CO2 Technology Update

Steve Moorman – Mgr Business Development
Advanced Technologies
Advanced Technology Program Emphasis

Advanced Ultra-Supercritical
Confirm new designs, materials

Oxy-Combustion
Get to the demo with DOE

Advanced Energy
Non-coal solutions – solar, biomass

Advanced Environmental
Move catalyst systems to demo

CO₂ Scrubbing
Lab to pilot to demonstration
Babcock & Wilcox Research Center
Advanced Technology Development

Innovation with a vision for solutions
• Cap & Trade or Carbon Tax -- are all $$$$

• The path forward for Carbon Capture and Storage is of great interest to all of us – government, generators, suppliers, consumers

• Scale of CO2 capture is a huge – hundreds of millions of tons
  
  A 600 MW PC Plant produces about 781,000 lbs/day of SO2 (@ 3% Sulfur)
  33,000,000 lbs/day of CO2 (@ 70 % Carbon)

• How will we replace the lost capacity?

• Two components – “capture” and “storage” are both required but different paths, different players, different opportunities

• Technology indicates that the reductions are plausible, but an aggressive multi-dimensional response will be needed

• What will be the cost and will consumers ultimately be willing to pay??
Carbon Capture Technologies

Pre-Combustion

Air Separation Unit → Gasifier → CO₂ Separation & Compression → Gas Turbine

Oxy-Coal Combustion

Air Separation Unit → Boiler → CO₂ Compression

Post Combustion

Boiler → CO₂ Separation & Compression → Flue Gas

No obvious winner at this point
Oxy-Coal Combustion Principles

- Oxy-combustion is a means of replacing the nitrogen that comprises 80% of normal air with CO₂ by recycling flue gas from the combustion process. The subsequent increase in the CO₂ concentration in the flue gas facilitates its capture and storage.
  - Flue gas from coal combustion contains about 13% CO₂ making it difficult and costly to remove in a post-combustion scrubbing process
  - By concentrating the CO₂ up to 85% in the flue gas stream the CO₂ is more easily captured and compressed for storage
- Nearly pure oxygen from the Air Separation Unit is mixed with CO₂ from the flue gas to form “synthetic” air for the combustion process
- The CO₂ from the combustion process is cleaned and compressed in the Compression and Purification Unit prior to transporting via pipeline to the permanent storage location
Oxy-Coal Combustion Principles

Air

Oxygen → + Coal → CO₂ → Nitrogen

Oxy

Oxygen → + Coal → CO₂ → CO₂

70-80% reduction in flow rate to CO₂ capture process

Percent by Volume

<table>
<thead>
<tr>
<th>Component</th>
<th>Air</th>
<th>Flue Gas after WFGD</th>
</tr>
</thead>
<tbody>
<tr>
<td>N₂</td>
<td>75</td>
<td>0</td>
</tr>
<tr>
<td>O₂</td>
<td>25</td>
<td>100</td>
</tr>
<tr>
<td>CO₂</td>
<td>0</td>
<td>70-80% Lb/hr</td>
</tr>
</tbody>
</table>

Percent by Volume

<table>
<thead>
<tr>
<th>Component</th>
<th>Synthetic Air</th>
<th>Flue Gas to CPU</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂O</td>
<td>75</td>
<td>0</td>
</tr>
<tr>
<td>CO₂</td>
<td>25</td>
<td>100</td>
</tr>
<tr>
<td>O₂</td>
<td>0</td>
<td>70-80% Lb/hr</td>
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</table>
Oxy-Fuel Plant Configuration

**ASU**
- Air In
- Nitrogen ($N_2$) Out
- Pure Oxygen ($O_2$)

**Boiler Island**
- Coal In
- Recycled Flue Gas
- CO$_2$ and Flue Gas
- Environmental Cleanup Equipment
- Ash
- $H_2O$
- $SO_2$
- Other Captured Emissions

**CPU**
- Other gases (NCGs)
- CO$_2$ Compression
- CO$_2$ Capture (liquid)
30 MW_{th} Test Facility located in Alliance, Ohio

- Built in 1994 with DOE and others
- 100 Million Btu/hr input with coal
Oxy-Coal Testing at CEDF Successfully Completed in 2008
Oxy Demo Plant Arrangement

150 MW_{\text{gross}} - 100 MW_{\text{net}}

PC – PRB Subcritical Boiler
Project Objectives

- Establish technical and economic viability of a Near-Zero Emissions plant for pulverized coal-fired power (SO$_2$, NO$_x$, Hg and PM)
- Safely capture and permanently store large volumes of CO$_2$ in deep saline formations or EOR
- Build the knowledge to make informed CO$_2$ policy decisions for coal-based power plants
- Develop a public education program on transport and permanent underground storage of large volumes of CO$_2$
- Given coal is our nation’s most abundant energy resource, demonstrate that coal can remain a long-term solution for reliable electric power generation
Environmental Performance of Oxy-Coal Near Zero Emission Plant (NZEP)

- IGCC has been touted as best emissions performance
- Oxy with CCS is predicted to be lower by several orders of magnitude

Present reliable measurement limit (lb/Mbtu)

<table>
<thead>
<tr>
<th>Emissions</th>
<th>IGCC with CCS</th>
<th>Oxy-fuel with CCS</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOx in lb/MBtu</td>
<td>.005</td>
<td>.005</td>
</tr>
<tr>
<td>SOx in lb/MBtu</td>
<td>.005</td>
<td>.005</td>
</tr>
<tr>
<td>Particulate in lb/Mbtu</td>
<td>.0005</td>
<td>.0005</td>
</tr>
<tr>
<td>Hg in lb/TBtu</td>
<td>.4</td>
<td>.4</td>
</tr>
</tbody>
</table>

Logarithmic Scale
Oxy-Coal Demonstration Plant

Project Schedule

- Selection 4th Qtr 2009
- Award – 3rd Qtr 2010
- NEPA Study – 2010 thru 2011
- Begin Matl Procurement – Late 2011
- Begin Erection – Mid 2012
- Startup – Late 2015
- Commercial – Early 2016
- Begin CO2 to EOR / Storage – Mid 2016
- Complete Demo – 2019

Almost 10 years to complete 1 demonstration!
**CO₂ Capture Cost: Effects of Learning**

McKinsey and Company Study: “Assessing the Economics”

- Early plants to be small
- Focus to be on learning and not operating efficiency
- Benefits occur with scale
- Early commercial and mature plants will be larger

Oxy Plant Stacks Up Well

- Demo within range of expectations
- Reference Plant at ~ $50/ton
- What are people willing to pay?

**Levelized Cost of Electricity Comparison**

- **Case 1**: SC PC Air-Fired (6.32 c/kWh)
- **Case 2**: USC PC Air-Fired (6.44 c/kWh)
- **Case 1**: IGCC Avg Air-Fired (7.78 c/kWh)
- **Case 5**: SC PC Oxy-Fired w/CCS (10.47 c/kWh)
- **B&W**: SC PC Oxy-Fired w/CCS (9.63 c/kWh)
- **Case 2**: IGCC Avg w/CCS (10.63 c/kWh)
- **B&W**: USC PC Oxy-Fired w/CCS (8.94 c/kWh)

* Data from DOE/NETL 2007-1291 (revised Case 5 data)
** Data from DOE/NETL 2007-1281, averaged for IGCC as DOE did for DOE/NETL-1291
*** Data from B&W Integration Study 2008
Net Plant Efficiency Comparison

<table>
<thead>
<tr>
<th>Technology</th>
<th>Net Plant Efficiency % (HHV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1* SC PC Air-Fired</td>
<td>39.4</td>
</tr>
<tr>
<td>Case 2* USC PC Air-Fired</td>
<td>44.6</td>
</tr>
<tr>
<td>Case 1** IGCC Avg Air-Fired</td>
<td>39.4</td>
</tr>
<tr>
<td>Case 5* SC PC Oxy-Fired w/CCS</td>
<td>29.3</td>
</tr>
<tr>
<td>B&amp;W*** SC PC Oxy-Fired w/CCS</td>
<td>33.6</td>
</tr>
<tr>
<td>Case 2** IGCC Avg w/CCS</td>
<td>32.1</td>
</tr>
<tr>
<td>B&amp;W*** USC PC Oxy-Fired w/CCS</td>
<td>37.5</td>
</tr>
</tbody>
</table>

* Data from DOE/NETL 2007-1291 (revised Case 5 data)
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*** Data from B&W Integration Study 2008
How will CCS systems get into the existing fleet?

**Technical issues**

- Space for CCS equipment – very large footprint for either CO2 Scrub or Oxy 4 – 6 acres for a ~ 500 Mwnet plant
- Loss of plant output - Steam for Scrub or Aux power for ASU / CPU ~ 25-35%
- Plant Performance changes
  - Ability to cycle, load swing will be minimized
- Plant capacity upgrades – how much could be recovered from a typical plant
- Water / wastewater treatment modifications potential net+ water balance
- Additional NOx and SOx reductions may be needed for CO2 purity
- ΔP increase to system resistance effects on:
  - Boiler, Fans, Flues
- Difficult to incorporate heat integration into existing plant processes
- Outage time required for changeover
How will CCS systems get into the existing fleet?

Other issues

- How will CO2 cap and trade compare to SO2 C&T
- What will be the trigger price of CO2 for projects to go forward
- Will partial capture be a consideration
- How will the permitting process be affected by NZE and FOAK status
- How will Aux power required for CCS be replaced in the system
- Can we assure early CCS units have the flexibility to incorporate future technology improvements
- Access to permanent storage, EOR opportunities, CO2 pipelines
- What will consumers ultimately be willing to pay to affect climate change
Geologic Storage Potential

Source: Battelle, Pacific Northwest Division – Provided by Judd Virden
CO2 Scrubbing with B&W RSAT™
**RSAT™**

- Significant scale: 7 tonnes/day
- Absorber and Regenerator Columns – 2 ft diameter x 66 ft tall
- Can operate on boiler or synthetic flue gas
Concentrated Solar Power (Thermal)

2x10 MWt solar field
B&W Modular Reactor

500 MWe Plant Using 4 - 125 MWe Modules
B&W’s Commitment to Clean Power

- Biomass Power Plants
- Waste-to-Energy
- Concentrated Solar Thermal
- Biomass Gasification

- Nuclear services / construction
- Nuclear steam generators
- Commercial nuclear component fabrication
- Government operations

- High efficiency SCPC w/o CCS
- Ultra-supercritical boilers with CCS
- Advanced USCPC 1400F cycle
- Advanced low mass flux SCPC

- Oxy-coal retrofit application
- Oxy-coal new boiler application
- RSAT™ CO₂ scrubbers