IEAGHG 2011 International CCS Summer School
Champaign, Illinois; July 17-23, 2011

KJ McCauley
Director, Advanced Technology Development
Oxy-combustion: Laboratory to Deployment

- Near zero emissions and greater than 90% CO₂ capture
- Combustion system with pure oxygen and recycled CO₂
- Reference plant design completed
- Ready now to validate at commercial scale – new build, repowering or retrofit (eg: FG 2.0 200 MWe)
- Oxygen supply system provides added operation flexibility

Clean Environment Development Facility (CEDF), Alliance, Ohio
The Babcock & Wilcox Company
Leading technology innovator in power generation and nuclear components with a legacy spanning more than 140 years

Government Operations

- Supplies components for submarines and aircraft carriers
- Provides various other services to U.S. Government, primarily within the nuclear weapons complex of the DOE

Power Generation Systems

- Designs, engineers, manufactures and constructs large utility and industrial power generation systems
- Supplies fossil-fired boilers, commercial nuclear steam generators and components, and environmental equipment and related aftermarket parts and services
**B&W – Power Generation Group**

**Global Reach**

- Major locations

**Product Line Portfolio**

- **Traditional Power**
  - Steam Generation (e.g.: USC-PC)
  - Service and O&M (Operation & Maintenance)
  - Construction and EPC (Engineer-Procure-Construct)
  - Boiler Cleaning and Material Handling

- **Clean Coal**
  - Environmental Systems and Service
  - SO₂, NOx, Mercury, PM
  - CO₂ RSAT Scrubber, Oxycombustion

- **Renewables**
  - Biomass
  - Solar
  - Energy-from-Waste

**Total Employees: ~ 8,700**

- Including JV employees

- Installed 38% of boilers in North American coal-fired power plants
- Supplied worldwide capacity of more than 300,000 MW in 800+ utilities in 90+ countries
- Manage operations and maintenance of North America power facilities
OxyCombustion Principles

Conventional Combustion

- Oxygen
- Nitrogen
- Fuel

Oxy-Coal Combustion

- Oxygen
- Carbon Dioxide

Flue Gas
- Nitrogen
- Oxygen

20 to 30% flow rate to CO₂ capture process

Synthetic Air
- Flue Gas
- Oxygen
Near Zero Emission Plant (NZEP) Design

- Total flue gas stream is treated.
- Oxy-Coal predicted to be lower by several orders of magnitude.
- Not an extractive system.
Oxycombustion Technology R&D Summary

- 1.8 MWth small pilot testing
- Computer modeling and simulation validated
- Greenfield and retrofit pre-FEED proposals
- PC Oxy-combustion Power Plant study DOE/NETL 2007-1291
- 30 MWth CEDF large pilot testing, three coal types
- Detailed integration studies completed
- Reference plant design completed for EPRI
B&W Small Pilot

B&W Small Boiler Simulator
(SBS; 1.8 MWth)
B&W Large Pilot

Clean Environment Development Facility

(CEDF; 30 MWth)
Plaint Specification

Coal: Sub-bit, 8400 Btu/lb, 0.32% S
Steam: 3750 psig, 1100F/1100F
Cooling: Wet
Location: Kenosha, Wisconsin
Basis: EPRI Specifications & TAG
700 MWe Reference Plant

Process Schematic
## 700 MWe Reference Plant

### Plant Performance

<table>
<thead>
<tr>
<th>Performance Parameter</th>
<th>Baseline Plant</th>
<th>Oxy-PC Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross Plant Output, kW</td>
<td>697,778</td>
<td>701,696</td>
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<tr>
<td>Power Block Auxiliary Power, kW</td>
<td>19,008</td>
<td>16,713</td>
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<tr>
<td>ASU Auxiliary Power, kW</td>
<td>N/A</td>
<td>89,100</td>
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<tr>
<td>CPU Auxiliary Power, kW</td>
<td>N/A</td>
<td>60,900</td>
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<tr>
<td>BOP Auxiliary Power &amp; Transformer Losses, kW</td>
<td>21,792</td>
<td>26,361</td>
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<tr>
<td>Total Aux Power, kW</td>
<td>40,801</td>
<td>193,075</td>
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<tr>
<td>Net Plant Output, kW</td>
<td>656,977</td>
<td>508,621</td>
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<tr>
<td>Plant Fuel Consumption, klbs/hr</td>
<td>683.8</td>
<td>656.6</td>
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<tr>
<td>Plant Heat Input, MBtu/hr (HHV)</td>
<td>5744</td>
<td>5515</td>
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<tr>
<td>Net Plant Heat Rate, Btu/kWh (HHV)</td>
<td>8,743</td>
<td>10,842</td>
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<tr>
<td>Net Plant Efficiency, % (HHV)</td>
<td>39.0</td>
<td>31.5</td>
</tr>
</tbody>
</table>
700 MWe Reference Plant

Plant Plot Plan

- Power Block
- ASU
- Steam Turbine Building
- Cooling Towers
- CPU
Special Design Considerations

- **Air In-leakage**
  - Use of CO$_2$ for sealing systems uniquely designed
  - Pressure profile through the system optimized, balanced draft

- **Use of Nearly Pure Oxygen**
  - Standard industry practices for low pressure operational safety
  - Oxygen distribution system in flues designed for uniform mixing
  - Oxygen concentrations monitored closely by control system

- **Leakage of Flue Gas with High CO$_2$ Concentration**
  - Pressure boundary sealing systems uniquely designed
  - CO$_2$ monitors in sensitive external confined space areas
  - Building local ventilation system design, and system internal purge controls

- **Acid Gases and Corrosion**
  - Sulfur trioxide removal increased, adjusted minimum temperature limits used in boiler design and operation, and expanded use of corrosion resistant materials

- **Plant Operability**
  - Part load operation, daily cycling flexibility, extended air-firing periods

- **Heat Integration: Feedwater, Condensate, Oxygen**
  - Heat available from ASU, CPU and Flue Gas
# DOE Large Scale CCS Projects

<table>
<thead>
<tr>
<th>Project</th>
<th>Location</th>
<th>Capture Rate (tonnes/yr)</th>
<th>Repository</th>
<th>Start Date</th>
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<tbody>
<tr>
<td>Oxy-Combustion</td>
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<tr>
<td>FutureGen 2.0</td>
<td>Meredosia, IL</td>
<td>1,150,000</td>
<td>GS</td>
<td>2015</td>
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<tr>
<td>Pre-Combustion Capture (IGCC)</td>
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<tr>
<td>Summit Texas Clean Energy</td>
<td>Odessa, TX</td>
<td>2,700,000</td>
<td>EOR</td>
<td>2014</td>
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<tr>
<td>Southern Company</td>
<td>Kemper County, MS</td>
<td>1,800,000</td>
<td>EOR</td>
<td>2014</td>
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<tr>
<td>Hydrogen Energy California</td>
<td>Kern County, CA</td>
<td>1,800,000</td>
<td>EOR/GS</td>
<td>2016</td>
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<tr>
<td>Post-Combustion Capture</td>
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<tr>
<td>Basin Electric</td>
<td>Beulah, ND</td>
<td>450,000-1,360,000</td>
<td>EOR/GS</td>
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<td>NRG Energy</td>
<td>Thompsons, TX</td>
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<td>American Electric Power</td>
<td>New Haven, WV</td>
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<td>Industrial CCS Solicitation</td>
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<tr>
<td>Leucadia Energy</td>
<td>Lake Charles, LA</td>
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<td>Air Products</td>
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<tr>
<td>Archer Daniels Midland</td>
<td>Decatur, IL</td>
<td>900,000</td>
<td>GS</td>
<td>2014</td>
</tr>
</tbody>
</table>

- Three projects with geologic storage
- FG2.0 now flagship for “Integrated Demonstration”
FutureGen 2.0 Project Organizational Structure

- U.S. Department of Energy (Project Oversight)
- Ameren Energy Resources (Technology Collaboration Agreement)
- B&W Power Generation Group (Oxy-Combustion Boiler and GQCS)
- Air Liquide (ASU & CPU)
- WorleyParsons

Other providers include:
- CO₂ Pipeline & Storage Hub
- Project Management & Execution

Proprietary and Confidential
**FutureGen 2.0 Project Schedule & Status**

### Four Phases

<table>
<thead>
<tr>
<th>Phase I</th>
<th>Phase II</th>
<th>Phase III</th>
<th>Phase IV</th>
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</thead>
<tbody>
<tr>
<td>Pre-FEED (Front End Engineering Design)</td>
<td>FEED</td>
<td>EPC and Startup</td>
<td>Test Period</td>
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<tr>
<td>October 2010 to October 2011</td>
<td>October 2011 to October 2012</td>
<td>November 2012 to April 2016</td>
<td>May 2016 to December 2018</td>
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</tbody>
</table>

### Status

- DOE cooperative agreement signed September, 2010
- Teaming Agreement (AER, AL, and B&W PGG) signed October, 2010
- Project teams mobilized
- URS selected as Ameren’s A/E
- Phase 1 is basic design, project schedule & estimate, permit applications and is progressing on schedule
- WorleyParsons selected as B&W’s A/E in February, 2011
- DOE Phase 1 Review in the late Summer 2011
FutureGen 2.0 Process Schematic
FutureGen 2.0 – Carbon Capture Plant
**FutureGen 2.0 CO₂ Transport & Storage**

FGA announce Morgan County selected Feb. 2011

4500 ft Deep Saline Formation (DSF) in Morgan County (~32 miles pipeline from the plant)

**Reservoir**
Potential CO₂ Storage Resource (billion metric tons)
Mt. Simon Sandstone - 27 to 109

**State**
Potential CO₂ Storage Resource (billion metric tons)
Illinois 20 to 79
Indiana 7.9 to 32
Kentucky 1.5 to 6.3
Total 29 to 117 billion metric tons
Oxy-combustion Benefits

- Near zero air emissions
- Low fresh water use
- Safety procedures already industry practiced
- Conventional proven equipment
- Looks like and operates like a current power plant (minimal retraining)
- Construction lead time similar to conventional plants
“We are passionate about innovation and technology leadership”

Thank-you

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