Development of Cost Effective Oxy-Combustion for Retrofitting Coal-Fired Boilers

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Who We Are: Babcock & Wilcox PGG

Since 1867, we are the original Babcock & Wilcox with extensive experience in engineering, manufacturing, constructing and servicing steam generating and environmental control systems.

George Babcock

Stephen Wilcox
B&W Oxy/Coal Combustion Experience

- 1979 Numerical Modeling per request of a major oil company
- 2000 Member CANMET

Recent Developments with Air Liquide Collaborations

- 2001-2002 - Oxy-combustion with IL#6 coal performed at 5 million Btu/hr SBS facility, sponsored by the State of Illinois
  - Substituted secondary air with recycled flue gas & oxygen
  - Gained experience with oxygen/flue gas mixing and combustion
- 2003-2004 - Oxy-combustion with PRB, sponsored by DOE
  - Demonstrated oxy-combustion at 5-million Btu/hr, achieved stable low-NO$_x$ flame with acceptable heat transfer conditions
- 2005-2006 - Economic analysis
  - Working with DOE, Parsons, Air Liquide
  - Oxy-combustion compared favorably to amine scrubber
- 2007-2008 – 30 MW$_{th}$ Demonstration at B&W’s CEDF
  - Near-Full scale burner development fed directly from an on-line pulverizer
Development of Cost Effective Oxy-Combustion for Retrofitting Coal-Fired Boilers

- **Funding Sponsors**
  - DOE $2,762,643
  - B&W/Air Liquide $690,644
  - Total $3,453,287

- **Project Duration**
  - March 2006 to September 2009

- **Project Team**
  - B&W
  - Air Liquide
  - Battelle Memorial Institute
Project Objectives

To Significantly Expand the Applicability of Oxy-Combustion:

- Evaluate the effect of coal rank that is currently used in existing boilers (i.e., bituminous, sub-bituminous and lignite) in an oxy-combustion design.
- Determine the equipment requirements for the boiler island, flue gas purification, CO₂ compression, transportation, and storage for different coals and combustion systems (cyclone and wall-fired).
- Investigate the potential for multi-pollutant (NOₓ, SO₂, and particulate) reduction.
- Validate an existing 3-dimensional computational flow, heat transfer, and combustion model for oxy-combustion scale-up to a commercial size boiler.
- Conduct an engineering and economic assessment of the technology for commercial-scale for cyclone and wall-fired units.
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Process Modeling

- **Boiler island**: modeling to predict flue gas compositions

- **Sequestration**: simulations to determine “sequestration-ready” gas specifications

- **CO₂ CPU**: process design to capture CO₂ from flue gas for sequestration purposes

- 3 coals considered
  - North Dakota Lignite
  - Decker coal (sub-bituminous)
  - Illinois #6 coal (bituminous)
Flue Gas Composition from Boiler

- Flue gas compositions predicted assuming high air infiltration rate & minimal SO$_2$ removal with bituminous coal

<table>
<thead>
<tr>
<th></th>
<th>ND Lignite</th>
<th></th>
<th></th>
<th>Decker</th>
<th></th>
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<th>Illinois # 6</th>
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<tr>
<td></td>
<td>Wet mol%</td>
<td>Dry mol%</td>
<td></td>
<td>Wet mol%</td>
<td>Dry mol%</td>
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<tr>
<td>H$_2$O</td>
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<td>17.42</td>
<td>0.00</td>
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<td>17.43</td>
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<td>CO$_2$</td>
<td>59.63</td>
<td>72.20</td>
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<td>59.57</td>
<td>72.14</td>
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<td>58.18</td>
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<td>N$_2$</td>
<td>16.01</td>
<td>19.38</td>
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<td>16.32</td>
<td>19.76</td>
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<td>O$_2$</td>
<td>4.10</td>
<td>4.96</td>
<td></td>
<td>4.00</td>
<td>4.85</td>
<td></td>
<td>4.11</td>
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<td>SO$_2$</td>
<td>0.3797</td>
<td>0.46</td>
<td></td>
<td>0.1350</td>
<td>0.16</td>
<td></td>
<td>0.1004</td>
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<tr>
<td>Ar</td>
<td>2.40</td>
<td>2.90</td>
<td></td>
<td>2.50</td>
<td>3.03</td>
<td></td>
<td>2.50</td>
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<td>NO$_2$</td>
<td>0.0619</td>
<td>0.075</td>
<td></td>
<td>0.0248</td>
<td>0.030</td>
<td></td>
<td>0.0380</td>
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<td>CO</td>
<td>0.0165</td>
<td>0.020</td>
<td></td>
<td>0.0165</td>
<td>0.020</td>
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<td>0.0165</td>
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</table>

- Low air infiltration case also considered
  - N$_2$ reduced to 10%
Reservoir and Geochemical Interactions

- Co-sequestration of CO$_2$ and SO$_2$ appears to be technically feasible in many deep saline reservoirs, but the injection lifetime of these reservoirs could be reduced if precipitation reactions take place.
- In carbonate-rich formations, sulfate could be a problem. Geochemical modeling results indicate that screening must be done to identify potential precipitation of sulfate minerals, such as anhydrite, which could reduce injectivity.
- To maintain supercritical state in a mixture of CO$_2$ and noncondensable gases, the flue gas will need to be injected in formations with higher pressure than would be needed for pure CO$_2$.
- In some reservoirs, storage space may be so limited that it is necessary to remove N$_2$ and O$_2$ to maximize the storage capacity.
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- Existing CO₂ pipeline specifications are mainly for gasification units
  - No NOₓ guidelines
  - Limited SOₓ guidelines
  - Significant variation in other specifications
    - H₂O: -5°C to -40°C dew point
    - O₂: 10 to 100 ppmv

- Specifications assumed for this study:
  - 175 bara
  - 90% CO₂ capture (DOE target)
  - H₂O reduced to 30lb/MMSCF (~600ppmv)
    - existing Kinder Morgan specification
  - No restriction on other gas components
    - Possibility of co-sequestration
    - Chance to assess tradeoff between purification cost and sequestration cost
Basic CO₂ CPU Process

- **3 processes**
  - No purification
    » only drying to Kinder Morgan specifications
  - Partial condensation at cryogenic conditions (cold box)
    » 95% CO₂ purity target
  - Cold box, including distillation
    » 1 ppm O₂ target
Operating Energy Requirement of CPU

- Addition of a cold box REDUCES specific energy requirement!
  - Will a different pipeline pressure requirement give different results?
• Above 125 bar (1815 psi) pipeline pressure, cold box + distillation has lowest specific energy requirement
Operating Energy Requirement of CPU

- Low air infiltration reduces power need by 15-18%

Compare with 150-160 kWh/ton
- Due to high pipeline pressure requirement, CO$_2$ purification reduces specific energy (Compare to compression only case)

- Air Infiltration has a significant effect on overall energy requirement of oxy-coal combustion

- It has to be evaluated (experimentally) whether the wet compressors can handle the SO$_x$ and NO$_x$ levels in the wet flue gas from the boiler island
  - Not in the scope of this project
Pilot-Scale Process

Diagram includes:
- Furnace
- Convection Pass
- Trim Heater
- Flue Gas Cooler
- SA Heater
- Baghouse
- WFGD
- Stack
- ID Fan
- Recycled Flue Gas (RFG) to Boiler
- Raw Coal Feeder
- Mill
- Pulverizer Air Heater
- PA Heater
- BTH
- PC
- Primary Oxynator
- Secondary Oxynator
- Secondary O₂
- Primary O₂
- Primary Air (PA)
- Secondary Air (SA)
- SA Fan
- PA Fan
- Cooling Air Fan
- Vent Air
- Vent
- Furnace Water In
- CP Water In
- Furnace and CP Blowdown
- Burner Lance O₂
- Overfire Oxidant
- Primary RFG
- Secondary RFG
Significantly Expand Applicability
- Bituminous, PRB, lignite
- Cyclone firing

New Oxy-Combustion ready Facility
- 6 million Btu/hr – SBS- II
- Cyclone and Wall-firing
- Dry/Wet Scrubber
- Construction Completed
- Just passed EPA performance

Currently Planning for:
- DOE Oxy-cyclone
- USC Materials Oxy-combustion

2nd to 4rd Quarter 2009 Testing
<table>
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<tr>
<th>U.S. State</th>
<th>Vintage</th>
<th>$MW_e$</th>
<th>Eff. (HHR)</th>
<th>Coal Type</th>
<th>SOx (ppm)</th>
<th>SO2 Control</th>
<th>NOx Control</th>
<th>Selection</th>
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<tbody>
<tr>
<td>Illinois</td>
<td>1967, 1968</td>
<td>2x 660</td>
<td>33%</td>
<td>Sub-bituminous</td>
<td>200-300</td>
<td>No</td>
<td>OFA/-SCR</td>
<td>Good Location (primary and secondary targets)</td>
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<tr>
<td>Indiana</td>
<td>1974</td>
<td>521</td>
<td>32%</td>
<td>Sub-bituminous</td>
<td>200-300</td>
<td>No</td>
<td>OFA/-SCR</td>
<td>Marginal Location (locally shallow; needs long pipeline)</td>
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<tr>
<td>North Dakota</td>
<td>1977</td>
<td>440</td>
<td>30%</td>
<td>Lignite</td>
<td>700-800</td>
<td>Yes</td>
<td>OFA</td>
<td>Satisfactory</td>
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<tr>
<td>Missouri</td>
<td>1972, 1977</td>
<td>2x 600</td>
<td>33%</td>
<td>Sub-bituminous</td>
<td>200-300</td>
<td>No</td>
<td>SCR</td>
<td>Near seismic zone</td>
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<tr>
<td>Kentucky</td>
<td>1963</td>
<td>2x 650</td>
<td>35%</td>
<td>Bituminous</td>
<td>2000</td>
<td>Yes</td>
<td>OFA/-SCR</td>
<td>Near fault zone</td>
</tr>
</tbody>
</table>
Path to Commercialization

B&W & Air Liquide have performed the following activities:

- Pilot-scale proof of concept – Sponsored by DOE and State of Illinois
- Near-full scale demonstration at B&W’s 30 MW_{th} CEDF
- Engineering and System integration studies
- **Significantly expand the applicability of the technology – this project**
- We are currently planning for a commercial demonstration of the technology
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