Fuel Tech’s NOx Reduction and Fuel Chem Performance Improvements for Coal-Fired Steam Generators

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Process Engineering
Fuel Tech, Inc.
http://www.ftek.com

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Clearwater Beach, Florida
Overview

• Introduction to Fuel Tech
• Summary of Fuel Tech’s Technologies
  - FUEL CHEM®
  - Air Pollution Control (APC)
• Modeling Software Used
  - Computation Fluid Dynamics (CFD)
  - Chemical Kinetics Modeling (CKM)
• Case Studies
• PEPSE
• Q&A
About Fuel Tech...

• Incorporated in 1987; Currently ~ 175 Employees

• Corporate Headquarters in Warrenville, IL; additional domestic offices in Durham, NC and Stamford, CT. International offices in Milan, Italy and Beijing, China.

• Uses advanced technologies to provide boiler optimization, efficiency improvement, and air pollution reduction and control solutions to utility and industrial customers worldwide.

• Member of the following organizations:
  - The Institute of Clean Air Companies (ICAC)
  - Council of Industrial Boiler Owners (CIBO)
  - American Coal Council (ACC)
Fuel Tech’s Products

Products:

• **FUEL CHEM®**
  - TIFI® Targeted In-Furnace™ Injection Technologies

• **Air Pollution Control (APC) for NOx Reduction**
  - Selective Non-Catalytic Reduction (SNCR) – NOxOut® and HERT™ injectors
  - Low NOx Burners, Burner Modifications and Over-Fire Air (OFA) Systems
  - ULTRA™ - Urea to Ammonia Conversion for SCR Systems
  - ASCR™ Advanced Selective Catalytic Reduction
Fuel Tech’s Services

Services:

• Modeling (CFD and Experimental / Physical Flow Modeling)
• Combustion Testing
  – Coal and Air Flow Testing for Combustion Optimization
• SCR Services
  – SCR Design
  – SCR Catalyst Management Services
  – SCR Troubleshooting and Optimization
  – Static Mixers
  – GSG™ Graduated Straightening Grid
FUEL CHEM® Technologies

• FUEL CHEM® ➔
  – TIFI® Targeted In-Furnace Injection™ Chemical Injection Program
  – Improves the efficiency, reliability and environmental status of plants operating in the electric utility, industrial, pulp and paper, and waste-to-energy markets.
  – May be used to control slagging, fouling, corrosion, opacity, acid plume, loss on ignition (LOI) and SO$_3$-related issues, including ammonium bisulfate (ABS) and particulate matter formation (PM$_{2.5}$)
  – Used on a variety of fuels, including coal, heavy oil, biomass, and municipal waste.
Optimal locations for TIFI injection are determined by Computational Fluid Dynamics (CFD) modeling, and by consulting with site personnel on their experience with slagging issues.

- **TIFI MG™** – Most common; magnesium hydroxide slurry diluted with water.

- **TIFI XP™** – Multiple reagents; used on Illinois Basin (ILB) coal to reduce slagging, and mitigate corrosion for ILB coal with high chlorine levels.
• The crystalline structure of the slag is modified during formation.

• TIFI injection results in the slag becoming more friable, lighter, and more easily controlled.

• Modified deposits are more easily removed by sootblowing.
FUEL CHEM® Technologies

• Demonstrate Operating Savings to Customer with Fuel Chem TI FI

Key Cost Savings Considered
• Reduction of Forced Outages
• Cleaning Costs (Blasting, Hydro, Shot Gun)
• Tube Repair Costs
• Equipment Maintenance
• Ability to Burn Cheaper Fuel
• Reduced Net Unit Heat Rate
APC Technologies

- APC Technologies installed worldwide on over 680 combustion units, including utility, industrial and municipal solid waste applications.

- Products include customized NO\textsubscript{x} control systems, which can reduce emissions from 30% - 85%, and proprietary urea-to-ammonia conversion technology, which can provide safe reagent for use in selective catalytic reduction systems.
APC Technologies

• **SNCR Systems - NOxOUT® and HERT™**
  - Urea-Based Selective Non-Catalytic Reduction (SNCR).
  - 25-50% NOx reduction.

<table>
<thead>
<tr>
<th>NOxOUT® Process Injection</th>
<th>SNCR Technology</th>
<th>HERT™ High Energy Reagent Technology Injections</th>
</tr>
</thead>
<tbody>
<tr>
<td>• High momentum injectors</td>
<td>• CFD/CKM Modeling</td>
<td>• High energy, low momentum injectors</td>
</tr>
<tr>
<td>• Maximize performance</td>
<td>• Reliable equipment</td>
<td>• Maximize performance with minimal ammonia slip</td>
</tr>
<tr>
<td>• Adjustable for NOx reduction downstream of injection point</td>
<td>• On-site optimization</td>
<td>• Localized NOx reduction</td>
</tr>
</tbody>
</table>

• **ULTRA™ - Urea to Ammonia Conversion for SCR Systems**
  - Proprietary Urea Conversion Process to Generate Ammonia for SCR Systems.
  - Simplified System - No Hydrolysis.
  - Compatible with a Wide Range of Urea Sources - No Special Requirements.
• **Low NOx Burners ➔**
  - Coal and Oil Fired Burners – Reduced primary air flow and controlled mixing zones allow deep staging with high combustion efficiency and carbon burn-out. Inhibits the formation of NO\textsubscript{x} from fuel bound nitrogen as well as thermal NO\textsubscript{x}.
  - Natural gas burners - the peak flame temperature is reduced to limit thermal NO\textsubscript{x} formation.
  - 40-60% NO\textsubscript{x} reduction depending on fuel type.

• **Over-Fire Air (OFA) Systems ➔**
  - Deeply stages combustion for enhanced NO\textsubscript{x} reductions.
  - Unique port design enhances mixing to limit impact on combustion efficiency.
  - Additional NO\textsubscript{x} reductions, beyond low NO\textsubscript{x} burners of 35%-50%, are possible on wall, tangential, turbo or cyclone fired boilers on all fuel types.
• **ASCR™ Advanced Selective Catalytic Reduction ➔**
  - “Layered” approach combining Fuel Tech’s proven Low-NOx Burner and OFA systems, with post combustion NO\textsubscript{x} controls (SNCR, smaller SCR).
  - 80% + NO\textsubscript{x} Reductions.
  - Lower Capital and Operating Costs vs. Conventional SCR.
CFD Modeling

- Custom CFD Process Model is built for all FUEL CHEM® and APC Product Installations.
- CFD Model generates predictions of operating temperatures, velocities and other variables from a virtual replication of real-world geometry and operating inputs.
- The model is used to optimize the injection of the right amount of the right chemical under the right conditions to achieve desired performance levels.
Chemical Kinetics Modeling (CKM)

• CKM: Fuel Tech proprietary modeling software, comprising more than 31 species in 93 different reactions.

• CKM predicts NO$_x$ reduction by simulating relevant chemical reactions along gas temperature profiles derived from the CFD models in the presence of anticipated chemical dosage and key flue gas compositions.

• For SNCR Applications, Results from CFD Modeling and CKM are used to determine the NOxOut and/or HERT injection locations and operation for optimal NOx reduction.
Fuel Chem® Case Study 1

Basin Electric Power Cooperative
Leland Olds Station Unit 2
Leland Olds Station Station Perspectives

• Leland Olds Station (LOS) Description
  – Unit 1, 1966, Wall-Fired, 220 MWg
  – Unit 2, 1975, Cyclone-Fired, 440 MWg

• Fuels
  – North Dakota Lignite & PRB
  – Blend to Control Sulfur, Ash, Sodium

• Key Objectives & Goals
  – High Availability Base Load Power
  – Low Cost Power
  – Eliminate Vermiculite Injection
Specific Success Criteria

- Annual Generation Gains (net MWh)
- Net Unit Heat Rate Improvement
- Reduced Slagging & Fouling
- Ability to Recover from Poor Coal Quality
- Increased Operator Safety
- Reduction in Cleaning Outages
- Contribute to NOx Reduction Efforts
- Reduce/Eliminate Vermiculite System Maintenance, Reliability, & Safety Issues
Slag Management Program at LOS

- Lignite/PRB Blend Adjusted Based on Incoming Coal Report
- TIFI Program On-Going on Unit 2 Since January 2009; TIFI Program recently started on Unit 1.
- TIFI Injection Rate Adjusted Based on Incoming Coal Properties
- Soot Blower Optimization Team
- 10-Point Boiler Grading Scale Based on Slag Surveys
TIFI® Program Results

- Eliminated One Annual Cleaning Outage
- Remaining Annual Outage Shortened by 4 Days
- Reduced Sootblowing, Rodding, Shot Gun Cleaning, & Blasting
- Over 45% of Run Time Greater Than 400 MW vs 29% Pre-TIFI
- 40 – 60°F Reduction in Economizer Exit Gas Temp
- 5% Decrease in ID Fan Amps
- 120 – 180 Btu/kWh Decrease in Heat Rate
- 15 – 16% Decrease in NOx Emissions with Cleaner Furnace & O₂ Trim
LOS Unit 2 Net Generation

- Reduced Cleaning Outages in 2009 & 2010
- Unit Output Maintained in 2009 & 2010
Increased Operating Time Above 400 MW
Heat Rate Controllable Parameters

- Improvements in Key Parameters w/TIFI
  - Main Steam Temp
  - Economizer Exit Gas Temp
  - APH Exit Gas Temp
NUHR vs Generation

- Improvements in Key Parameters Reduce Heat Rate in 2009 w/TIFI
- Heat Rate Efficiencies Maintained in 2010
NUHR Comparisons

- Averages at 440 MW for each run
- 2009 NUHR Reduction w/TIFI Prior To Fall Outage
- 2010 NUHR Shows Continued Improvement
NOx versus O₂

- 15 – 18% NOx Reduction With TIFI Slag Management
- 30 – 40% NOx Reduction With OFA
Fuel Chem® Case Study 2

Colorado Springs Utilities
Martin Drake Station Unit 7
Martin Drake Station Perspectives

- Plant Description
- Fuels
  - Colorado Coal
  - PRB Coal
  - Blend Strategies
- Issues with High PRB Blends
  - De-Rates and Forced Outages
  - Blast Cleaning and Tube Leak Repairs
TIFI® Program Results at Drake

- 6 Week Testing on Unit 6 (85 MW Wall-Fired)
  - Short Test due to Fuel Blend Issues
  - Improved Waterwall Absorption and Reduced SH Sprays
- 5 Month Testing on Unit 7 (142 MW Wall-Fired)
  - PRB Blend Up To 50% With TIFI
  - Waterwall and Superheat Absorptions Maintained with 50% PRB Blend
  - SH & RH Steam Temperatures Maintained at 1,005°F
  - Slag Shed De-Rates and Forced Outages on Same Pattern as Baseline Colorado Coal
  - Operating Cost Savings of 4.2 : 1 Against TIFI Cost
# Unit 7 Coal Options

<table>
<thead>
<tr>
<th>Proximate Analysis (As Received)</th>
<th>Colorado Coal</th>
<th>PRB Coal</th>
<th>Mineral Analysis of Ash</th>
<th>Colorado Coal</th>
<th>PRB Coal</th>
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<tbody>
<tr>
<td>Moisture H₂O (%)</td>
<td>9.21</td>
<td>25.24</td>
<td>Silicon Dioxide SiO₂ (%)</td>
<td>54.79</td>
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<tr>
<td>Ash (%)</td>
<td>9.31</td>
<td>5.46</td>
<td>Aluminum Oxide Al₂O₃ (%)</td>
<td>26.91</td>
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<td>Volatile Matter VM (%)</td>
<td>37.23</td>
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<td>Titanium Dioxide TiO₂ (%)</td>
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<td>Fixed Carbon C (%)</td>
<td>44.25</td>
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<td>Iron Oxide Fe₂O₃ (%)</td>
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<td>Total (%)</td>
<td>100</td>
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<td>Calcium Oxide CaO (%)</td>
<td>3.99</td>
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<td>Total Sulfur S (%)</td>
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<td>Magnesium Oxide MgO (%)</td>
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<td>lb SO₂/MMBtu (lb/MMBtu)</td>
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<td>Potassium Oxide K₂O (%)</td>
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<td>lb Ash/MMBtu (lb/MMBtu)</td>
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<td>Sodium Oxide Na₂O (%)</td>
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<td>Ash to Sulfur Ratio</td>
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<td>Sulfur Trioxide SO₃ (%)</td>
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<td>Phosphorus Pentoxide P₂O₅ (%)</td>
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<td>Strontium Oxide SrO (%)</td>
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<td>Barium Oxide BaO (%)</td>
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<td>Manganese Dioxide MnO₂ (%)</td>
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<td>Undetermined (%)</td>
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<td>Total (%)</td>
<td>98.37</td>
<td>97.41</td>
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<td>Ultimate Analysis (As Received)</td>
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<td>Carbon C (%)</td>
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<td>Ash (%)</td>
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<td>Oxygen O (%)</td>
<td>8.24</td>
<td>11.53</td>
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<td>Total (%)</td>
<td>100</td>
<td>100</td>
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<td>Higher Heating Value HHV (Btu/lb)</td>
<td>11,411</td>
<td>8,993</td>
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<td>Higher Heating Value (MAF)</td>
<td>12,568</td>
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<td>Hardgrove Grindability Index HGI</td>
<td>46</td>
<td>49</td>
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<td>Ash Fusion Temperatures - Oxidizing</td>
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<td>Ash Fusion Temperatures - Reducing</td>
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<td>Initial Deformation IT (°F)</td>
<td>2622</td>
<td>2193</td>
<td>Initial Deformation IT (°F)</td>
<td>2548</td>
<td>2078</td>
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<td>Softening ST (°F)</td>
<td>2670</td>
<td>2200</td>
<td>Softening ST (°F)</td>
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<td>Hemispherical HT (°F)</td>
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<td>2206</td>
<td>Hemispherical HT (°F)</td>
<td>2631</td>
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<td>Fluid FT (°F)</td>
<td>2700</td>
<td>2215</td>
<td>Fluid FT (°F)</td>
<td>2656</td>
<td>2145</td>
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</tbody>
</table>
Coal Slagging Indices

**Colorado**

\[
\frac{\text{Fe}_2\text{O}_3}{(\text{CaO} + \text{MgO})} = 0.86 \quad \Rightarrow \quad \text{Lignitic Ash}
\]

\[
R_s = \frac{(\text{Max HT}) + 4(\text{Min IT})}{5} = 2576 \quad \Rightarrow \quad \text{Low}
\]

**PRB**

\[
\frac{\text{Fe}_2\text{O}_3}{(\text{CaO} + \text{MgO})} = 0.24 \quad \Rightarrow \quad \text{Lignitic Ash}
\]

\[
R_s = \frac{(\text{Max HT}) + 4(\text{Min IT})}{5} = 2104 \quad \Rightarrow \quad \text{Very High}
\]
Colorado Coal Ash Softening Isotherms

2,670 ºF (Oxidizing)

2,595 ºF (Reducing)
PRB Coal Ash Softening Isotherms

2,200 °F (Oxidizing)

2,120 °F (Reducing)
Drake Unit 7 PRB Blends

- Baseline Blend Averaged 10% PRB
- TIFI Demo Increased to 50% PRB
Unit 7 Waterwall Absorption

- TIFI Maintains Waterwall Absorption with High PRB Blend

[Graph showing data points for 'Surface Heat Transfer (MMBtu/hr)' against 'Gross Generation (MW)'. The graph compares December 2007 - May 2008 (Baseline) and December 2008 - May 2009 (With TIFI).]
Slight Decrease in SH Absorption Due to Reduced Flue Gas Flows
SH Attemperator Sprays

- Superheat Spray Flows Reduced
- Main Steam Temperature Maintained
## Financial Analysis

<table>
<thead>
<tr>
<th>Site Conditions</th>
<th>Units</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>Colorado Coal Higher Heating Value</td>
<td>Btu/lb</td>
<td>11,411</td>
</tr>
<tr>
<td>Colorado Coal Delivered Price</td>
<td>$/ton</td>
<td>$50.00</td>
</tr>
<tr>
<td>PRB Higher Heating Value</td>
<td>Btu/lb</td>
<td>8,993</td>
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<tr>
<td>PRB Delivered Price</td>
<td>$/ton</td>
<td>$21.00</td>
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<tr>
<td>Retail Power at Busbar</td>
<td>$/MWh</td>
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## Financial Analysis

### Operating Parameters

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<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Case I: Baseline Operation</th>
<th>Case II: Test Burn w/o TIFI</th>
<th>Case III: Operation w/TIFI</th>
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<tbody>
<tr>
<td>Gross Generating Capacity</td>
<td>MW Gross</td>
<td>142</td>
<td>142</td>
<td>142</td>
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<tr>
<td>Net Generating Capacity</td>
<td>MW Net</td>
<td>131</td>
<td>131</td>
<td>131</td>
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<tr>
<td>Net Unit Heat Rate</td>
<td>Btu/kWh</td>
<td>11,600</td>
<td>11,700</td>
<td>11,695</td>
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<td>Scheduled Outages per Year (Average)</td>
<td>Days/Year</td>
<td>10</td>
<td>10</td>
<td>10</td>
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<tr>
<td>Unscheduled Outages per Year</td>
<td>Days/Year</td>
<td>1</td>
<td>8</td>
<td>1</td>
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<tr>
<td>Slag Shed Derates per Year</td>
<td>Events/Year</td>
<td>4</td>
<td>48</td>
<td>4</td>
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<tr>
<td>Lost Net Generation for Slag Sheds</td>
<td>MWh/Year</td>
<td>2,400</td>
<td>28,800</td>
<td>2,400</td>
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<td>Dispatched Load Reductions</td>
<td>MWh/Year</td>
<td>60,000</td>
<td>60,000</td>
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<td>Effective Annual Capacity Factor</td>
<td>%</td>
<td>92</td>
<td>87</td>
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### Annual Cost Impacts

<table>
<thead>
<tr>
<th>Cost Item</th>
<th>Units</th>
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<th>Case II: Test Burn w/o TIFI</th>
<th>Case III: Operation w/TIFI</th>
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<tbody>
<tr>
<td>Blasting &amp; Cleaning Costs</td>
<td>$/Year</td>
<td>($20,000)</td>
<td>($80,000)</td>
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<td>Tube Leak Repairs</td>
<td>$/Year</td>
<td>($50,000)</td>
<td>($200,000)</td>
<td>($50,000)</td>
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<td>Lost Revenue due to Unscheduled Outages and Slag Derates</td>
<td>$/Year</td>
<td>($166,320)</td>
<td>($1,618,560)</td>
<td>($166,320)</td>
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<td>Annual Fuel Cost</td>
<td>$/Year</td>
<td>($26,699,416)</td>
<td>($22,089,186)</td>
<td>($20,631,252)</td>
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<tr>
<td>TIFI Program Cost</td>
<td>$/Year</td>
<td>0</td>
<td>0</td>
<td>($1,172,589)</td>
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</table>

**Fuel Savings (Compared to Baseline)**

<table>
<thead>
<tr>
<th>Yearly Savings</th>
<th>Case I: Baseline Operation</th>
<th>Case II: Test Burn w/o TIFI</th>
<th>Case III: Operation w/TIFI</th>
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</thead>
<tbody>
<tr>
<td>$/Year</td>
<td>$0</td>
<td>$4,610,230</td>
<td>$6,068,164</td>
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**Total Savings (Compared to Baseline)**

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<th>Yearly Savings</th>
<th>Case I: Baseline Operation</th>
<th>Case II: Test Burn w/o TIFI</th>
<th>Case III: Operation w/TIFI</th>
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<tr>
<td>$/Year</td>
<td>$0</td>
<td>$2,947,990</td>
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**Return on TIFI Program Investment**

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<th>ROI</th>
<th>Case I: Baseline Operation</th>
<th>Case II: Test Burn w/o TIFI</th>
<th>Case III: Operation w/TIFI</th>
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<tbody>
<tr>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>4.2</td>
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</table>
Low-NOx Burner Case Study

- Midwestern Utility
- 670 MW Opposed Wall-Fired Unit
  - Front & Rear Walls Each Have 12 Burners
- Fuel Tech Scope of Supply
  - Turnkey project with water wall tube replacement, refractory, insulation, additional platforms, mechanical and electrical
  - LNB and OFA port installation and commissioning early 2011
- Achieved 60% NOx Reduction
- Economizer CO less than 350 ppm
- Loss on Ignition (LOI) less than 1%
Low-NOx Burner Case Study

CKM Analysis of Existing & New Burners

Figure 11: Comparison of NOx ppm Dry Profiles of Existing vs. Low NOx Burner
7.3. Streamline Comparison of Existing OFA and New OFA

Figure 21: Streamlines from Existing OFA Ports and New OFA Ports – Side View
Advanced SCR Technology

- Layered Technologies of LNB/OFA/SNCR/SCR as Needed
- Single Layer SCR Catalyst
  - No need for new foundation and heavy structural work
- Ammonia Slip from SNCR Provides Reagent for Catalytic Reactions – AIG used to supplement
- NOx Reduction Performance - 50-85%
- Lower Capital Cost ($30 to $75 per kW) compared to Full Scale SCR (Up to >$300/kW)
ASC R Case Study 1

- **32 MW, B&W front wall-fired unit with 6 burners**
  - 29,334 lb/hr Coal; 372,187 lb/hr Air (14% excess)
  - Coal Heating Value: 11,291 BTU/lb
  - Primary/secondary/OFA splits
    - Primary: 63,510 lb/hr (17.1%)
    - Secondary: 234,239 lb/hr (62.9%)
    - OFA: 74,438 lb/hr (20%)
  - Baseline NOx: 0.42 lb/mmBTU

- **ASC R Design**
  - Combustion Mods: 21% removal (0.33 lb/mmBTU)
  - SNCR: 20% removal (0.26 lb/mmBTU)
  - SCR: 25% removal (0.195 lb/mmBTU)
  - Total: 53.5% removal
ASCR Case Study 2

- Industrial Steel Plant
- 200 tonnes/hr (~50 MW) Tangential-Fired Unit
- Indonesian Adaro Coal / Coke Oven Gas

ASCR Design
- Combustion Mods: 52% removal (230 ppm to 110 ppm at 6% $O_2$)
- SNCR: 36% removal (110 ppm to 70 ppm at 6% $O_2$)
- SCR: 29% removal (70 ppm to 50 ppm at 6% $O_2$)
- Total: 78% NOx removal

- Project Underway, Commissioning in 2012
Where Does PEPSE Fit In?

• Fuel Tech’s CFD and Chemical Kinetics Models do not model the water/steam side of things. PEPSE helps to complete the boiler modeling arsenal.

• The goal is to develop expertise with PEPSE within Fuel Tech to:
  – Better predict performance changes that result from the installation of Fuel Tech’s Technologies.
  – Provide a value-added service to our customers by being geared to answer other performance-related questions.
Previous PEPSE Modeling

- **Objective:** Determine the change in flue gas temperature at the economizer outlet, at reduced load, with the SNCR System dilution water in service.

- **Result:** PEPSE Model of the boiler was developed, with an extra source stream of water injected into the furnace to simulate urea injection dilution water. The results showed minimal change in economizer outlet flue gas temperature.
Questions?