Doosan Babcock Energy

Oxyfuel CO_2 Capture for Pulverised Coal – An Evolutionary Approach

THE COAL RESEARCH FORUM – 18th Annual Meeting
ZERO EMISSIONS POWER – CURRENT DEVELOPMENTS

Gnanapandithan Sekkappan, Ragi S. Panesar and Scott A. Hume

Date: June 20, 2007
Department: Process Technology and Development

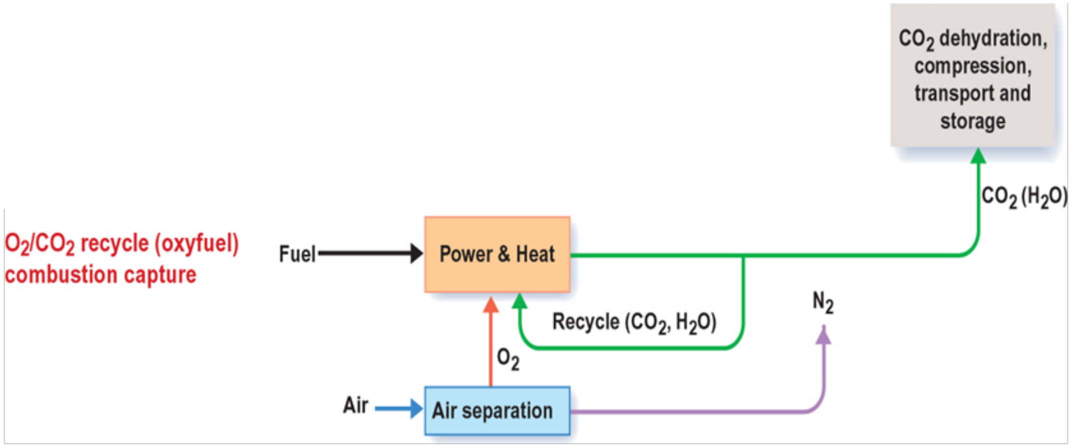
Presentation Outline

- 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

……..offering utility-scale Oxyfuel PF Plant post - 2010

Oxyfuel CO_2 Capture – Key Features

- **Use of mixture of near pure oxygen and CO_2 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 CO_2 rich Oxyfuel flue gas to deliver high pressure CO_2 product.**

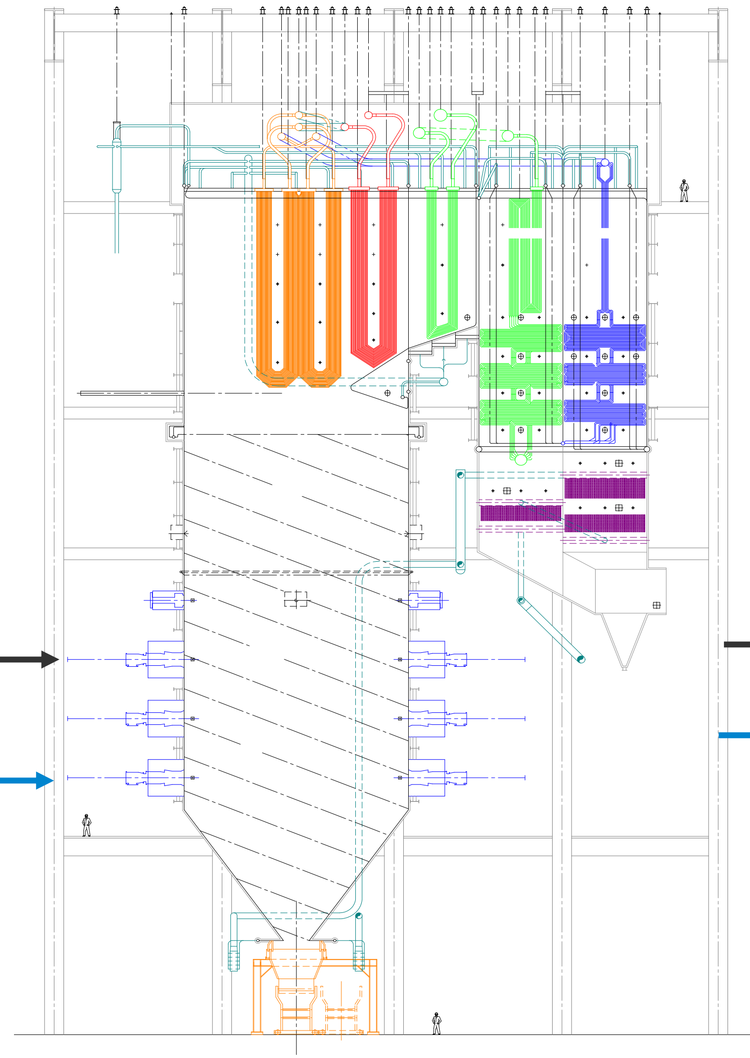


……..offering utility-scale Oxyfuel PF Plant post - 2010

Doosan Babcock Energy

Advanced Supercritical Boiler Technology with Oxyfuel

Gas Analysis (%v/v, wet)	Air Firing	Oxyfuel
O_2	3	3
CO_2	15	55
SO_2	0.1	0.2
H_2O	8	29
N_2 + Ar	75	11



Air firing:

Coal +O_2 +$4N_2$

Oxy firing:

Coal +O_2 +xCO_2

from ASU

Air firing:

CO_2 +$4N_2$

FGD

Flue

Oxy firing:

CO_2

FGD

CO_2

Purification & Compression

CO_2 Recycle line

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**

……..offering utility-scale Oxyfuel PF Plant post - 2010

Oxyfuel CO_2 Capture for Pulverised Coal - An Evolutionary Approach

Low Risk Evolutionary Approach - Foundation

- **Investigations on Oxyfuel technology by Doosan Babcock since the early 1990s**
  - Oxyfuel technology is competitive with alternate CO_2 capture technologies
  - Reduction in net plant efficiency due to CO_2 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

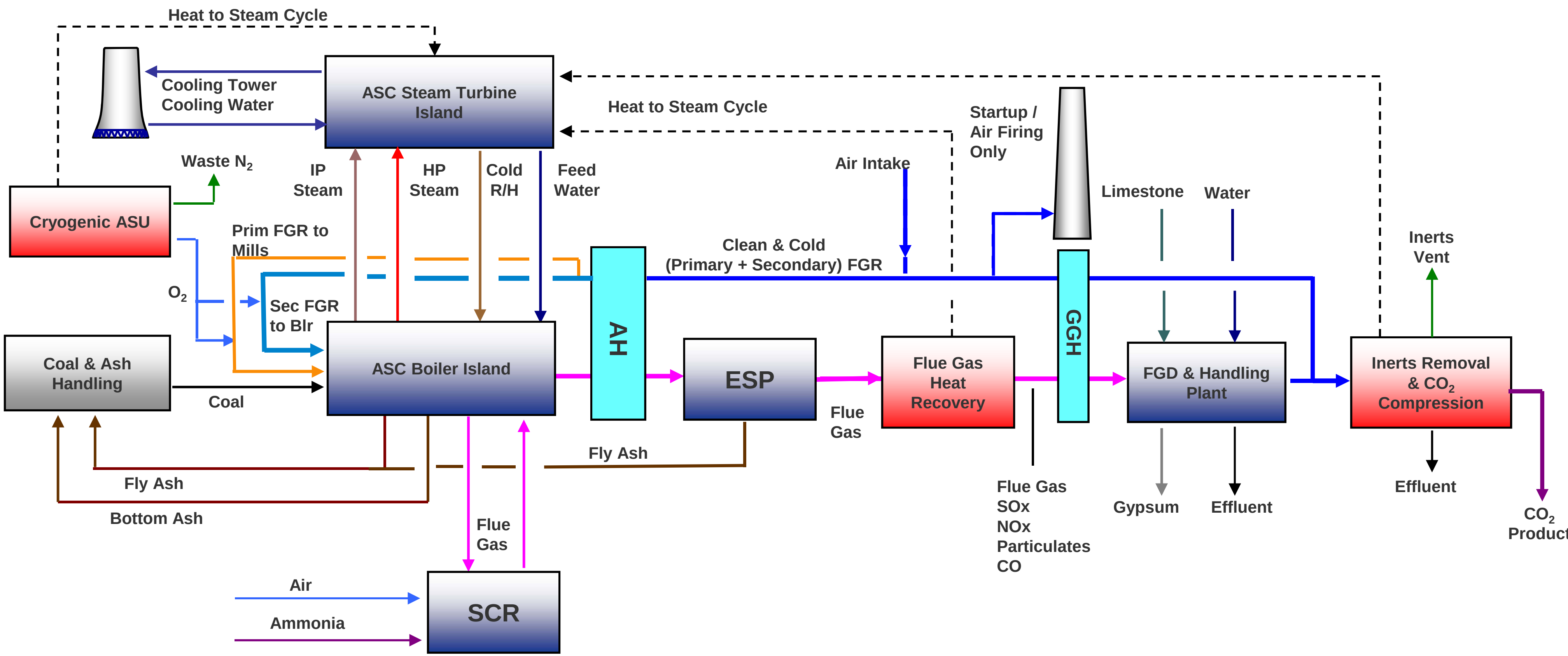
- **Attractive in terms of similarities to air-fired plant**

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

……..offering utility-scale Oxyfuel PF Plant post - 2010

Oxyfuel CO_2 Capture for Pulverised Coal - An Evolutionary Approach

With Oxyfuel Capability



……..offering utility-scale Oxyfuel PF Plant post - 2010

Doosan Babcock Energy

Oxyfuel CO_2 Capture for Pulverised Coal - An Evolutionary Approach

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

……..offering utility-scale Oxyfuel PF Plant post - 2010

Oxyfuel CO_2 Capture for Pulverised Coal - An Evolutionary Approach

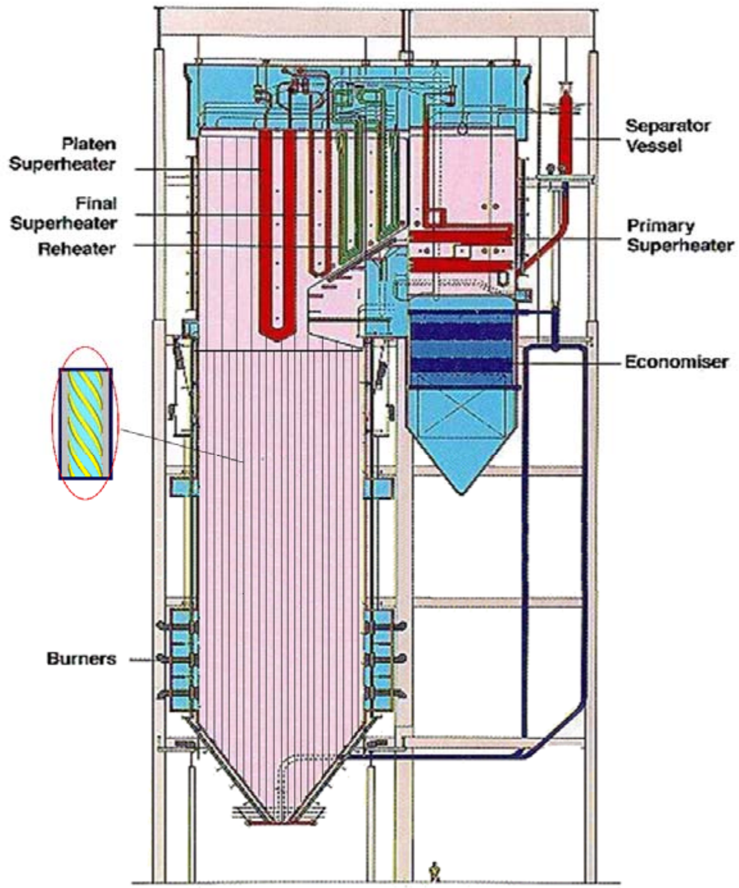
Major Power Plant Components - Low Risk Approach (1)

- **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 NO_X burner designs can be adapted to obtain acceptable combustion performance

……..offering utility-scale Oxyfuel PF Plant post - 2010

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_2O)
  - 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



……..offering utility-scale Oxyfuel PF Plant post - 2010

Major Power Plant Components - Low Risk Approach (3)

- **NO_X reduction**
  - Appropriate NO_X reduction technologies to ensure legislative compliance- whilst in air-firing mode
  - Majority NO_X 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 NO_X 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

……..offering utility-scale Oxyfuel PF Plant post - 2010

Major Power Plant Components - Low Risk Approach (4)

- **Particulate Removal Equipment**
  - Conventional ESP to ensure legislative compliance whilst in air-firing mode
  - Oxyfuel mode – mitigates erosion in fans and CO_2 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

……..offering utility-scale Oxyfuel PF Plant post - 2010

Major Power Plant Components - Low Risk Approach (5)

- **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_X Reduction**
  - In FGR loop
  - Conventional FGD Plant
  - Ensures SO_2 and SO_3 concentrations in the furnace for Oxyfuel – no worse than air-firing
  - Additional mitigation measures for control of SO_3, if required (e.g. wet ESP)
  - Co-capture of balance SO_X along with CO_2 or 100% removal in CO_2 purification unit

……..offering utility-scale Oxyfuel PF Plant post - 2010

Major Power Plant Components - Low Risk Approach (6)

- **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

……..offering utility-scale Oxyfuel PF Plant post - 2010

Major Power Plant Components - Low Risk Approach (7)

- **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 CO_2 rich flue gas to be processed
    - Eliminates risk of high oxygen concentration/ particle impingement on high speed fan blades
    - Reduces ASU, CO_2 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

Oxyfuel CO2 Capture for Pulverised Coal - An Evolutionary Approach

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
- **CO_2 compression and Inerts Removal Plant**
  - Multiple stage flash separation
  - Commercially available CO_2 compressors
- **Balance of Plant**
  - Conventional equipment

……..offering utility-scale Oxyfuel PF Plant post - 2010

Doosan Babcock Energy

Power Plant Operational Expectations

- **Safety**
  - Following established safe operating practices used in other industries (extensive experience exists on handling oxygen and CO_2)
  - Balanced draught design mitigates CO_2 rich flue gas leakage related safety risks
  - FGR loop CO_2 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

……..offering utility-scale Oxyfuel PF Plant post - 2010

Power Plant Operational Expectations

- **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/ CO_2 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

……..offering utility-scale Oxyfuel PF Plant post - 2010

Oxyfuel CO_2 Capture for Pulverised Coal - An Evolutionary Approach

Doosan Babcock Three Phase Development Programme

1995	2000	2005	2008	2009	2010
Conceptual Investigations			Laboratory	Pilot Plant	Demo-Plant

1995 – Oxyfuel PF

EU Joule Project

- Research
- 160kWt NRTF
- Combustion Trails
- Techno-Economic

2000 – Oxyfuel Oil/Gas

Techno-Economic Retrofit Feasibility Studies (BP / CCP)

2005 – 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)

Laboratory – Oxyfuel PF

Doosan Babcock Phase 1

- Fundamentals
- System Design
- OxyCoal Phase 1

Pilot Plant – Oxyfuel PF

Doosan Babcock Phase 2

- Design Tools
- Component Testing / Demos
  - MBTF
  - VAB Pilot Plant
- OxyCoal Phase 2

Demo-Plant – Oxyfuel PF

Doosan Babcock Phase 3

- Reference Designs
- Commercially viable
- Subsidies ?

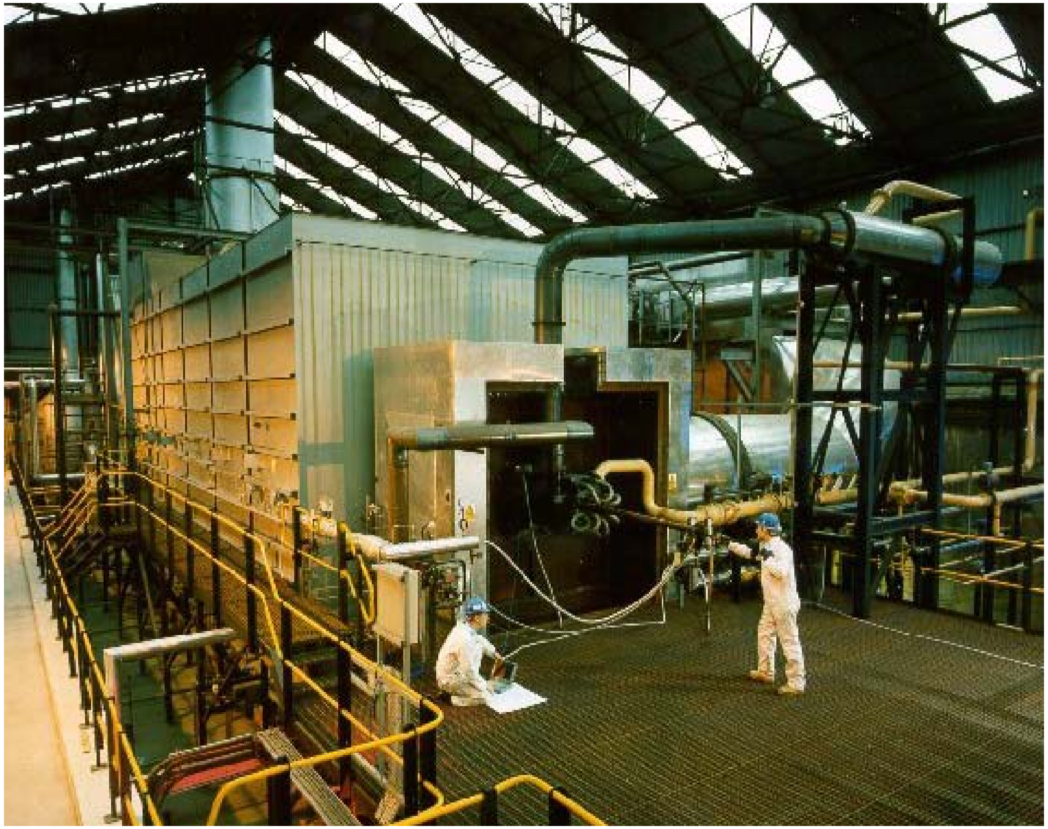
Doosan Babcock burner test facility to be converted to Oxycoal firing

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

90 MW_{th} Burner Test Facility



Oxyfuel CO_2 Capture for Pulverised Coal - An Evolutionary Approach

Conclusions

- **Low risk Oxyfuel technology is technically viable**
- **Full air-firing capability minimises commercial risk**
- **Application of an evolutionary approach to Oxyfuel CO_2 capture – Will provide generators confidence to move towards near emission free power generation with fossil fuels**
- **Oxyfuel PF technology for CO_2 capture can be offered to utility plant operators' post 2010.**
- **Future improvements may completely diminish air-firing capability requirements**

Thank You For Your Attention