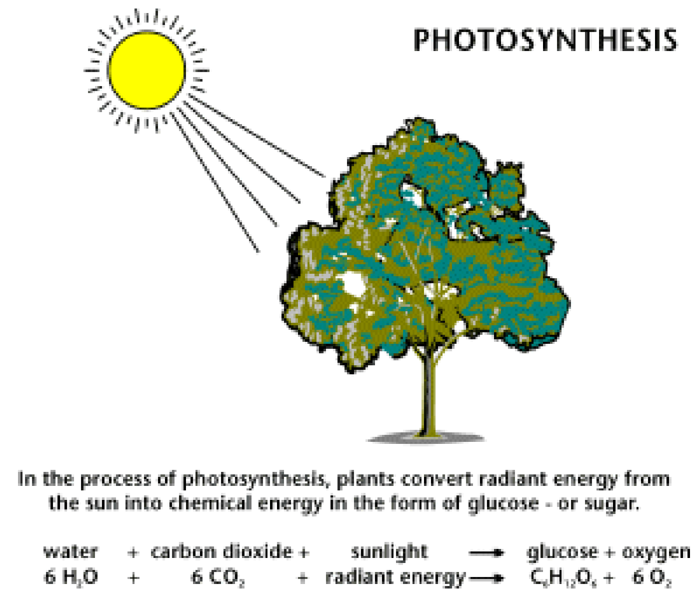
- What is Biomass?
  - US Dept of Energy (DOE) Website:
    - Any Organic Material Made From Plants or Animals
  - DOE Claims Biomass Supplies
    - ≈ 3% of the US Total Energy Consumption
    - Pulp & Paper Mills
    - Electrical Generation (≈ 45-50 million MW from Biomass)
  - Many Different Types
    - Agriculture (e.g., manure, corn stalks, straw, etc.)
    - Forestry Residues (fresh wood, bark, wood chips, brush, etc.)
    - Municipal Wastes (sewage sludge, household waste, yard waste, etc.)
    - Industrial Wastes (hazardous/toxic waste, hospital waste, etc.)
    - Terrestrial & Aquatic Crops (switch grass, algae, etc.)

Define Biomass

- US DOE Defined Four Primary Classes of Biomass Systems
  - Direct-Fired (Similar to Most Fossil Fueled Fired Plants)
    - Biomass Boilers Typically 20-50 MW Range (≈ 20% Efficiency)
  - **Co-Fired (Substitute Biomass for Portion of Coal in Plant)**
    - Economical Since Existing Equipment Typically Used (≈ 35% Efficiency)
    - After "Tuning" Boiler; Reduction in SO_2, NO_x May Be Achievable
    - Co-Firing Rates Typically Limited to 5-20% (Avoid Efficiency Loss)
      - For Example; Using Mills & Firing Green Wood (50% H_2O); Lowers Flame Temperature Reducing kW Generated
  - Gasification
    - Gasifiers Heat Solid Biomass, Forms Flammable Gas
    - Gas Cleaned & Filtered & Used in Combine Cycle Gas Turbine and Steam Turbines (≈ 60% Efficiency)
  - Modular Systems
    - Employ Same Technologies As Above; Smaller Scale
    - Applicable to Farms & Small Industries

Biomass Market

- Attractive Petroleum Alternative
- Attractive to Electrical Generation
  - US DOE Estimates Biomass Could Supply 14% of Power Needs
  - Environmental Benefits
    - Biomass Typically Has Less Than 50% Nitrogen Content of Coal & Higher Moisture Content (Lowering Flame Temp)
    - NO_x Emissions Can Be Reduced (Reduce Smog)
    - Carbon Cycle: No Additional Green House Gases Generated When Burned (CO_2 Released When Burned = CO_2 Captured When Grown)
    - Biomass Crops Can Reduce "Heat Island Effect" of Urban Areas



Biomass Market

- Attractive to Electrical Generation
  - Economic Incentive For Firing Biomass
    - Buyback Rates for Renewable Electricity To Grid
    - Reduce Fuel Costs vs. Energy Consumption (5,000-7,000 Btu/lb vs. 8,000-10,000 Btu/lb)
    - Avoidance of Landfills & Associated Costs
    - Reduce Emissions
  - Economic Offset For Firing Biomass
    - Avoid Loss in Efficiency (High H_2O, Energy to Pulverize, etc.)
    - May Require Changes to Fuel Handling/Feed Systems & Increase in Maintenance Costs
    - Examine Affects on Pollution Controls (e.g., **SCR Catalyst Design & Management**)
- For Further Biomass Information Recommend: US DOE Website, EPRI, National Renewable Energy Laboratory, EU BioEnergy Network, etc.

Wood Pellets

Saw Dust

Biomass "Typical" Constituents

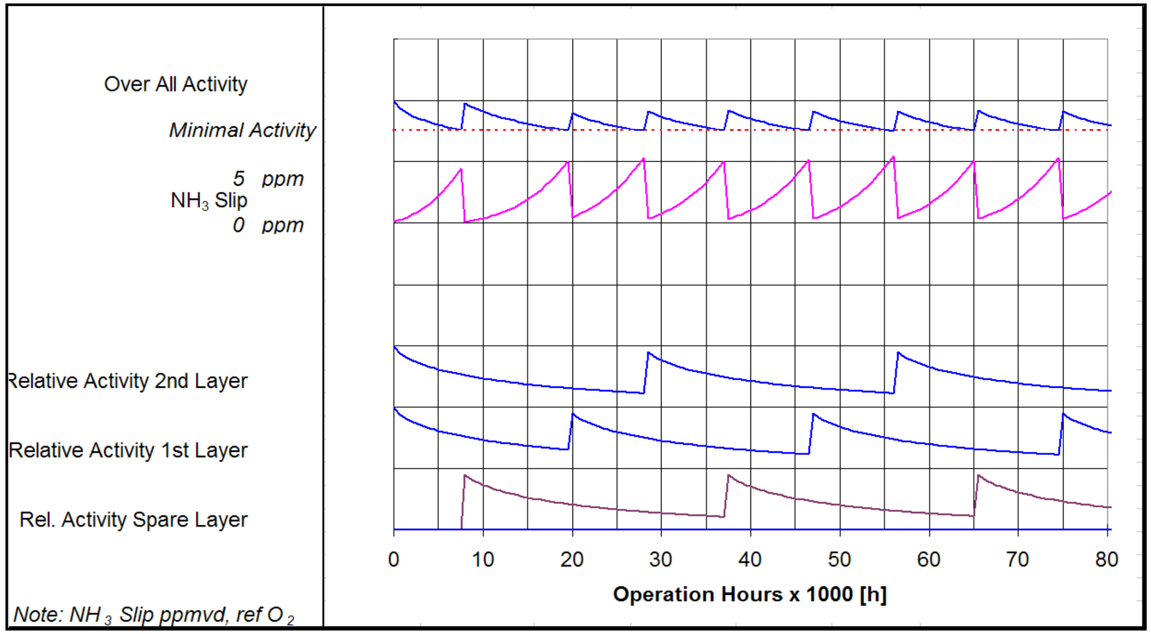
		Concentrations (%)			
Element	**Ash Analysis**	**Wood***	**Corn**	**Sewage Sludge**	**Bone Meal MBM**
Silicon (Si)	SiO_2	20-70	0.5-5	5.6 - 25.7	
Aluminum (Al)	Al_2O_3	5-10	0.1-1	1.1 - 8.5	
Calcium (Ca)	CaO	2-30	0.1-1	1.4 - 42.9	
Sodium (Na)	Na_2O	1-10	0.1-2	0.1 - 0.8	4 - 7
Potassium (K)	K_2O	2-15	10-30	0.3 - 1.6	1.5 - 4
Phosphorus (P)	P_2O_5	1-5	10-60	1.2 - 4.4	25 - 40

- In Fuel Analysis
  - Low Sulfur
  - Low Nitrogen
  - High Moisture

*Consists of pallet grindings, wood chips, mill residue & clean wood waste

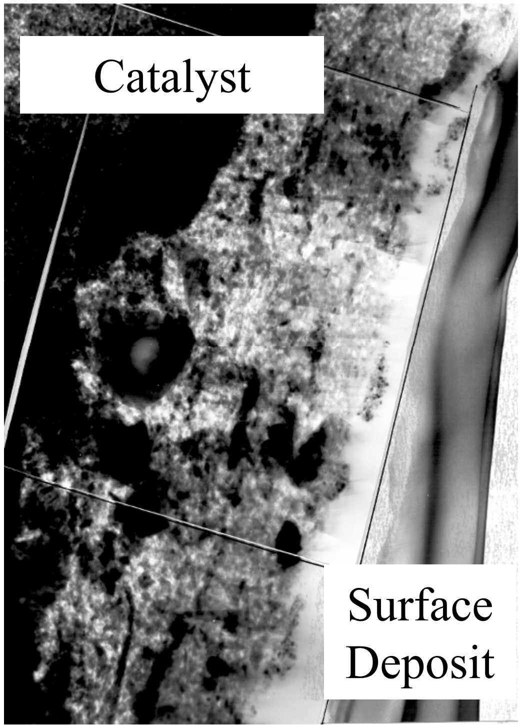
How Does It Affect SCR Catalyst Design?

- Catalyst Design
  - Examine Big 4!!!
    - Deactivation
    - Plugging
    - Erosion
    - Sintering



How Does It Affect SCR Design?

- Deactivation (Biggest Issue!!!)
  - Caused by Exposure to Various Poisons/Masking Agents Formed During Combustion Process
    - Calcium Sulfate, Alkaline Metals, Arsenic, Silica, Sodium, Potassium, Phosphorous, Etc.,
  - Elevated Temps Change Ash Characteristics And Can Cause Deactivation



TEM (60,000 mag; 0.5 µm)

EXTREMLY IMPORANT TO GET ASH, MINERAL AND TRACE ANALYSES!!!

How Does It Affect SCR Design?

- Deactivation (Continue)
  - Different Boiler Types Will Affect Deactivation
    - PC/Cyclone/Stoker Type High Dust Applications for 100% Biomass
      - Increased Deactivation Due to Nature of Ash (Extremely Poisonous!!!)
    - Local Areas of Hot Flame Temps & Incomplete Combustion From Fuel Rich Areas Can Increase Amount of Catalyst Poisons
    - Catalyst Poisons Oxidize & Become Gaseous They Penetrate Active Sites and Deactivate Anyone's Catalyst
    - Three Solutions ($$$):
      - Use Low Dust Arrangement with Lime/Limestone Injection (Boiler or Baghouse)
      - Use Tail End Arrangement
      - Add Substantially More Catalyst

How Does It Affect SCR Design?

- Deactivation (Continue)
  - Different Boiler Types Will Affect Deactivation
    - CFB and/or BFB Types Are Acceptable In High Dust Applications Firing 100% Biomass
      - Lower Flame Temperatures Compared To Other Boiler's; Lower Amount of Catalyst Poisons Oxidized; Better for Catalyst
      - Fuel, Sorbent (Limestone) and Ash Entrained (Ash Produced Less Poisonous)
  - CERAM Has Developed Theoretical and Experimental Methods To Predict These Effects Based on Experience

Plant Simmering (BFB)

How Does It Affect SCR Design?

LPA Screens

- Plugging
  - Catalyst Can Be Plugged By Ash Due to Tenacious Nature of Ash
    - High Potassium Can Make Sticky Ash
  - Remove Large Particle Ash (LPA) and Reduce Unburned Carbon; Use Appropriate Pitch, Catalyst Pluggage Can Be Mitigated
- Erosion
  - Mechanical Catalyst Damage Due To Flow Irregularities, Dust Maldistribution and Plugging Even Though “Softer” Ash
  - Proper Flow Modeling Is Critical
  - Proper Size Pitch and Wall Thickness Selection Is Critical
    - Catalyst Washing/Regeneration
- Sintering
  - All Catalyst Oxidizes Unburned Carbon
  - High Unburned Carbon Results In Pluggage and Possible Fires

How Does It Affect SCR Design?

- Biomass Deactivates Catalyst (Some Lessons Learned for 100% Biomass)
  - Conservative Estimate That Washing May Be Required; Need Sufficient Mechanical Strength (Thick Walls)
    - Potassium, Phosphorus and Highly Alkaline Ash Can Pose Both Pluggage and Deactivation Challenges (Proper Volume and Washing Solves These Issues)
    - During Layup Periods or Outages Due To Hygroscopic Nature of Wood Ash Reactor Must Be Filled With Dry Air (e.g. ≈ 120 ^{o}F)
    - Catalyst Should Be Preheated to ≈ 250 ^{o}F Before First Flue Gas Introduced To Avoid Condensation
    - Operating at Temperatures Greater Than 700 ^{o}F Can Lead To Severe Deactivation Due to High Levels of Potassium In Ash
      - Potassium Lowers Melting Point of Ash, Which Increases Deactivation Rate

KEEP CATALYST WARM & DRY AT ALL TIMES!!!

Plant Examples – Summary Sheet

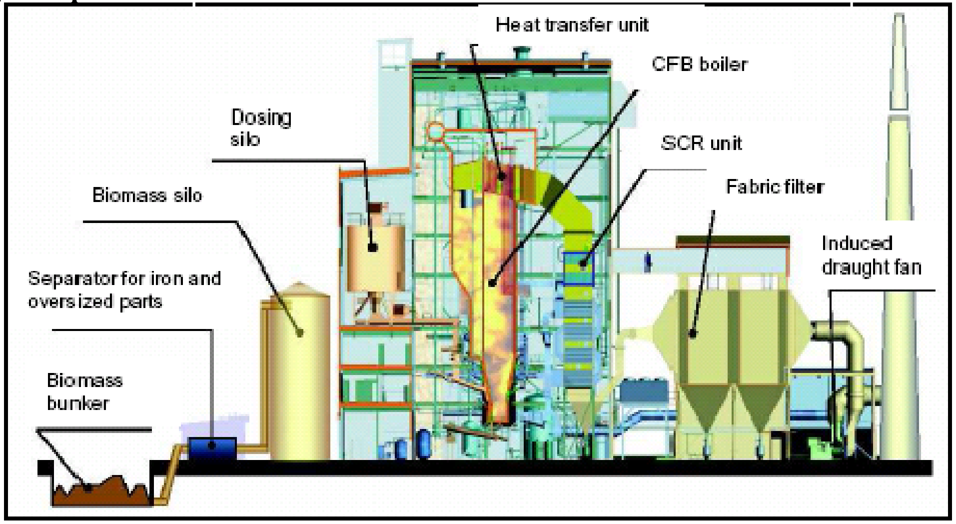
- Presentation Will Focus on the Following Facilities

	Plant Simmering	Dallman 31	Bexbach	Herne	Lünen
Unit Size	65.7 MW	80 MW	775 MW	2 – 150 MW 1 – 300 MW	1 – 150 MW 1 – 350MW
Boiler Type	CFB	Cyclone	PC Tangential	PC U Fired – Wet Bottom	PC Wall Fired PC U Fired
Fuel(s)	Wood Chips	Illinois High Sulfur	Bit. Low Sulfur Biomass (?)	Bit. Waste Coal Bone Meal	Bit. Waste Coal Sewage Sludge Bone Meal
SCR Type	High Dust	High Dust	High Dust	Tailing End	Tailing End
Catalyst Type	Honeycomb	Honeycomb	Honeycomb	Honeycomb	Honeycomb

Plant Simmering Wood Burner Example

- Plant Background
  - Location: Vienna, Austria
  - Austria's Largest Biomass CoGen Plant (CFB Boiler; 65.7 MW Capacity)
  - Fires Wood Chips From Forest Residues (100 mm size maximum)
    - 24 tons/hr Biomass Burned (40 Trucks Per Day
  - SNCR and Catalyst Hybrid (High Dust Application)
    - Originally Only SNCR, But Local Regulations Required More NO_x Removal
- Catalyst Design
  - 41% NO_x Reduction; 5 ppmvd NH_3 Slip
    - Outlet NO_x = 50 mg/Nm^3
    - Permit at 100 mg/Nm^3
  - 7.4 mm Pitch (20 x 20 cell) & 0.8 mm wall thickness
  - Design SO_2/SO_3 Oxidation Rate < 3.0% (NH_3 Off); Temp = 675 F
  - 6 x 2 Module Arrangement; 1+1 Reactor

Simplified Schematic of Simmering



Plant Simmering Wood Burner Example

- SCR Operations
  - Catalyst Exposed ≈ 8,000 hrs
  - Operates at 80 mg/Nm^3 NO_x Outlet
  - Uses Steam Soot Blowers
  - Catalyst Heated Using Dry Air to 266 F Before Flue Gas First Enters Reactor
  - Catalyst Kept Warm & Dry
- Affects of Biomass (Performance Deactivation)
  - Design DeNOx Efficiency Still Achievable
  - Catalyst Testing Will Be Performed When Unit Comes Offline
    - Originally Scheduled In October, But Unit Meeting Emissions

CWLP Dallman Unit 31 Example

- Plant Background
  - B&W Cyclone (80 MW)
  - Design Coal – Illinois (3% Sulfur)
    - 9% Ash, 2-14 ppm Arsenic, 5% CaO
    - 51% SiO_2, 14% Al_2O_3, 0.24% P_2O_5
    - 1.3% Na_2O_3, 1.6% K_2O, etc.
  - SCR High Dust; Operational 2003
- Co-Firing 5% Seed Corn in 2004-05
  - 52% P_2O_5 in Ash of Seed Corn
  - Equates to Adding ≈ 0.5% P_2O_5 To Coal
    - 0.6-1.5% Assuming 30/70 Split & All Phosphorous Converted to P_2O_5
  - Catalyst Design Did Not Account for Co-Firing Biomass
- Unit 31, 32 and 33 Catalyst Interchangeable

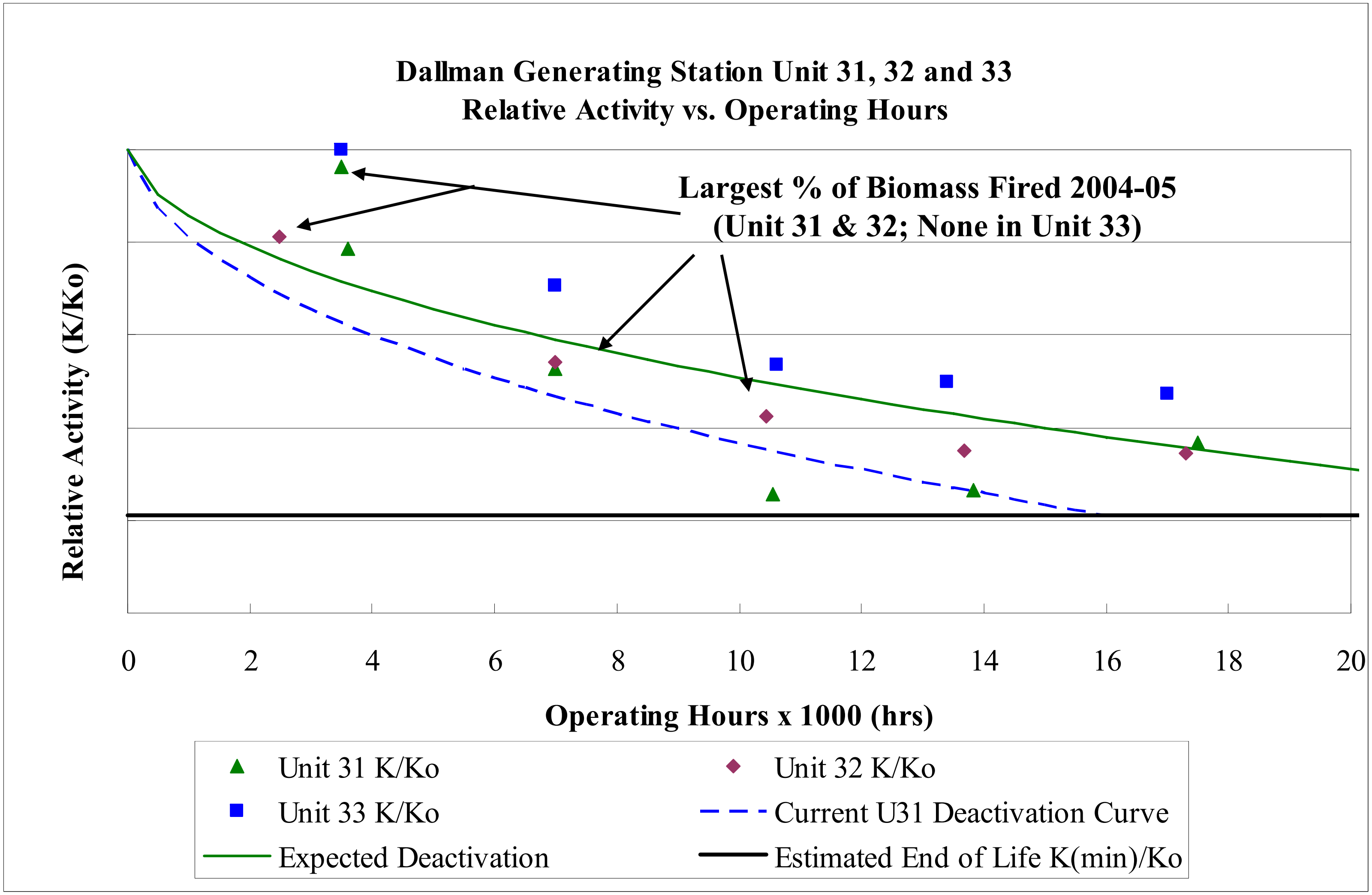

Sister Unit 32

CWLP Dallman Unit 31 Example

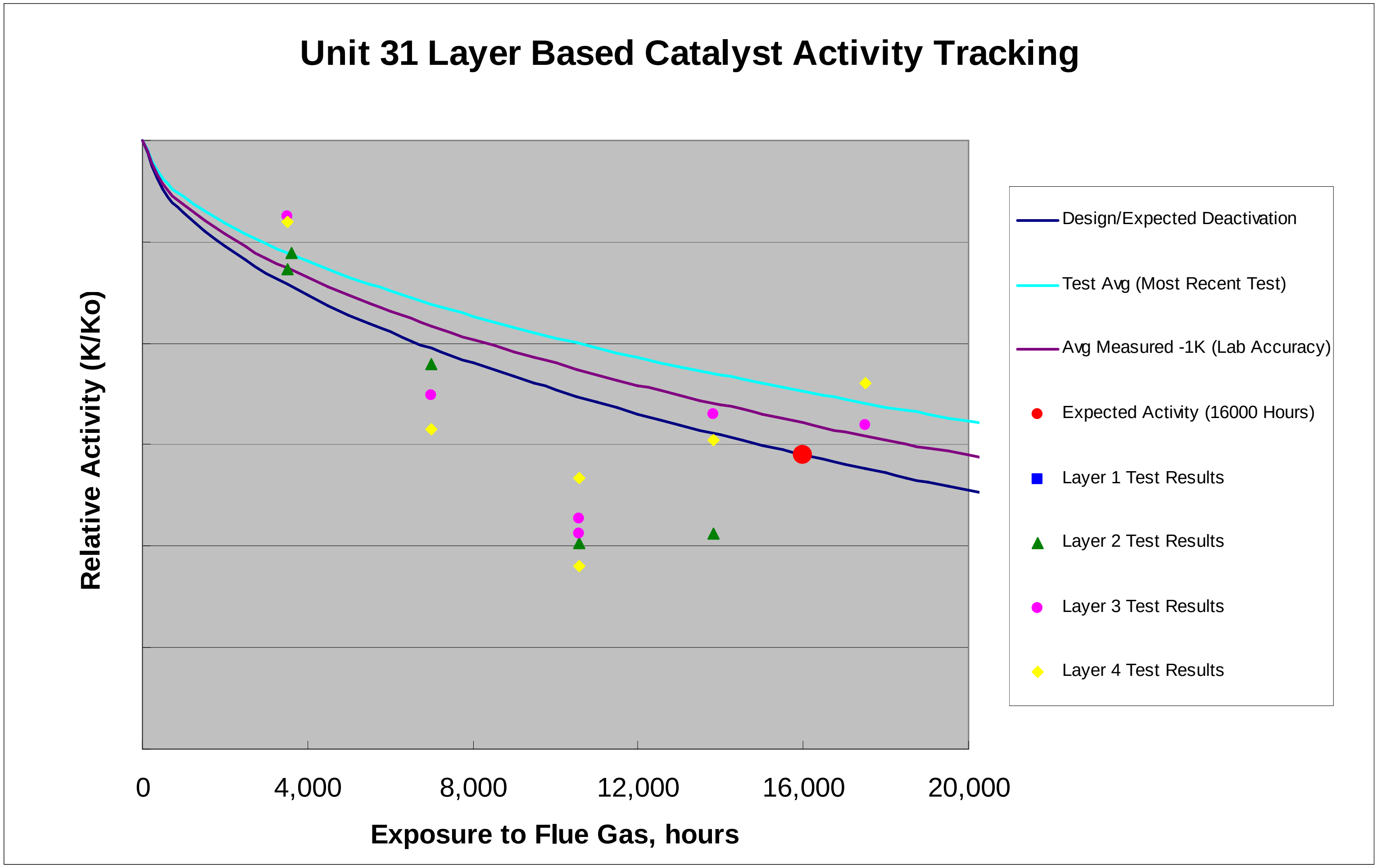
- Catalyst Design
  - 92% NO_x Reduction; 2 ppmvd NH_3 Slip
  - 6.7 mm Pitch (22 x 22 cell) & 0.9 mm wall thickness
  - Design SO_2/SO_3 Oxidation Rate < 0.5% (NH_3 Off); Temp = 700 F
  - 4 x 6 Module Arrangement; 3+1 Reactor
- SCR Operations
  - Layers 2 & 3 Exposed ≈ 17,000 hrs
  - Layer 1 Plugged (≈ 14,000 hrs)
    - Rejuvenated; Now In Unit 32
  - Operates ≥ 92% NO_x Reduction
  - Uses Steam Soot Blowers
  - Reactor Kept Warm & Dry During Non-Ozone Season
  - LPA Pluggage (e.g., slag)

"Dirty" Inspection

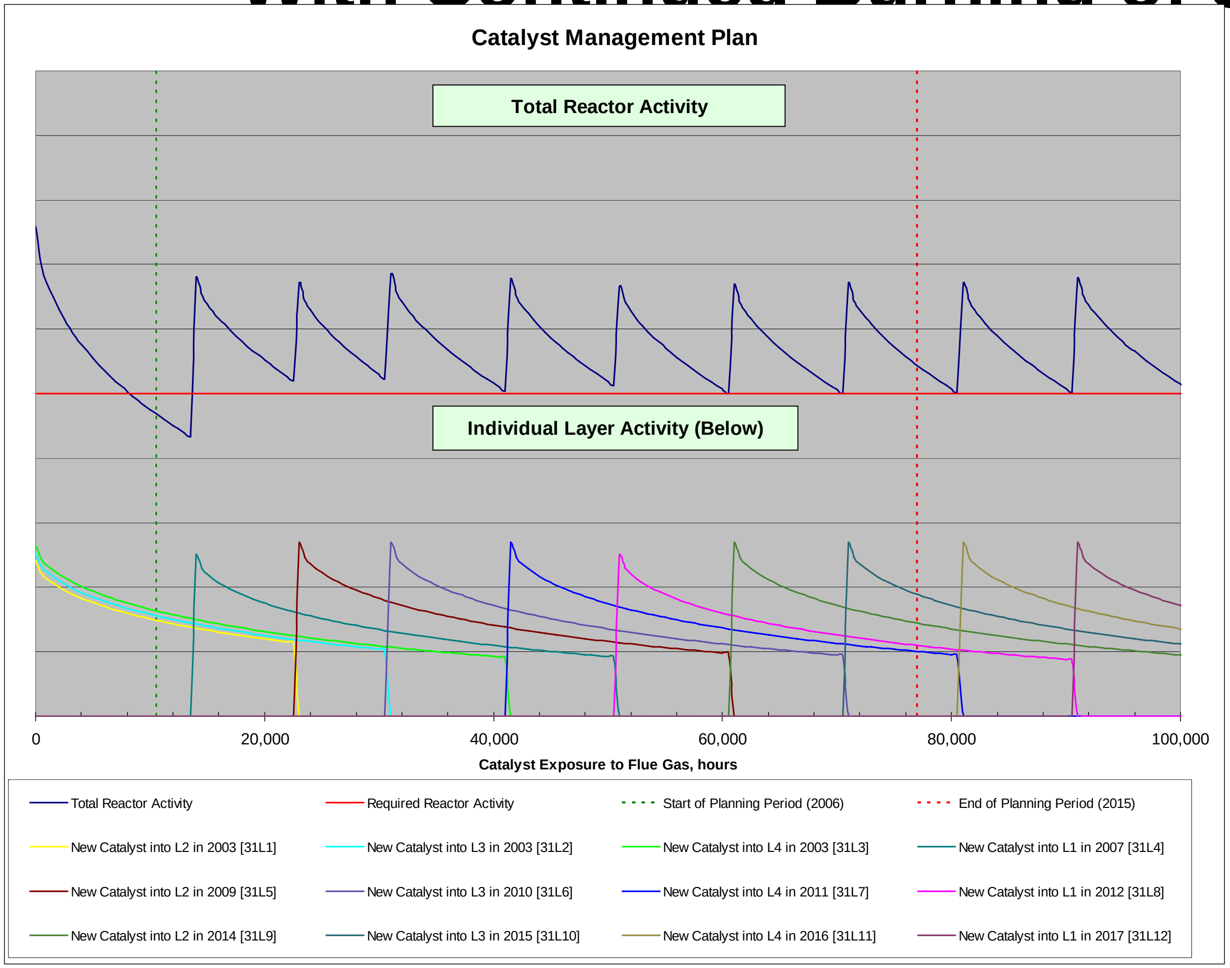
CWLP Dallman Unit 31, 32 & 33 Catalyst Test History



Layer Based Catalyst Activity Tracking for Unit 31



10 Year Catalyst Management Plan With Continued Burning of Seed Corn



- Economic Evaluation
  - NH_3 Cost = $225
  - Fan Energy Cost = $0.10
  - PWDR = 8.6%
  - Capacity Factor = 85%
  - In/Out Costs = $700/m^3
  - New Catalyst Cost
  - Catalyst Cleaning Costs (Rejuv/Regen)
  - Disposal Costs

Net Present Value Analysis	
Catalyst Related Expenditures	$1,950,000
Credit for Residual Catalyst Activity Remaining at End of Planning Period (2015)	($28,000)
Fan Energy Costs for Reactor Pressure Drop	$923,000
Ammonia Cost	$2,160,000
Total Net Present Value of Plan (2006 to 2015)	$5,005,000

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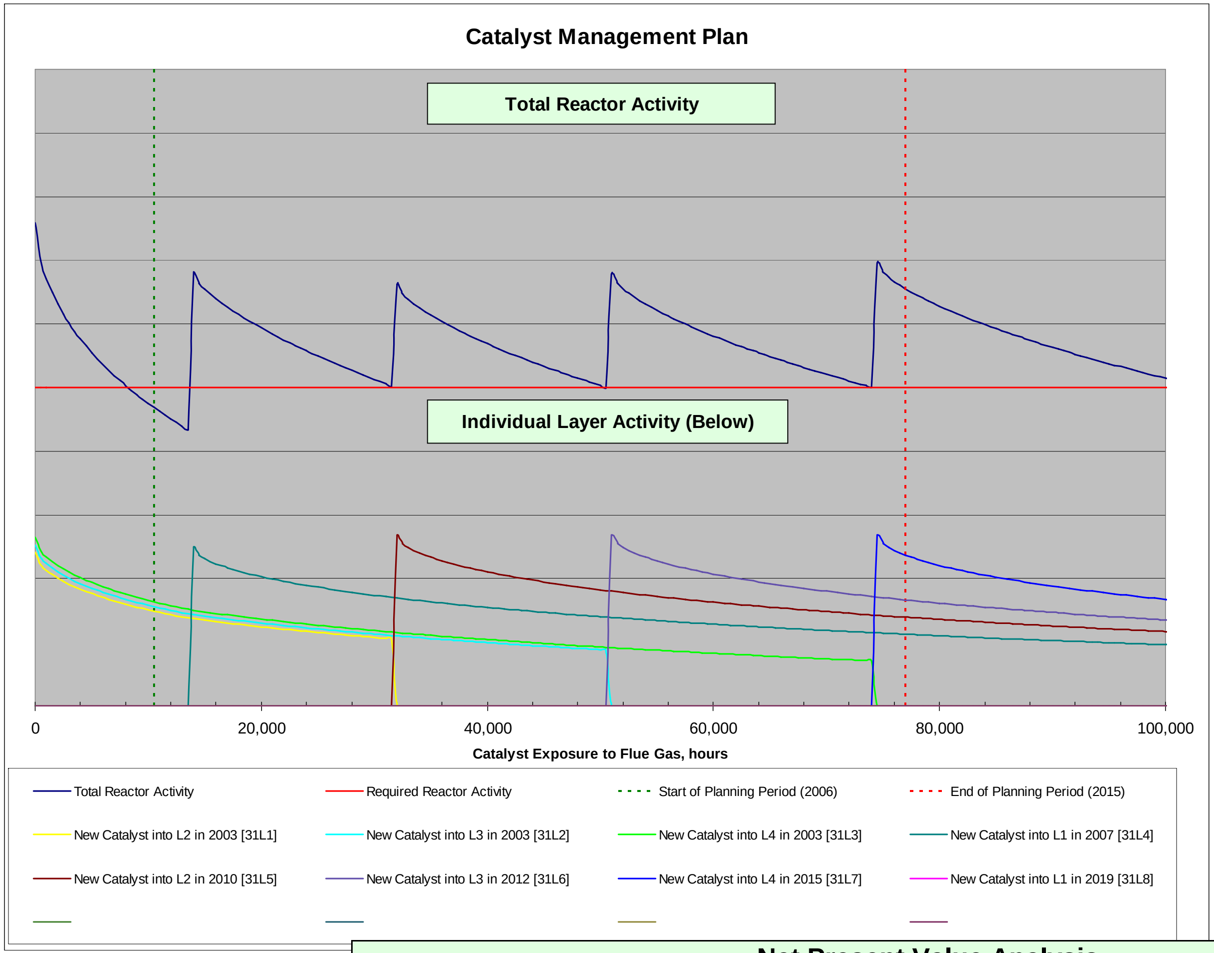
10 Year Catalyst Management Plan
Discontinue Burning Seed Corn in 2007



- Economic Evaluation of Continued Co-Firing
  - NPV Difference of $848,000
- Dallman Co-Fired < 5 tons in 2006
- Mainly Fire in Non-SCR Units
- Biomass Not Fired in U31/32 in 2007

Net Present Value Analysis	
Catalyst Related Expenditures	$1,102,000
Credit for Residual Catalyst Activity Remaining at End of Planning Period (2015)	($98,000)
Fan Energy Costs for Reactor Pressure Drop	$974,000
Ammonia Cost	$2,160,000
Total Net Present Value of Plan (2006 to 2015)	$4,138,000

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CWLP Dallman Unit 31 Example

- Affects of Biomass (Performance, Deactivation)
  - Catalyst Deactivation Increased 2004-05 Due to Co-Firing Biomass in Unit 31
    - Test History Graph Showed 22% Unexpected Decrease in Relative Activity
    - Higher P_2O_5 Found in Bulk & Surface Chemical Analysis
  - DeNOx Performance Still Achieved; Recommended Discontinuing Co-Firing

Unit No.	**P_2O_5 Bulk**	**P_2O_5 Surface**	**As_2O_3 Bulk**	**As_2O_3 Surface**
Unit 31 Cyclone (w/corn)	**0.45 (2004)** **0.80 (2005)** **0.35 (2006*)** 0.31 (2007)	**1.16 (2004)** **1.09 (2005)** **0.85 (2006*)** 0.85 (2007)	**0.08 (2004)** **0.14 (2005)** **0.16 (2006*)** 0.11 (2007)	**0.09 (2004)** **0.12 (2005)** **0.11 (2006*)** 0.21 (2007)
Unit 32 Cyclone (w/corn)	**0.35 (2004)** **0.41 (2005)** 0.23 (2006) 0.27 (2007)	**1.06 (2004)** **0.78 (2005)** 0.61 (2006) 0.63 (2007)	**0.09 (2004)** **0.14 (2005)** 0.12 (2006) 0.12 (2007)	**0.10 (2004)** **0.13 (2005)** 0.10 (2006) 0.15 (2007)
Unit 33 PC Boiler (w/out Corn)	0.06 (2004) 0.06 (2005) 0.05 (2006) 0.04 (2007)	0.08 (2004) 0.13 (2005) 0.15 (2006) 0.25 (2007)	0.04 (2004) 0.03 (2005) 0.03 (2006) 0.03 (2007)	0.05 (2004) 0.03 (2005) 0.03 (2006) 0.03 (2007)

*2006 < 5 tons fired

CWLP Dallman Unit 31 Example

- After 2006 Ozone Season replaced top 6.7 mm Pitch Layer with new 6.7 mm pitch catalyst due to LPA pluggage
  - CERAM evaluated options and recommended Rejuvenation/Regeneration of layer removed
  - Specifications were prepared and proposals solicited for Rejuvenation and Regeneration
  - Evonik Rejuvenation option selected based on Pricing and Guarantees - Restored Catalyst Activity and SO_2/SO_3 Oxidation Rate to near Original Design
  - Testing indicated Evonik restored 93% of Catalyst Activity and Maintained Original Oxidation Rate through Washing/Rejuvenation
  - Inspection indicated that the pluggage after cleaning was less than 2% per visual inspection

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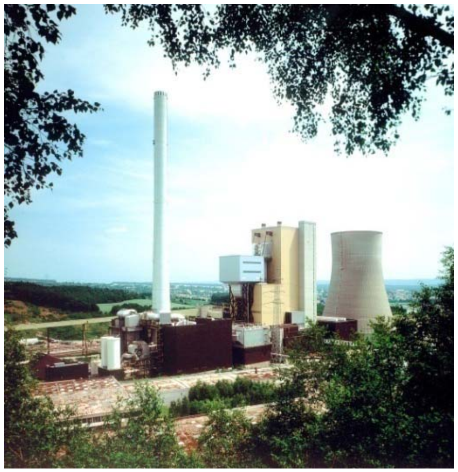
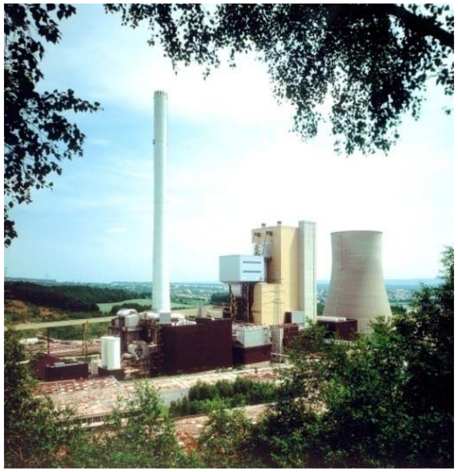
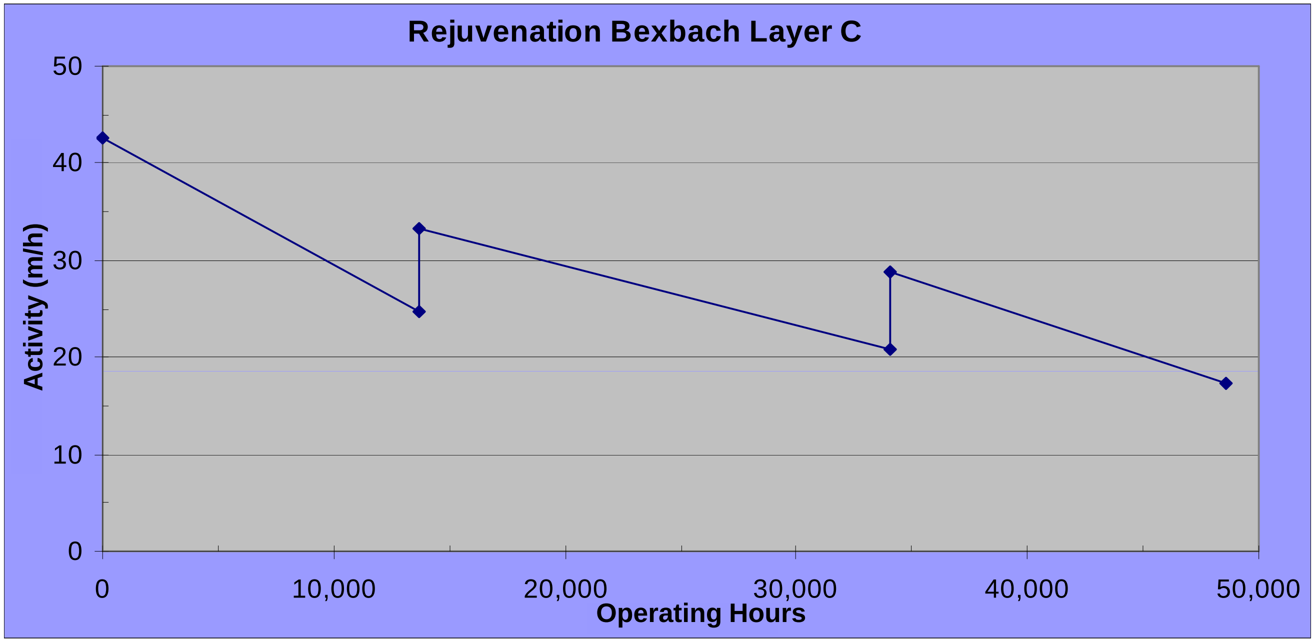
Evonik's – Bexbaugh Station



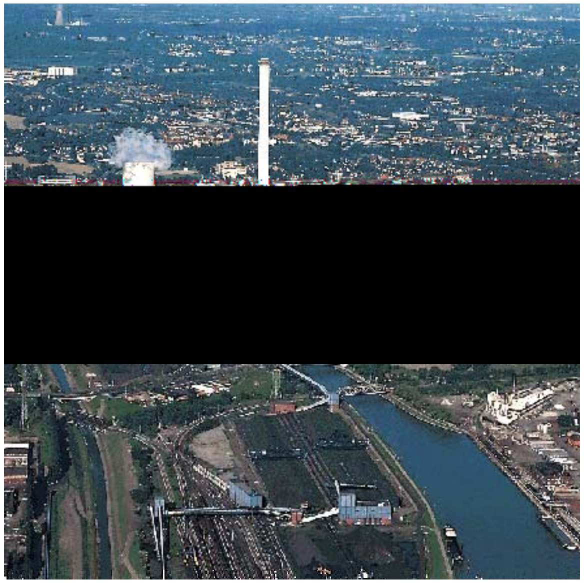
- Unit 1 – 775 MW
- Fuel
  - Bituminous Coal
  - Biomass (less than 5 - 10% by heat input) – Fired when available
- PC tangentially-fired, dry bottom boiler
- High-Dust SCR System (1986)
  - Honeycomb Catalyst , 20 X 20 cell , 1mm Thick
  - 3 X 0 Arrangement
- Wet LSFO FGD - wall board quality gypsum
- Flue gas reheat via rotary gas/gas heat exchanger
- Just completed 4th regeneration – Catalyst has over 100,000 hours of operation
- Minimal effect on the SCR operation. Catalyst layer replace annually

Evonik's – Bexbaugh Station





Evonik's – Herne Cogeneration Plant



- Unit 1& 2 – 150 MW electric each
  - PC, wet bottom boiler
- Unit 3 - 300 MW electricity
  - PC, wet bottom boiler
- Fuel
  - Bituminous Waste Coal (<40% ash)
  - Biomass - Bone meal (Less than 10% by heat input)
- Tail End SCR System
  - Honeycomb Catalyst
- Wet LSFO FGD - wall board quality gypsum
- Catalyst currently being received in Kings Mountain facility for regeneration.
- Essentially there is no effect on the catalyst operation. The poisons are captured in the FGD system.

Evonik's – Lünen Power Station

- Unit 1 – 150 MW electric
  - PC wall-fired, dry bottom boiler
- Unit 11 - 350 MW electricity
  - PC , wet bottom boiler
- Fuel
  - Bituminous Waste Coal (<40% ash)
  - Biomass
    - Sewage sludge (less than 15% by heat input)
    - Bone meal (Less than 10% by heat input)
- Tail End SCR System (1986)
  - Honeycomb Catalyst, 20 X 20 cell, 7.1 pitch
  - 3 X 0 Arrangement
  - 20 X 20 cel
- Wet LSFO FGD - wall board quality gypsum
- Flue gas reheat via rotary gas/gas heat exchanger
- Similar to Herne, little effect on the SCR.

Evonik's – 100% Biomass Units

Buchen 27 MWth
Germany

Dold 8 MWth
Germany

Dresden 25 MWth
Germany

Flohr 32 MWth
Germany

Großaitingen 22 MWth
Germany

Ilmenau 24 MWth
Germany

Lünen 80 MWth
Germany

Neufahrn 21 MWth
Germany

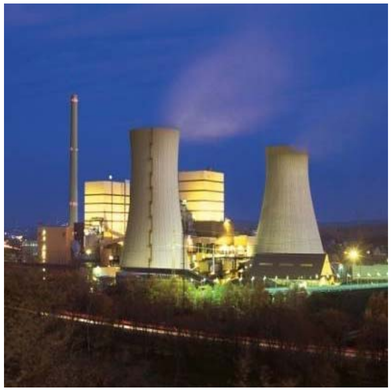
Traunreut 20 MWth
Germany

Werl 14 MWth
Germany

- These units do not have SCR however, they provide experience with biomass as a fuel

SCR Catalyst Regeneration Nomenclature

Evonik's Bexbach Power Station



Evonik's Fenne Cogeneration Plant

- **Cleaning** = **Removal of physical restrictions such as blinding layers and large particle ash – can be done on-site as well as off-site.**
- **Rejuvenation** = **Removal of catalyst poisons without the need for replenishing catalytically active compounds – can sometimes be done in-situ, but is most commonly done either on-site or off-site.**
- **Regeneration** = **Removal of catalyst poisons plus restoration of catalytic activity by addition of catalytically active ingredients – can typically not be done in-situ or on-site, but should be done off-site to ensure required close process control.**

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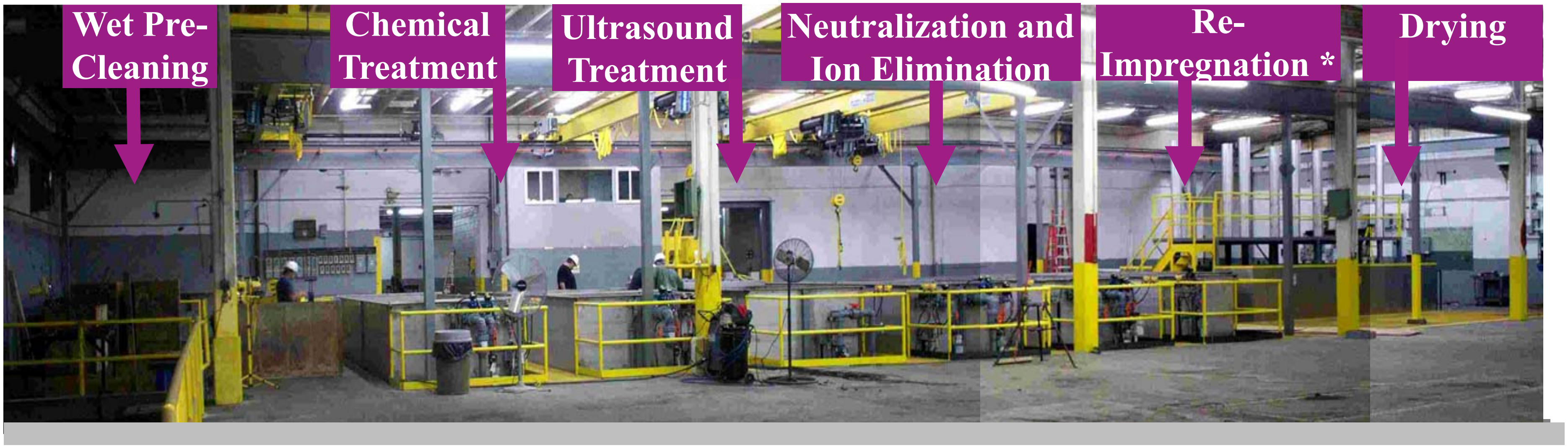
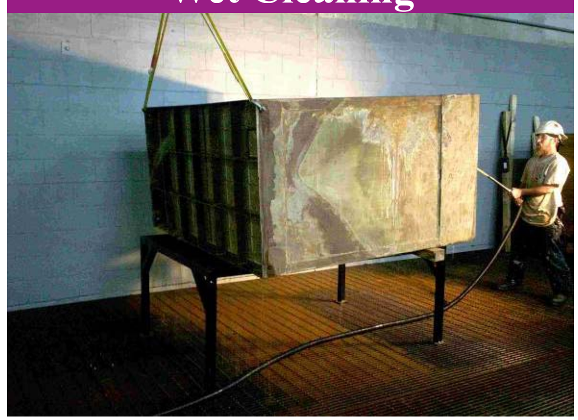
Catalyst Rejuvenation/Regeneration Process

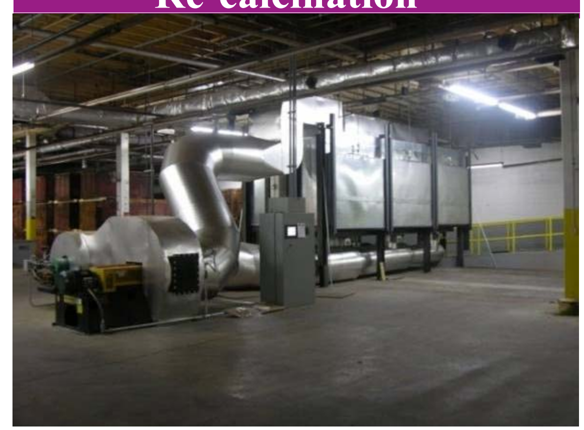


Dry Cleaning

Wet Cleaning

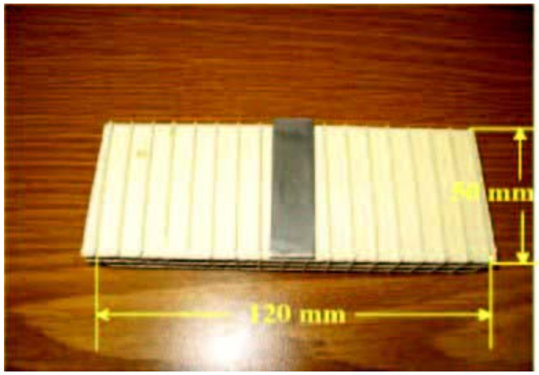


Re-calcination*

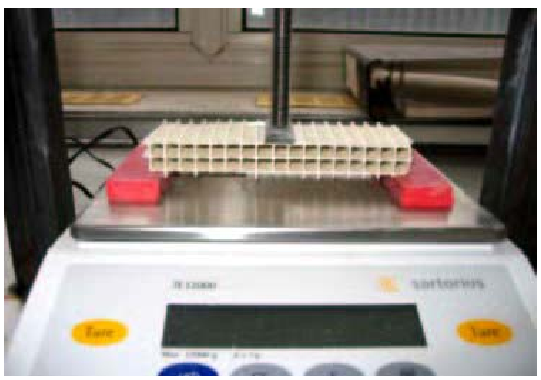


* Not part of rejuvenation process

Critical Issues For Catalyst Rejuvenation / Regeneration

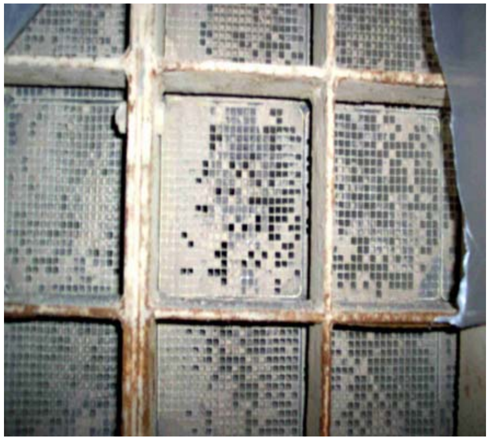


Compressive Strength Tests



- Catalyst wall thickness - 0.8 mm wall thickness
- Damage of catalyst substrate by means of erosion from:
  - Sootblowers
  - High flue gas velocities caused by i.e. large particle ash (LPA) pluggage
- Mechanical strength of catalyst before and after regeneration is critical:
  - Compression strength – longitudinal stability
  - Bonding strength – transversal stability
- Catalyst poisons on the surface and in the bulk material:
  - X-ray fluorescence analyses (XRF) to determine chemical composition
  - X-ray defraction (XRD) and scanning electron microscope (SEM) analyses to determine the mineralogical composition

Critical Issues during the catalyst rejuvenation / regeneration process



LPA plugged catalyst

Rejuvenated catalyst

- The amount of catalyst pluggage, i.e. due to LPA
- The types and amounts of poisons in the catalyst i.e. blinding layers, As, Na, K, P etc.
  - Determine the cleaning process, with biomass, a two stage process will probably be warranted (low pH & High pH, depending upon the Arsenic content, the pH could be above a pH of 12.
  - Determines amount of additional vanadium and molybdenum / tungsten needed from cleaning process
- Addition of tungsten / molybdenum to fully regain catalyst strength
- Re-calcination to fully restore activity and regain catalyst strength. 20 to 30% of the catalyst' compression strength and 50 to 60% of the catalyst's bonding strength often get lost without re-calcination in case of arsenic and/or phosphorus removal.

What can be expected?

Dry & Wet Cleaning

- Catalyst activity can be restored through rejuvenation if blinding of the catalyst from poisons is occurring
- Catalyst can be cleaned to remove significant amounts of LPA or other pluggage
- Catalyst strength can usually be fully restored
- The types of biomass and the quantity fired will greatly depend on the amount of chemical cleaning required
- Minimizing the time of chemical cleaning is critical to the catalyst strength and longevity of regenerations.

Economics Benefits of Regeneration

Combined Bituminous Coal & Biomass Fired

Example:

- 600 MW plant - 993 m^3 of catalyst
- Co-fire 15% biomass
- 3 X 1 arrangement
- Replacement of one of the 3 layers per year
- 20 year life cycle; 3% discount rate
- New catalyst for each replacement versus regeneration (new after 4 regenerations)

New catalyst life cycle cost	$42.5 M
Regenerated life cycle cost	$27.0 M
NPV Benefit	**$15.4 M**

100% Biomass Fired

Example:

- 100 MW plant - 150 m^3 of catalyst
- 100% Biomass
- 2 X 0 arrangement
- Replacement of 1 layer every year
- 20 year life cycle; 3% discount rate
- New catalyst for each replacement versus regeneration (new after 4 regenerations)
- 95% of original K value for all regenerations.

New catalyst life cycle cost	$9.2 M
Regenerated life cycle cost	$6.1 M
NPV Benefit	**$3.1 M**

Note: Economics for full regeneration – A combination of rejuvenation / regeneration would show better econmics

Considerations When Firing Biomass

- Success Can Be Tied to Type of Boiler
- May Require Changes to Fuel Handling/Feed Systems
- May Increase Maintenance Costs
- Possible Reduction in Fuel Costs
- Possible Increase in Energy Consumption
  - Avoid Loss in Efficiency (High H_2O, Energy to Pulverize, etc.)
- Possible Reduction in Emissions
- SCR Reactor Design
  - Flue Gas Composition
    - Gas Weight Normally Increases With Biomass (Reactor Could Get A Little Bigger)
  - SCR Reactor Velocities; Typically 16.4 – 18 ft/s (5 – 5.5 m/s)
- Ammonia Delivery System (Similar To 100% Coal Fired Unit)

Considerations When Firing Biomass

- Affects SCR Catalyst
  - Increase in Deactivation
    - Function of Biomass Analysis and Boiler Type
  - Plugging, Erosion and Sintering Can Be Similar to Coal Firing
    - Use Proper Pitch and Wall Thickness
  - Need Correct Volume in Reactor
    - Experience Critical Factor
  - Need Catalyst That Can Be Washed/Rejuvenated/Regenerated
    - Mechanical Strength Is Critical Factor (> 0.8 mm Wall Thickness)
  - Operations
    - Examine Full Temperature Range for 100% Biomass and Co-Firing Cases
    - Keep Catalyst Warm and Dry

Considerations When Firing Biomass

- Rejuvenation / Regeneration
- Restore Activity Through Rejuvenation / Regeneration From Catalyst Poisons
- Clean Catalyst To Remove LPA Or Other Pluggage
- Types of Biomass and Quantity Fired Will Depend On Amount Of Chemical Cleaning Required
- Minimizing Time Of Chemical Cleaning Critical To Catalyst Strength And Longevity of Regenerations
  - Biomass is a two stage process (low pH & High pH)
  - Need for additional vanadium & molybdenum / tungsten for catalyst strength
  - Re-calcination to Restore Activity and Regain Catalyst Strength
- Mechanical Strength of Catalyst Before & After Regeneration is Critical (> 0.8 mm wall thickness)

Summary

- SCR can be operated with biomass as a fuel source
- Catalyst can be rejuvenated / regenerated
- Keep Catalyst Warm and Dry