Oxy-combustion for CO$_2$ capture in pulverized coal boilers (PC-OC)
Key Drivers

- Climate change
  - Awareness raising
  - Ambitious targets “Factor 4”
- Need to reduce GHG emissions

Coal role in energy mix
- Large availability in some areas
- Need technologies for clean coal use
Clean fossil fuel technology pathways

Multiple pathways for multiple applications & situations

1. Post-combustion: scrubbing
2. Pre-combustion: hydrogen
3. Pre-combustion: oxy-fuel & CO₂ concentration

- Natural Gas
- Heavy Oil
- Coal/Lignite

- Conventional Boiler & Gas Turbine
  - Reforming / CMR
  - Partial Oxidation
  - Gasification
- Water Shift + CO₂ Separation
- Oxycombustion (all fuels)
- CO₂ Capture
  - Scrubbing
  - Adsorption
  - Membrane,
  - Cryogenics...
- CO₂ Handling
- Transportation
- CO₂ Storage

HRSG & H₂ rich GT
Oxy-combustion Developments

- Years of Industrial Experience
- Large Pilot Facilities
- Several Projects covering most Fuels
- Direct Oxy and FGR

Natural Gas

Liquid/HFO

Coal/Lignite
Oxycombustion in PC Boilers ("PC-OC")

- Raw coal
- Pulverizer
- Boiler
- Steam
- Water
- Flue gas drying, CO₂ compression
- FGD
- ESP
- Sulfur
- Ash
- Water
- CO₂ transport & storage
- Flue Gas Recycling (FGR)
- Pure Oxygen
- ASU
- AIR
- Added for CO₂ capture vs reference plant (air-fired PC without CO₂ capture)
Pilot Modifications for Oxycombustion

B&W’s Small Boiler Simulator (SBS)
5 million Btu/hr - 1.5 MWth

Flue Gas Recycling (FGR)

Oxynator

Oxygen Supply System

Coal & O₂/Flue Gas

O₂/Flue Gas

Primary superheater

Reheater

Secondary superheater

OFA

O₂/Flue Gas

O₂/Flue Gas to stack

CO₂

O₂

NOₓ

SO₂

CO
Pilot tests Results

- **Successful demonstration and process characterization**

  - **Technical feasibility demonstrated**: Safe and smooth conversion from air-fired to O₂/Flue Gas operation
  - **Flue gas volume**: reduced by 80% ⇒ Reduced cost of CO₂ purification
  - **CO₂ content** in Flue Gases: increased from 15% in air-fired conditions up to 80% in oxy-combustion.
  - **NOₓ emission**: reduced by 60 to 70%
  - **Heat Transfer Performances**: similar in air and oxy firing ⇒ retrofit application ok

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**NOₓ emissions**

- 0.25-0.3 lb/10⁶Btu
- -60% to -70%
- 0.1 lb/10⁶Btu

**Flue gas volume**

- 15% CO₂
- 80% CO₂
- 96% CO₂
- -80%
Tests Results: Flue Gas Volume and Content

- Flue Gas Volume Reduced by 80%
- CO₂ concentration increased from 15% in air-firing to 80% in O₂-firing

<table>
<thead>
<tr>
<th></th>
<th>AIR</th>
<th>O₂/CO₂ exp (5% air infiltration)</th>
<th>O₂/CO₂ without air infiltration</th>
</tr>
</thead>
<tbody>
<tr>
<td>O₂</td>
<td>3%</td>
<td>3%</td>
<td>3%</td>
</tr>
<tr>
<td>CO₂</td>
<td>15%</td>
<td>80%</td>
<td>96%</td>
</tr>
<tr>
<td>N₂</td>
<td>82%</td>
<td>17%</td>
<td>1%</td>
</tr>
<tr>
<td>Volume</td>
<td>100 a.u.</td>
<td>19 a.u.</td>
<td>16 a.u.</td>
</tr>
</tbody>
</table>

a.u. = Arbitrary Units
Tests Results: NO$_x$ Emission

- NO$_x$ emission reduced by up to 70% vs air-firing

- NO “reburning” (FGR)
  NO $\Rightarrow$ N$_2$

- Control of temperature:
  - Higher devolatilization temp. via O$_2$ local enrichment:
    Fuel-NO$_x$ ↓
  - Control of flame peak temperature:
    Thermal NO$_x$ ↓

0.08 to 0.1 lb/10$^6$Btu

0.25-0.3 lb/10$^6$Btu

- 60% to - 70%

AIR, O$_2$/CO$_2$ exp
## Test Results: Heat Transfer Characteristics

### Typical Results

<table>
<thead>
<tr>
<th></th>
<th>Air</th>
<th>(\Delta (\text{Air} - \text{Oxycombustion})/\text{Air})</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Boiler Mass Flow Rate</strong></td>
<td>1</td>
<td>3.7 %</td>
</tr>
<tr>
<td><strong>FEGT</strong></td>
<td>1</td>
<td>4.69 %</td>
</tr>
<tr>
<td><strong>Convection Pass Temp.</strong></td>
<td>1</td>
<td>1.37 %</td>
</tr>
</tbody>
</table>

- Maintained similar Mass flow Rates in the boiler
- Convection Pass Exit Temperatures are similar
- Total Convection Pass Heat absorptions are similar
Conclusions of Experimental Tests

Technical Feasibility of the Oxycombustion Process

- An existing pilot-scale boiler has been modified to enable oxygen combustion in flue gas recycle.
- The feasibility of the oxycombustion process has been demonstrated on a pilot-scale (1.5MWth) unit designed for development of industrial boiler and burner technologies.
- A safe and smooth transition from air to oxy-combustion has been achieved.
- Improved know-how on O2 management in PP environment, operability & safety procedures.

CO2 Capture Capability

- The CO2 in flue gases has been concentrated to 80% (vol. Dry basis) vs 15% in air-firing. Additional developments are likely to further reduce the air infiltrations.
- The Flue Gas Volume has been reduced by 80% vs air-fired operation enabling cost effective removal of other pollutants if needed (depending on CO2 purity requirement).
Conclusions of Experimental Tests

- **Heat Transfer Characteristics**
  - Boiler exit gas temperatures and FEGT measurements indicate *similar heat temperature profiles*.
  - **Flame emissivity** is similar in air and (dry) $O_2$-firing operation
  - Flamme T controlled by FGR dilution
  - Combustion efficiency controlled via ad-hoc selection of $O_2$ content in each oxidant stream
  - ⇒ No adverse side effects on boiler performance is anticipated.

- **NO$_x$ emissions**
  - NO$_x$ emissions have been *reduced by up to 70%* vs staged air-firing operation: reduced need for SCR
Conclusions & next steps

- Oxy-coal combustion tests
  - No “show stopper” encountered regarding larger scale plants
  - Operational experience gained
  - Inherent NO\textsubscript{X} reduction

- O\textsubscript{2}/CO\textsubscript{2} combustion allows retrofit of existing PP

- New units would allow better management of air inlet

- New PP
  - CO\textsubscript{2} capture plants
  - “Capture-ready” plants
    ………. to be ready for capture

- Economics show oxy-coal is competitive

- Next steps
  - Detailed engineering studies
  - Participation to large scale demo plant
Thank you for your attention

Questions?
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