Oxyfuel CO₂ Capture for Pulverised Coal - An Evolutionary Approach

Presentation Outline

• Key Features
• Low Risk Evolutionary Approach
• Foundation
• Low Risk Oxyfuel ASC PF Power Plant - Process Flow Diagrams
• Low Risk Approach – General Considerations
• Major Power Plant Components - Low Risk Approach
• Power Plant Operational Expectations
• Future Developments
• Conclusions

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Oxyfuel CO₂ Capture – Key Features

• Use of mixture of near pure oxygen and CO₂ rich flue gas recycle as oxidant for fuel combustion; flue gas recycle mainly used to
  – retain conventional milling plant and combustion equipment
  – retain conventional furnace and boiler arrangement
  – maintain combustion and boiler thermal performance as that of conventional air-fired PF boiler

• Air Separation Unit (ASU) to remove inerts from air and supply near pure oxygen

• Purification and compression of CO₂ rich Oxyfuel flue gas to deliver high pressure CO₂ product.

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Advanced Supercritical Boiler Technology with Oxyfuel

<table>
<thead>
<tr>
<th>Gas Analysis (%v/v, wet)</th>
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<th>Oxyfuel</th>
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Air firing:
Coal + O₂ + 4N₂

Oxy firing:
Coal + O₂ + xCO₂

from ASU

Flue

FGD

CO₂ Recycle line

CO₂ Purification & Compression

Gas Analysis (%v/v, wet)

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Low Risk Evolutionary Approach

- Real or perceived risk associated with introduction of new process/technology
- Issue of scale of process and key plant components
- Build upon previous operational and practical experience
- Retain full air-firing capability in recognition of the above
- Boiler design to meet 100% MCR rating in both air-firing and Oxyfuel firing mode
- Delivery of low risk Oxyfuel technology comprising well proven, familiar plant components
- Deliver minimal technical and commercial risk to power generation

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• Investigations on Oxyfuel technology by Doosan Babcock since the early 1990s
  – Oxyfuel technology is competitive with alternate CO₂ capture technologies
  – Reduction in net plant efficiency due to CO₂ capture addition is similar or lower to that of alternate technologies.
  – Cost of electricity – increase due to capture addition is also similar or lower to that of alternate technologies

• Attractive in terms of similarities to air-fired plant

• Wide experience base of air-fired PF power generation technology

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With Oxyfuel Capability

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1. Install Flue Gas Recycle Heat to Steam Cycle
2. Add Oxygen Source
3. Add CO₂ Recovery
4. Install Heat Recovery

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Low Risk Approach – General Considerations

• Build upon air-fired PF power generation technology operational and practical experience and utilisation of familiar main plant equipment
  – Provide generators with confidence in the near term to move towards near emission free fossil fuel power generation

• Utilisation of well proven and commercially available plant components
  – Conventional coal handling, coal pulverising, combustion equipment, boiler, steam turbine, ASU

• Retain full air-firing capability, with appropriate and well proven emission control
  – Minimal risk to power generation

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Major Power Plant Components - Low Risk Approach (1)

• Air Separation Unit
  – Well proven, industry leading cryogenic air separation units
  – Low purity and pressure cycle

• Milling Equipment
  – Conventional plant
  – Use of clean/dry flue gas to dry and transport coal
  – Oxygen concentration and volumetric flow rate of primary FGR equivalent to that of primary air in conventional plant – studies anticipate similar mill performance for Oxyfuel compared to air-firing

• Combustion Equipment
  – Early application of Oxyfuel combustion will utilise burner designs derived from air-firing experience
  – Proven low NOx burner designs can be adapted to obtain acceptable combustion performance

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Major Power Plant Components - Low Risk Approach (2)

• Furnace and boiler
  
  – Advanced Supercritical Steam Cycle
  – Conventional two-pass balanced draught design
  – Conventional furnace arrangement – similar mechanical design limits
  – Radiant heat transfer dominated by particulates; marginal increase in overall radiant heat transfer (due to increase in non-luminous radiation by CO$_2$/H$_2$O)
  – FEGT typically slightly lower than the air-firing equivalent - avoids high temperature slagging in early banks
  – Clean FGR – corrosion no worse than for air-firing

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Major Power Plant Components - Low Risk Approach (3)

• NOₓ reduction
  – Appropriate NOₓ reduction technologies to ensure legislative compliance whilst in air-firing mode
  – Majority NOₓ reduction by in-furnace measures (Oxyfuel and air-firing)
  – Oxyfuel mode: Bypass of SCR (if provided) whilst Oxyfuel operation, if not required to assist in NOₓ reduction

• Air Heater / Gas-Gas Heater
  – Conventional regenerative type with appropriate material selection to mitigate cold end corrosion

• Flue Gas Recycle (FGR)
  – Single FGR take-off, with bifurcation to provide primary and secondary streams
  – Similar layout to conventional FGR systems
  – Clean FGR

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• Particulate Removal Equipment
  – Conventional ESP to ensure legislative compliance whilst in air-firing mode
  – Oxyfuel mode – mitigates erosion in fans and CO₂ capture equipment
  – Operating temperature (Oxyfuel mode) : 160 to 200°C – Not dissimilar to that of some existing air-fired plants

• Fans
  – FD Fan as FGR Fan
  – PA Fan as PFGR Fan
  – ID Fan as ID fan
  – Volume flow through FD & ID Fans unlikely to be exceeded in Oxyfuel mode (low volume flow)
  – Fan impellers, casing materials to suit air and Oxyfuel gas compositions

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Flue Gas Heat Recovery

- Similar to heat recovery equipment used in Combined Cycle Power Plants and CHP Plants
- Already realised in PF Power Plants also
- Considerations to protection against acid corrosion

SO\textsubscript{x} Reduction

- In FGR loop
- Conventional FGD Plant
- Ensures SO\textsubscript{2} and SO\textsubscript{3} concentrations in the furnace for Oxyfuel – no worse than air-firing
- Additional mitigation measures for control of SO\textsubscript{3}, if required (e.g. wet ESP)
- Co-capture of balance SO\textsubscript{x} along with CO\textsubscript{2} or 100% removal in CO\textsubscript{2} purification unit

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• Moisture Removal Equipment
  – Commercially available direct contact coolers or flue gas condensers
  – Ensures adequate fuel drying while in Oxyfuel mode

• Heating of ASU Oxygen Stream
  – No. of options available
  – Oxygen stream preheating with LP steam chosen
  – Preheating to 150°C – allows use of carbon steel materials
• Oxygen Stream Injection/ Mixing
  
  – Primary FGR oxygen concentration - equivalent to that in air
  
  – Injection downstream of gas-gas heater
    • Eliminates cross leakage losses
    • Eliminates contamination (due to oxygen stream leakage) of CO₂ rich flue gas to be processed
    • Eliminates risk of high oxygen concentration/ particle impingement on high speed fan blades
    • Reduces ASU, CO₂ Compression and Inerts Removal plant load
  
  – No direct injection into the PF pipes/ burners
    • No oxygen stream supply lines at burner front
    • Eliminates any safety issues at boiler front

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Major Power Plant Components - Low Risk Approach (8)

• **Steam Turbine Island**
  – Conventional arrangement
  – Low grade heat recovery to water-steam-condensate cycle
    • reduces bleed steam requirements
    • increased gross power generation – partially offsets capture equipment power requirements

• **CO₂ compression and Inerts Removal Plant**
  – Multiple stage flash separation
  – Commercially available CO₂ compressors

• **Balance of Plant**
  – Conventional equipment

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Power Plant Operational Expectations

• Safety
  – Following established safe operating practices used in other industries (extensive experience exists on handling oxygen and CO₂)
  – Balanced draught design mitigates CO₂ rich flue gas leakage related safety risks
  – FGR loop CO₂ rich flue gas leakage – safety risks – mitigation by design
  – Careful selection of oxygen concentration for the FGR streams
  – Use of low temperature and low pressure oxygen
  – Homogenous mixing of oxygen with FGR
  – Purging of FGR duct work

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Operability/ Flexibility

- Oxyfuel PF power plant controls primarily based on modifications to conventional air-fired PF power plant control technologies
- Initial investigations through application of dynamic mathematical models show that operability characteristics similar to that of conventional air-fired PF plant is achievable
- Selection of appropriate number of ASU/ CO₂ compression units
- Liquid Oxygen Storage

Reliability and Availability

- Process integration expected to have some impact
- First generation Oxyfuel PF Plants – Lower Availability
- Full air-firing capability contributes to improvement in availability
- Maintainability – no significant differences

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## Oxyfuel CO₂ Capture for Pulverised Coal - An Evolutionary Approach

### Doosan Babcock Three Phase Development Programme

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<tr>
<th>Year</th>
<th>Phase</th>
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| 1995 | Conceptual Investigations | Oxyfuel PF EU Joule Project  
- Research  
- 160kWt NRTF  
- Combustion Trails  
- Techno-Economic  
Oxyfuel Oil/Gas Techno-Economic Retrofit Feasibility Studies (BP / CCP)  |
| 2000 | Laboratory | Oxyfuel PF Techno-Economic Feasibility Studies  
- DTI-407 Retrofit UK Plant  
- New-Build (IEA)  
- ENCAP New-Build Europe  
- DTI-366 New-Build Canadian Market  
Capture-Ready (IEA GHG) Modelling Tools  
- OxyMod (EU RFCS)  
Oxyfuel PF Doosan Babcock Phase 1  
- Fundamentals  
- System Design  
OxyCoal Phase 1  |
| 2005 | Pilot Plant | Oxyfuel PF Doosan Babcock Phase 2  
- Design Tools  
- Component Testing / Demos  
- MBTF  
- VAB Pilot Plant  
OxyCoal Phase 2  |
| 2008 | Demo-Plant | Oxyfuel PF Doosan Babcock Phase 3  
- Reference Designs  
- Commercially viable  
- Subsidies?  
Oxyfuel PF EU Joule Project  
- Research  
- 160kWt NRTF  
- Combustion Trails  
- Techno-Economic  |
The Multi Fuel Burner Test Facility was commissioned in Renfrew in 1999 and will be converted to Oxyfuel PF firing.

Demonstration of full-size utility Oxycoal combustion in a collaborative project.

First full-scale test of Oxyfuel firing in the world.
Conclusions

• Low risk Oxyfuel technology is technically viable

• Full air-firing capability minimises commercial risk

• Application of an evolutionary approach to Oxyfuel CO₂ capture – Will provide generators confidence to move towards near emission free power generation with fossil fuels

• Oxyfuel PF technology for CO₂ capture can be offered to utility plant operators’ post 2010.

• Future improvements may completely diminish air-firing capability requirements
Thank You For Your Attention