Worldwide Pollution Control Association

ESKOM Scrubber Seminar
April 12th – 13th, 2007

Visit our website at www.wpca.info
WPCA/ESKOM Scrubber Seminar

FGD Design and Operating Criteria

Tony Licata

Babcock Power Environmental Inc.
Wet Scrubbing Challenges

- Liquid to Gas Ratio
- Oxidation
- Chloride Concentration (Blowdown)
- Gypsum
- O&M
- Turndown
Wet FGD Challenges

• Materials of Construction
  – Vessels and headers
• Plugged Nozzles/Lines
• Mist Eliminator Washing
• Filtering Process
• Limestone/lime Storage
## Existing Plants Roadmap Performance Targets

<table>
<thead>
<tr>
<th>Innovations for Existing Plants</th>
<th>2005</th>
<th>2010</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Emissions</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>SO$_2$, % removal</td>
<td>90 – 95</td>
<td>98+</td>
<td>99</td>
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<tr>
<td>(emissions, lb SO$_2$/MMBtu)</td>
<td>(0.22 – 0.04)</td>
<td>(0.09 – 0.009)</td>
<td>(0.04 – 0.01)</td>
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<tr>
<td>mg/Nm$^3$</td>
<td>40-7</td>
<td>16 - 5</td>
<td>7 - 2</td>
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<tr>
<td>NO$_x$, lb/MMBtu (SCR equipped)</td>
<td>0.04 – 0.08</td>
<td>0.02 – 0.04</td>
<td>0.01 – 0.02</td>
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<tr>
<td>mg/Nm$^3$</td>
<td>14 – 28</td>
<td>7 - 14</td>
<td>3.5 - 7</td>
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<tr>
<td>NO$_x$, lb/MMBtu (comb. cntls.)</td>
<td>0.1 – 0.3</td>
<td>0.06 – 0.1</td>
<td>&lt;0.05 – 0.1</td>
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<tr>
<td>mg/Nm$^3$</td>
<td>35 - 105</td>
<td>21 – 35</td>
<td>17.5 - 35</td>
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<tr>
<td>Hg removal, %</td>
<td>co-benefits</td>
<td>65 – 90</td>
<td>80 – 95</td>
</tr>
<tr>
<td></td>
<td>30 – 90%</td>
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</table>
# Existing Plants Roadmap Performance Targets

## Innovations for Existing Plants

<table>
<thead>
<tr>
<th></th>
<th>2005</th>
<th>2010</th>
<th>2015</th>
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<tbody>
<tr>
<td><strong>Emissions</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>PM emissions, lb/MM Btu</td>
<td>0.03 – 0.1</td>
<td>0.01 – 0.02</td>
<td>0.01</td>
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<tr>
<td>mg/Nm³</td>
<td>43/144</td>
<td>14/28</td>
<td>14</td>
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<tr>
<td>SO₃ emissions, ppmv</td>
<td>50 - &lt;=2</td>
<td>10 - &lt;=2</td>
<td>&lt;=2</td>
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<tr>
<td>mg/Nm³</td>
<td>14 - 0.56</td>
<td>2.8 – 0.56</td>
<td>0.56</td>
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<tr>
<td>Fresh water use, % reduction</td>
<td>baseline</td>
<td>5 – 10</td>
<td>25</td>
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<tr>
<td>By-product utilization, %</td>
<td>39</td>
<td>50</td>
<td>75</td>
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</table>

Note targets are dependent on the coal type being used and that the data represents targets for both bituminous and sub-bituminous coals

*Electric Power Research Institute, and the Coal Utilization Research Council*
Integrated Coal Source to Stack Pollutant Control Solution

- **Boiler**
  - SNCR
  - OFA
  - WC
  - Fuel

- **Economizer**
  - Limestone
  - Dolomite
  - Pulverizers
  - Low NOx Burners
  - Slag & Foul
  - Temperature control

- **Sorbent**
  - Hg Control
  - SCR
  - Cat. Life Arsenic
  - Efficiency NH₃ Slip
  - SO₃
  - NH₃

- **Air Heater**
  - Hydrated lime
  - Other sorbents
  - Mixing
  - Dew Point
  - Temperature control (trap)
  - Speed
  - By Pass/Steam Coils

- **Baghouse or ESP Blinding**

- **Wet ESP**
  - FGD
  - Limestone
  - Lime
  - Water quench
WFGD Process Flow Diagram

Limestone / Gypsum will dominate utility applications
Absorber Island
Cutaway View Showing Absorber Internals

- Agitators
  - 6+1 configuration

- 4+1 Recycle Pumps

- Recycle Piping
  - (Discharge)
  - (Suction)

- 4+1 Recycle Spray Headers & Nozzles

- Maintenance Floor w/Support Beams
  - (Optional Scope)

- Isolation Valves

- Suction & Discharge reducers
  - 15° Slope minimizes wear

- Recycle Piping
  - (Suction)
Absorber Internals
FGD Absorber Internals
Weather Protected Limestone Storage and Feeding
Enclosed Ball Mill for Sound Protection and Maintenance in Cold Climate

Outdoor Ball Mill
Warm Climate
Maintenance Crane
Oxidation Air Blowers in Sound Enclosure
Gypsum Dewatering

Hydrocyclone & Belt Filter Arrangement
Power Optimization

Design Influence

- Recycle Pumps
- Fans – Gas Side DP
- Oxidation Air Blowers
- Limestone Grinding Mills

Operational Influence

- On-line Optimization
- Automatic and in Real Time
Power Optimization
Oxidation & Agitation

- Tank Sizing
  - Limestone Dissolution
  - Oxidation
    - Mixing
    - Residence Time
  - Reaction Completion
    - De-supersaturation
  - Gypsum Crystal Growth
    - Size
    - Shape
- On-line Monitoring
## Power vs. SO₂ Removal
750 MW East. Bituminous Coal

### Wet FGD Power Usage

<table>
<thead>
<tr>
<th></th>
<th>SO₂ Removal</th>
<th></th>
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<tr>
<td></td>
<td>95%</td>
<td>97%</td>
<td>99%</td>
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<tr>
<td>Booster Fan</td>
<td>4,253</td>
<td>4,593</td>
<td>5,303</td>
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<tr>
<td>Recycle Pumps</td>
<td>4,160</td>
<td>4,593</td>
<td>6,961</td>
<td></td>
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<tr>
<td>Oxidation Air Blowers</td>
<td>2,315</td>
<td>2,556</td>
<td>3,500</td>
<td></td>
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<tr>
<td>Ball Mills</td>
<td>1,614</td>
<td>1,648</td>
<td>1,682</td>
<td></td>
</tr>
<tr>
<td>Others</td>
<td>2,660</td>
<td>2,710</td>
<td>2,772</td>
<td></td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>14,572</strong></td>
<td><strong>16,100</strong></td>
<td><strong>20,218</strong></td>
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</table>
Operation and Maintenance
O & M Criteria

• **Safety**

• Balance between initial capital cost vs. long-term operating cost

• Plant availability/redundancy

• **Operating economics**
  – Elevators vs. stairs
  – Weather encloses

• **Wash down/Cleaning**
  – Drains/pits/pumps

• **All in one building**
Limestone preparation, recycle pumps, control room and gypsum system in one building for reduced operating cost.
Isolation Valves for Pump Maintenance
All pumps in straight line/overhead cranes

Note wide maintenance aisles

Floor drains
Overhead crane for maintenance

Room between pumps for forklift
Overhead cranes
Recycle pump screens to prevent pump wear and nozzle plugging
Scaffolding Provides Convenient And Safe Access to Nozzles
Allows Maintenance at the Upper Levels To Be Performed at the Same Time as Maintenance In the Reaction Tank Area (No Fall Thru).
Maintenance Support Grid

App. 7’ x 10’ Channel Iron Grid
Located Below Bottom Spray Level
# Operational WGFD Testing Requirements

<table>
<thead>
<tr>
<th></th>
<th>Frequency of sampling</th>
<th>pH</th>
<th>Density</th>
<th>Wt % of solids</th>
<th>Chemical composition of solids</th>
<th>Particle size Distr.</th>
<th>Cl- Content</th>
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<tbody>
<tr>
<td>Slurry recycle</td>
<td>1x per day</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X (2/week)</td>
<td>X</td>
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<tr>
<td>Gypsum Slurry</td>
<td>1x per week</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>--</td>
</tr>
<tr>
<td>Gypsum</td>
<td>1x per week</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Limestone Slurry</td>
<td>1x per week</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Limestone</td>
<td>Weekly composite</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Ball Mill Hydrocyclones</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
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<tr>
<td>Make Up Water</td>
<td>1x per week</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Waste Water</td>
<td>1x per week</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
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</table>
## Operational WGFD Testing Requirements

<table>
<thead>
<tr>
<th>Test Description</th>
<th>Test Method</th>
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<tr>
<td>pH</td>
<td>EPRI -C1</td>
</tr>
<tr>
<td>Density</td>
<td>EPRI -D2</td>
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<tr>
<td>Wt % of Solids</td>
<td>EPRI -F3</td>
</tr>
<tr>
<td>Chemical Composition-Sulfate</td>
<td>EPRI -L2</td>
</tr>
<tr>
<td>Chemical Composition-Sulfite</td>
<td>EPRI -M1</td>
</tr>
<tr>
<td>Chemical Composition-Carbonate</td>
<td>EPRI -N3</td>
</tr>
<tr>
<td>Particle Size</td>
<td>EPRI -G1</td>
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<tr>
<td>Crystal Water</td>
<td>ASTM C471M</td>
</tr>
<tr>
<td>Residual Moisture</td>
<td>ASTM C471M</td>
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<tr>
<td>Chloride</td>
<td>EPRI -I3</td>
</tr>
</tbody>
</table>
Operational WGFD Testing Manpower

- Man-hours per absorber 14.5 hours / week
- Man-hours plant common systems
  - Reagent system 15.5 hours / week
  - Water system 4.5 hours / week
  - Gypsum byproduct 4 hours / week
- Man-hour estimate 2 absorbers and common systems 53 hours
- Man-hour estimate 2 absorbers and common systems 2756 hours
Periodic Mechanical Inspection

- **Pumps** – Check
  - Oil level
  - Seal leakage
  - High vibration
  - Belt tension
  - Bearing temperature
  - Alignment

- **Agitators** – Check
  - Oil level
  - High vibration
  - Gland seal water leakage

- **Strainers**
  - Differential pressure each shift, clean if high
Periodic Electrical Inspection

- **Motors – Check**
  - Bearing temperature
  - Insulation resistance
  - Bearing vibration
  - Brush wear
  - Slip ring roughness
  - Motor heater current
  - Clean parts of carbon dust

- **Electrical**
  - Annual inspection or per manufactures instructions

- **Relays**
  - Differential pressure each shift, clean if high

- **Instrumentation**
  - Per manufactures instructions
Periodic Maintenance Manpower

- Man-hours per absorber 20 hours / week
- Man-hours plant common systems
  - Reagent system 20 hours / week
  - Assist with Operational Testing 20 hours / week
- Man-hour estimate 2 absorbers and common systems 80 hours
- Man-hour estimate 2 absorbers and common systems 4160 hours
Operation and Maintenance Manpower

• WFGD Operator, current control room operator from each unit will monitor and control
• Assistant WFGD Operator, one required for plant, perform WFGD operational testing
• Maintenance Mechanic, two required for plant, perform periodic maintenance and assist with testing
Scheduled Outage Inspection

- Absorber Tank
  - Inspect for corrosion, scale and deposits
  - Remove loose material
  - Map location of deposits
  - Repair lining as needed
- Spray Headers and Nozzles
  - Check spray nozzles for plugging and map
  - Clean or replace nozzles as necessary
  - Check headers for erosion
- Mist Eliminators
  - Check for damage or deposits
  - Check wash system for valve function and coverage
- Reagent Preparation
  - Inspect and repair in accordance with manufactures’ instructions
Outage and Maintenance Costs

- Estimated outage (3 yr) cost $250,000 / absorber including
  - Absorber scaffolding
  - Sump cleaning
  - Absorber vessel and header repairs
- Estimated yearly maintenance cost $150,000 / absorber including
  - Agitator parts
  - Recycle pump rebuilds
  - Misc. pump rebuilds
Unique Process Features

• Bi-Directional Spray Nozzles
• Wall Rings
• Advanced Hydraulic Spray Header Design
• Maintenance Platforms
Bi- Directional Spray Nozzles

• Upward Spray Energy Lowers Pressure

• Number of Liquid Orifices Doubles
  – Smaller Droplet Size at Same Pump Power

• Intersections of Spray - Greatly increased
  – Small ‘mist’ droplets are generated
    • Increased surface to mass ratio
  – Droplets mixed and reformed
    • Increased mass transfer at gas-liquid interface
Characterizing Spray Nozzle Flow

- Bi-Directional
- Hollow Cone
- Wide Angle
- Low Liquid Pressure
- Small Droplets
Isometric View Showing Spray Pattern Across Five Levels

Note: All Elevations Spray In 2 Directions Except the Top Spray Level To Avoid Clogging of Mist Eliminators
• Spray Nozzles Arranged
  To Provide Full Coverage Across
  The Section of the Absorber

• Outer Nozzles Arranged to Ensure
  Maximum Coverage
  And Reduce Impingement at
  The Absorber Wall
90° Spray Pattern (Outer Nozzles)

120° Spray Pattern (Inner Nozzles)

Absorber Wall

Wall Ring

Main Recycle Spray Header Piping

Piping
Spray Header/Nozzle Arrangement

Spray Level 5
Spray Level 4
Spray Level 3
Spray Level 2
Spray Level 1

Vessel ID
Wall Ring

- Wall Ring @ Spray Levels 2 & 4 Ensure No Gases Flow Thru At Wall Unrestricted
- Spray Nozzles and Piping Arranged to Minimize Vertical Alignment of Nozzles and Maximize Spray Pattern Coverage
Alloy Selection Criteria

Increased Pitting & Crevice Corrosion Potential
Increased (Cl) Stress Corrosion Cracking Potential

Need

Pitting & Crevice Corrosion Resistance
SCC Resistance
Both Shop & Field Fabricate-ability
Weld-ability
Availability

Economics

Chloride Conc.

pH (More Acidic)
<table>
<thead>
<tr>
<th>Materials of Construction</th>
<th>Design Chloride Limits (ppm)</th>
<th>GPM Wastewater</th>
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<tbody>
<tr>
<td>317LMN Stainless Steel (S31726)</td>
<td>8,000</td>
<td>287</td>
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<tr>
<td>Duplex 2205 Stainless Steel (S32205)</td>
<td>12,000</td>
<td>141</td>
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<tr>
<td>Super Duplex 255 Stainless Steel (S32550)</td>
<td>20,000</td>
<td>115</td>
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<td>Super Austenitic 6% Mo Stainless Steel (N08367)</td>
<td>40,000</td>
<td>57</td>
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<tr>
<td>C-276 (N10276)</td>
<td>50,000</td>
<td>46</td>
</tr>
<tr>
<td>Carbon Steel/Glass Lined</td>
<td>50,000</td>
<td>46</td>
</tr>
<tr>
<td>Carbon Steel/Rubber Lined</td>
<td>50,000</td>
<td>46</td>
</tr>
<tr>
<td>Concrete/Tile Lined</td>
<td>&gt; 50,000</td>
<td>46</td>
</tr>
<tr>
<td>Concrete/PP Lined</td>
<td>50,000</td>
<td>46</td>
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<tr>
<td>Materials of Construction</td>
<td>Installed Cost Ranking</td>
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<td>Duplex 2205 Stainless Steel (S32205)</td>
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<td>Super Duplex 255 Stainless Steel (S32550)</td>
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<td>C-276 (N10276)</td>
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<td>Carbon Steel/Glass Lined</td>
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<tr>
<td>Carbon Steel/Rubber Lined</td>
<td>1.5</td>
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<td>Concrete/Tile Lined</td>
<td>4</td>
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<tr>
<td>Carbon Steel/Tile Lined</td>
<td>6</td>
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<tr>
<td>Concrete/PP Lined</td>
<td>3</td>
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</table>
Metal Price Trends (Source: AMM)

- Steel Scrap
- Nickel
- Molybdenum
- Chrome
- Vanadium
- Manganese
- Copper
- Aluminum
- Tungsten

Percent Change

Date:
- 10/01/03
- 11/01/03
- 12/01/03
- 01/01/04
- 02/01/04
- 03/01/04
- 04/01/04
- 05/01/04
- 06/01/04
- 07/01/04
- 08/01/04
- 09/01/04
- 10/01/04
- 11/01/04
- 12/01/04
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- 02/01/06
- 03/01/06
- 04/01/06
- 05/01/06
- 06/01/06
- 07/01/06
- 08/01/06
- 09/01/06
- 10/01/06
Cost of FGD Vessel Materials

- $5.00
- $10.00
- $15.00
- $20.00
- $25.00
- $30.00

$/lb of Material Installed

ppm Chlorides

Waste water flow:
- 129 gpm
- 65 gpm
- 43 gpm

Materials:
- C-276
- AL6XN
- 2205
Owners Decisions

• Redundancy
  – Pumps
  – Ball Mills – 3 x 50% or 2 x 100%
  – Dewatering
  – Spares
• Organic Acids
• Waste Water
• Gypsum Markets/landfilling
Absorber Access

• **Safety First**
  - Confined Space
  - Fall Protection
  - Personal Safety Equipment
  - Working Conditions: Lighting, GFI’s, Tools, Noise, Welding, Flash Protection, etc.

• **Maintenance**
  - Minimize outage time
  - Simple PM programs
  - Easy access for service and cleaning
Ghent Station Unit 3 Absorber Island
Plan View

2 – Gypsum Transfer Tanks ea.207,000 gal.
- Carbon Steel (Rubber Lined)
- Return from 3 Recycle Pumps
- Each With Agitators

1- Process Water Tank 85,500 gal.
- Carbon Steel
- 2 Redundant Mist Eliminator Wash Pumps

Existing Unit 1 FGD Stack

Recycle Pumps

Oxidation Air Compressors

2nd Stage Mist Eliminator Access Platform
- Wrap Around Design Provides Access To Spray Header Valves
- A Lay Down Area for Demister Modules
Ghent Station Unit 3 Absorber Island
Cutaway View Showing Absorber Internals

- Primary & Secondary Mist Eliminators
- Recycle Piping (Discharge)
- Agitators 6+1 configuration
- 4 + 1 Recycle Pumps
- 4+1 Recycle Spray Headers & Nozzles
- Maintenance Floor w/Support Beams (Optional Scope)
- Isolation Valves
- Suction & Discharge reducers 15° Slope minimizes wear
- Recycle Piping (Suction)
Tile Lined Concrete
Project Execution

• Market volatility
  - Materials
• Labor
• Project time lines
• Project Management tools
## Equipment Delivery

### In Weeks

<table>
<thead>
<tr>
<th>Commodity</th>
<th>2003</th>
<th>2006</th>
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<tbody>
<tr>
<td>Structural Shapes</td>
<td>8-12</td>
<td>20-24</td>
</tr>
<tr>
<td>Recycle Pumps</td>
<td>26-30</td>
<td>52-94</td>
</tr>
<tr>
<td>Ball Mills</td>
<td>26-30</td>
<td>64</td>
</tr>
<tr>
<td>ID Fans</td>
<td>72</td>
<td>100</td>
</tr>
<tr>
<td>SCR Catalyst</td>
<td>46-48</td>
<td>48-52</td>
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</table>
What Can be Done to Mitigate On-Site Labor Cost

- Modularization
- Packaging components
- Alternative materials of construction
- Constructor alliances
- Standard designs
  - Rigging layouts
- Construction manuals
  - Lessons learned
What are can be done to shorten time line?

- Qualifying new vendors
- Packaging components
- New construction techniques
- Standard designs
- New design tools
Crane rigging plan

Maintenance platforms

Enclosed building
Pro/E Model
Of
Ghent Station Unit 3 Absorber Vessel
Exploded View Showing C-276 Plates
Before Assembly & Welding
Construction
Modularization

Ohio River
SCR Modules
AEP Amos Tier 2
Mist Eliminator and Absorber Outlet
Introduction

• Vectren, F.B. Culley Generating Station Units 2 & 3
  – Two boilers feeding one WFGD System
  – WFGD supplied by BPEI (1994)
  – No Bypass
Current BPEI FGD Upgrade Projects

- Vectren Culley - Unit 2 & 3
  - Continuous relationship
- LG&E Trimble County – Unit 1
  - Improve operation
  - Increase removal 98%
  - Recycle pump performance
## Changes in Design Parameters

<table>
<thead>
<tr>
<th>Original Design</th>
<th>Revised Design</th>
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<tr>
<td>368 MW</td>
<td>390 MW</td>
</tr>
<tr>
<td>6.5 lb SO$_2$/mmBtu</td>
<td>8.0 lb SO$_2$/mmBtu</td>
</tr>
<tr>
<td>95.0% SO$_2$ Removal Efficiency</td>
<td>95.5% SO$_2$ Removal Efficiency</td>
</tr>
<tr>
<td>Minimum of 1 Spare Recirculation Pump</td>
<td>Minimum of 1 Spare Recirculation Pump</td>
</tr>
</tbody>
</table>
Results (Normalized Data)

Vectren, F.B. Culley Station Units 2 & 3
Absorber Performance
Average SO₂ Removal Efficiency based on
WFGD system revised design conditions

Design Conditions:
- Maximum Flue Gas Flow Rate
- 8.0 lb SO₂/mmBtu
- 5 of 6 Pumps in Operation

Average SO₂ Removal Efficiency, (%)

- Before Absorber Baffle Installation: 92.7%
- Goal: 95.5%
- After Absorber Baffle Installation: 96.4%
Results (Raw Data)

Data points provided from the Culley Station WFGD DCS on a 10 minute basis.

5 of 6 Recirc. Pumps in Operation
4 of 6 Recirc. Pumps in Operation
Accomplishments

• Exceeded performance requirements
  – Customer assured of reliable operation firing maximum sulfur coal with 5 pumps operating and 1 spare
  – Reduction in total operating cost by utilizing only 4 of 6 pumps in operation when firing typical sulfur coal

• Successfully upgraded to 2004 NSR consent decree requirements

• Achieved all goals with existing equipment
Culley Performance

WFGD Commissioned in 1994

Vectren Has Increased Boiler Load and SO$_2$ Loading

<table>
<thead>
<tr>
<th></th>
<th>Design</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiler Load (MWe)</td>
<td>375</td>
<td>400</td>
</tr>
<tr>
<td>SO$_2$ Loading (lb/MMBtu)</td>
<td>6.5</td>
<td>10</td>
</tr>
<tr>
<td>SO$_2$ Removal Rate</td>
<td>95%</td>
<td>95%</td>
</tr>
</tbody>
</table>
Operational History (Jan. ’03 – Sept. ’05)

SO2 Emission 24-Hour, SO2 Emission 30-Day, Stack Gross Load

Ave = 0.308
New Limit = 0.17
Upgrade Results – Long Term Performance

- New Limit = 0.17
- BPEI Design = 0.11
- Long Term Ave = 0.074
- ’03 – ’05 Ave = 0.308
Thank You

Questions ??