Doosan Babcock Energy

Oxyfuel Combustion Technology

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Workshop on Operating Flexibility of Power Plants with CCS
Imperial College, London
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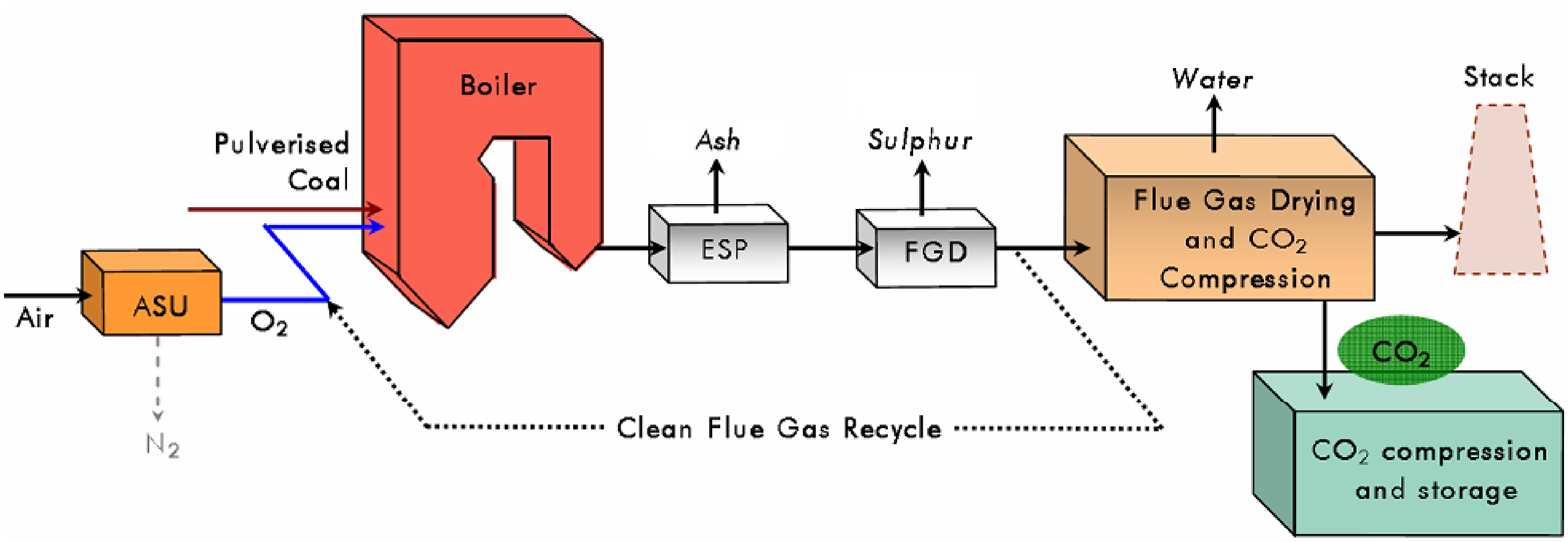
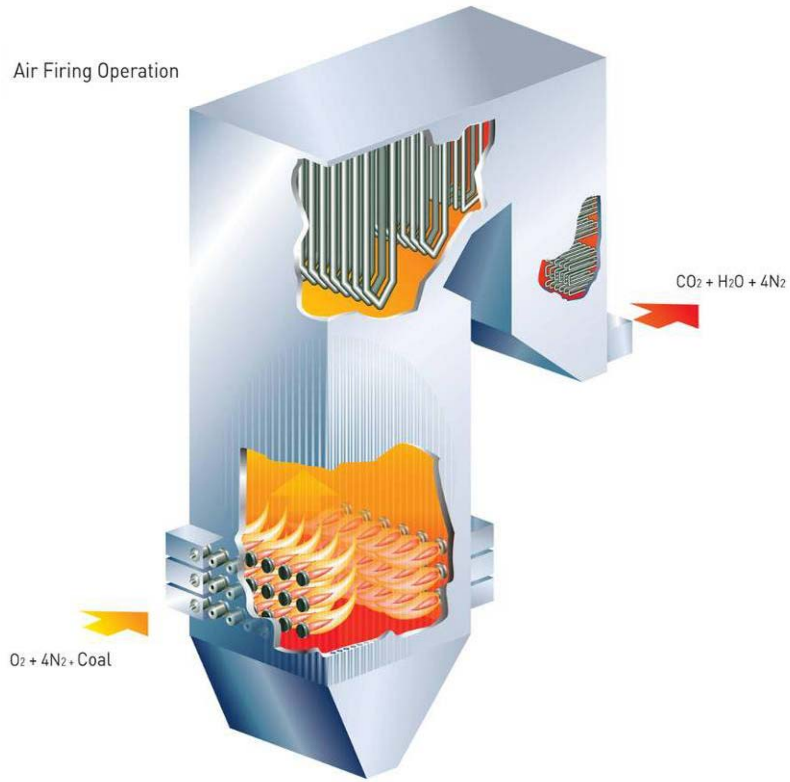
Oxyfuel Technology - Introduction

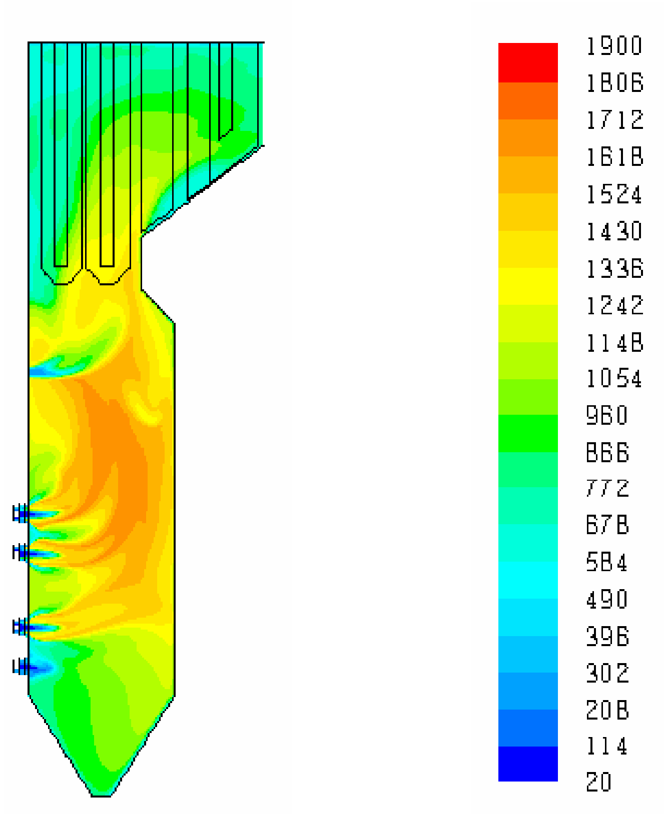


- Air Separation Unit (ASU) to supply nearly pure O_2; N_2 is removed from the process prior to combustion to produce a flue gas that is mostly CO_2 and H_2O
- Fuel burned in O_2/CO_2 atmosphere, Flue Gas Recycle (FGR) mitigates high temperatures from combustion in pure O_2 to maintain combustion and boiler thermal performance
- High CO_2 content allows simple compression cycle for CO_2 purification and capture

Air Firing Technology

Pulverised fuel combustion under air firing operation produces a flue gas CO_2 concentration of typically 15%v/v dry basis.





Air Firing Furnace Temperature Profile

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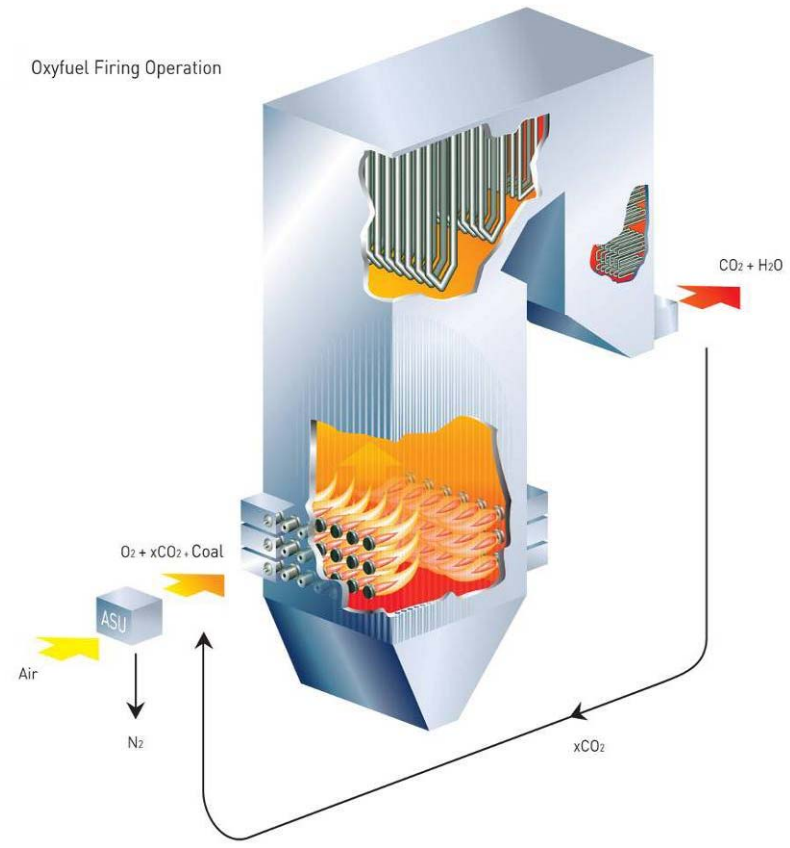
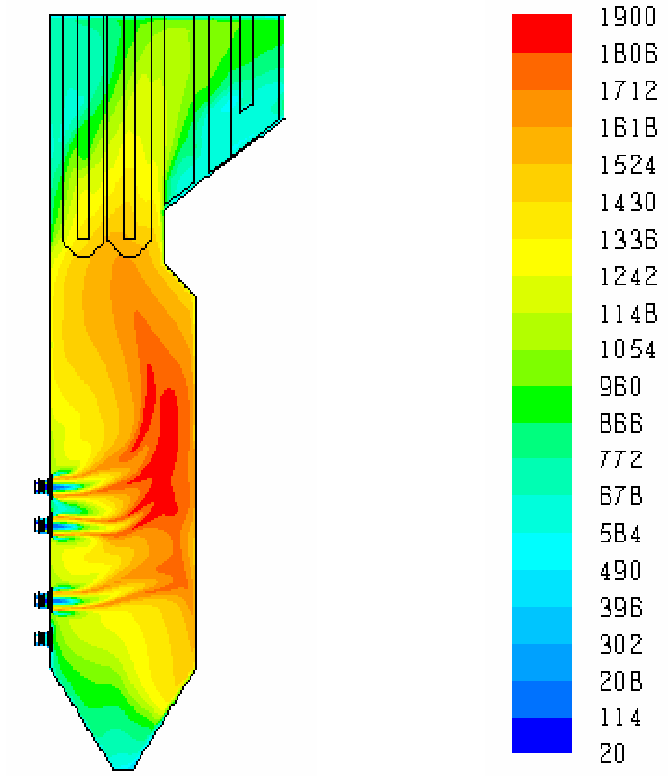
Oxyfuel Firing Technology

Pulverised fuel combustion under oxyfuel firing operation produces a flue gas CO_2 concentration of typically >75%v/v dry basis.





Oxyfuel Firing Furnace Temperature Profile

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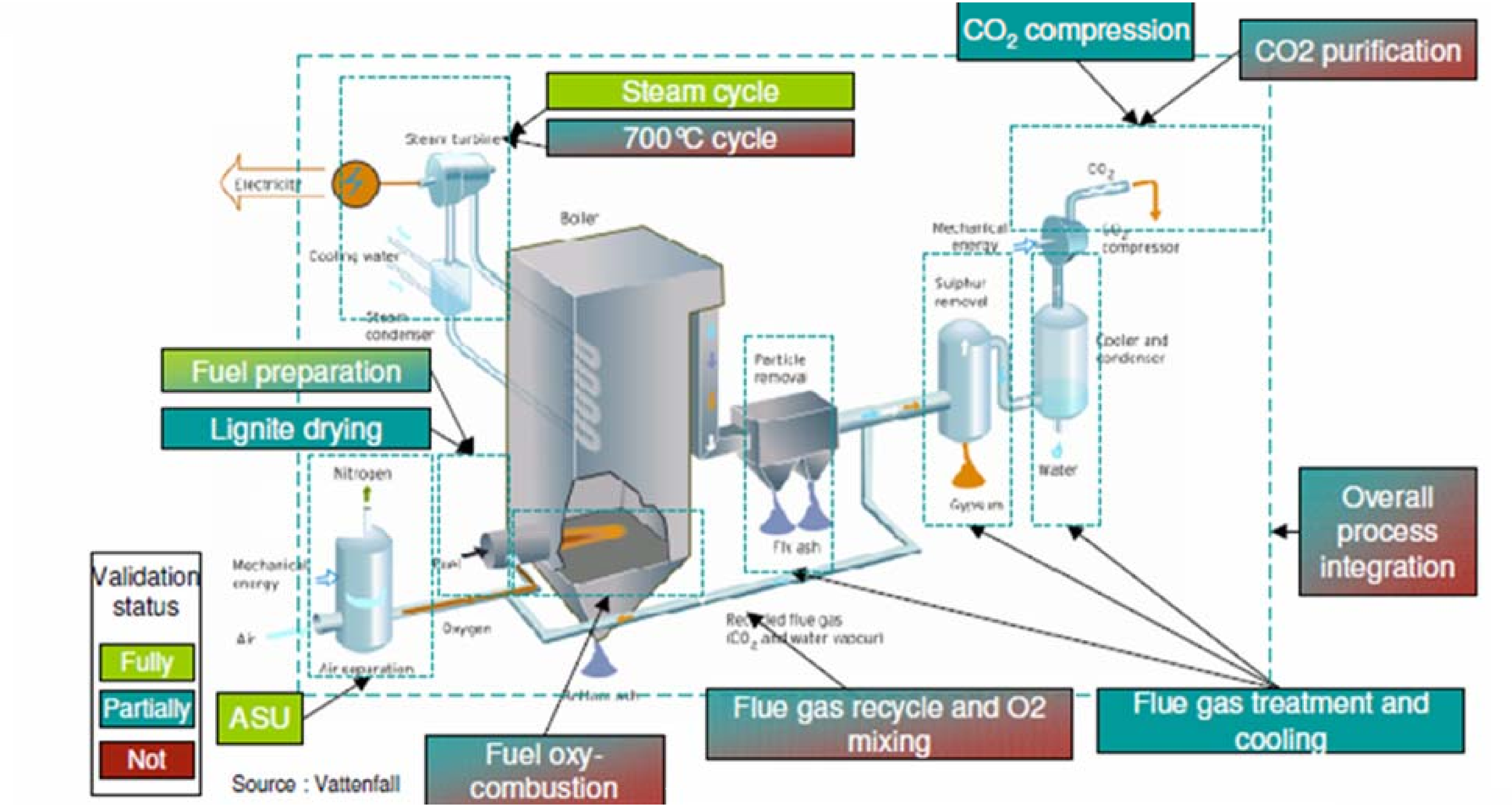
Oxyfuel Technology – Current Validation Status



Source: ETP ZEP Technology Blocks Nov 2008, reproduced in APGT strategy document, April 2009

Oxyfuel Technology – Air Separation Unit (ASU)

- Cryogenic air separation is a mature technology
  - Available now, but considerable power consumption
  - Drive to reduce specific power consumption from 200 kWh/tonne (current) to ~160 kWh/tonne (by 2012) – in-house R&D by suppliers

- New air separation technologies under development by suppliers – being evaluated in EPRI's "Coal Fleet for Tomorrow" programme

Fully Validated Improved processes being developed

Oxyfuel Technology – Fuel Preparation

- Conventional coal handling / pulverising technology will be used for oxyfuel
  - Engineering issues associated with the use of hot flue gas in place of air
  - Addressed in FEED projects
- Lignite pre-drying
  - Technology is independent of oxyfuel, and will be adopted regardless
  - Moisture content reduced to typically 12% before firing
  - Technology is already in “large” demonstration stage
  - Overall cycle efficiency significantly improved

Fully Validated Improved processes being developed

Oxyfuel Technology – Steam Cycle

- Oxyfuel can be applied to existing steam cycles, but improved cycles can mitigate the efficiency penalty associated with oxyfuel (and post-combustion) capture
  - Improvements to current steam cycle aim to improve cycle efficiency by increasing temperature and pressure
  - R&D activities are predominantly to develop the boiler and steam turbine materials to allow operation at elevated temperatures and pressures
  - The impact of oxyfuel on corrosion is also under investigation – e.g.
    - TSB OxyCoal-1 Fundamentals & underpinning studies
    - DTI Modelling of fireside corrosion of heat exchangers in advanced energy systems
- The continuing advances in steam cycles will happen, regardless of oxyfuel or post-combustion capture

Fully Validated Improved processes being developed

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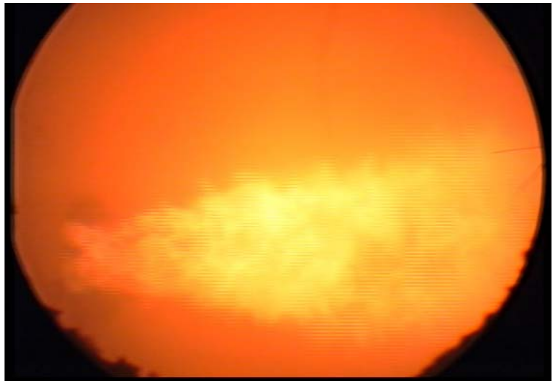
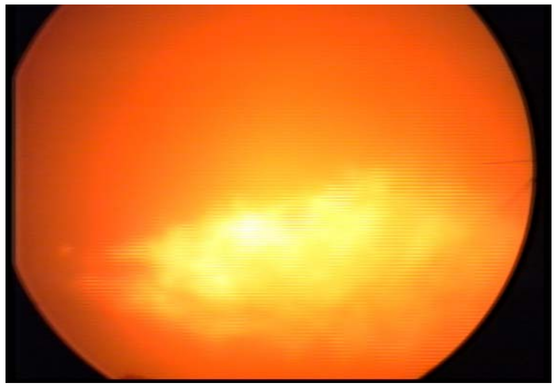
Oxyfuel Technology – Oxyfuel Combustion

- Combustion is at the heart of the power plant
  - If it does not perform to expectation, the impact on the steam cycle can be considerable
- Operating considerations
  - Flame length
  - Flame luminosity
  - Radiant heat transfer in the furnace (combustion / heat transfer interaction)
  - NO_x (does it matter anyway?)
  - SO_2 / SO_3
  - CO
  - Ash properties, slagging, fouling
- Practical experience is required at a realistic scale

Air Firing



Oxyfuel Firing



Oxyfuel Technology – Oxyfuel Combustion

- Considerable laboratory scale experience
  - e.g. in the UK in OxyCoal 1
- Considerable pilot scale experience
  - In the UK at E.ON, RWE, Doosan Babcock (OxyCoal 1, JOULE, etc.)
  - In Europe at IVD, IFRF, Chalmers, etc. (ENCAP, JOULE, OxyMod, etc.)
  - In the rest of the world (e.g. US DoE)
- Large industrial scale experience is becoming available
  - Vattenfall Schwarze Pumpe 30MW_t test facility
  - Doosan Babcock 40MW_t OxyCoal™ Clean Coal Test Facility burner demonstration is in progress (OxyCoal 2)
  - B&W 30MW_t burner test facility is operational (US DoE)
- CFD and Engineering modelling capability is being developed
  - e.g. in Europe in RFCS OxyMod
- Advanced oxyfuel burner development (for utility application)
  - TSB project “Optimised OxyCoal Combustion”

Partially / Not Validated

Oxyfuel Technology – Flue Gas Recycle and O_2 Mixing

- Flue gas recycle is an established means of controlling reheat steam temperature, for gas tempering, and for gas/coal reburn systems in large coal-fired utility boilers
- Mixing of a gas into another (bulk) gas is a common process requirement
- While there is limited experience of flue gas recycle and O_2/flue gas mixing for oxyfuel, there is sufficient expertise to engineer the combustion system, as has been carried out for:
  - Vattenfall Schwarze Pumpe 30MW_t test facility
  - Doosan Babcock 40MW_t OxyCoal™ Clean Coal Test Facility
  - B&W 30MW_t burner test facility
  - Numerous paper studies for full scale plant (e.g. DTI 407, ENCAP, IEA, etc.)

- However a full-scale oxyfuel plant has not been built

Partially / Not Validated

Oxyfuel Technology – Flue Gas Treatment and Cooling

- Considerable air firing experience, but need to apply to oxyfuel
- ESP
  - Laboratory scale work at Korea Institute of Machinery & Materials (KIMM) indicates that dust collection efficiency will be lower in high CO_2 atmospheres
  - ESP performance will be investigated at Vattenfall's Schwarze Pumpe test facility
- FGD
  - Suggestion that high CO_2 content will reduce SO_2 capture
  - Option to use lime (CaO) instead of limestone ($CaCO_3$)
  - Little ongoing R&D, most test facilities with SO_2 capture do not replicate large plant FGD
- SCR
  - Not thought to be necessary for oxyfuel (NO_x captured in CO_2 compression plant)
- Flue Gas Cooler
  - Basic engineering capability exists
  - Little ongoing R&D, test facilities may not be replicating large plant (e.g. rigs tend to use direct spray cooling, whereas indirect cooling may be favoured in large plant for technical, economic, and environmental reasons)

Partially Validated

Sources: KEPRI International Workshop on Oxy-Fuel Combustion 2008
Power Plant Air Pollutant Control Mega-symposium 2008

Oxyfuel Technology – CO_2 Compression

- CO_2 compression technology is required for oxyfuel, pre-combustion, and post-combustion capture technologies
- ASU equipment suppliers and operators already have considerable experience of large scale compression of gases
- There is already experience of CO_2 compression (and pipeline transportation & sequestration)
  - USA – CO_2 captured from the Beulah, Dakota gasification plant is compressed, transported 320km, and injected 1.5km underground in the depleted Weyburn oil/gas fields
  - Europe – the CO2SINK project is compressing and injecting CO_2 into the Ketzin, Germany saline aquifer
  - Australia – CO_2 separated from natural gas is compressed and injected 2.25km underground into the depleted Otway Basin gas field
- CO_2 compression of oxyfuel generated CO_2 is being undertaken at the Vattenfall Schwarze Pumpe test facility
- However there is no demonstration of the compression of CO_2 arising from a full-scale oxyfuel plant

Partially Validated

Oxyfuel Technology – CO_2 Purification

- CO_2 purification undertaken in conjunction with compression
  - Process proven at laboratory and small scale, e.g.
    - Air Products (OxyCoal 1)
    - US DoE Albany Research Centre
  - Process being tested at larger scale by several suppliers

- Capability to design the CO_2 purification process exists
  - Process will continue to be refined

Partially / Not Validated

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Sources: GHGT-9 “Purification of Oxy-fuel Derived CO_2”

Oxyfuel Technology – Overall Process Integration

- TheVattenfall Schwarze Pumpe test facility is the first large scale application of oxyfuel that combines the core elements of the ASU, the steam generator, and the CO_2 purification and compression plant
  - The plant is not highly integrated, and it is not optimised for efficiency
- There have been numerous paper studies investigating the options for process integration to maximise cycle efficiency (e.g. DTI 407, ENCAP, IEA, etc.)
  - Impact of integration on operability has not been considered to date (TSB project "Optimisation of Oxyfuel PF Power Plant for Transient Behaviour" starts to address this)
  - The optimisation of the overall process and the optimisation of the individual process operations should complement each other
- Process integration will continue to be refined – but it must not come at the cost of operational flexibility.

Partially / Not Validated

Oxyfuel Technology – Scale-Up and Timescales

Vattenfall	Janschwalde	2015	250MWe	Lignite

Alstom	Lacq	2009	30MWth	Oil?
Alstom	Schwartze Pumpe	2008	30MWth	Lignite
IHI	Callide	2010	30MWe	
B+ W	B+ W CEDF	2008	30MWth	Coal
Alstom	Alstom CE	2010	15Mwth	Coal
Doosan Babcock	Doosan Babcock	2009	40MWth	Coal

0.5 MW tests at RWE npower 2008/9

160KW tests at Doosan Babcock

1992-4

1MWt tests at E.ON

2007- 8

30 MWt full train demonstration at Schwarze Pumpe

in operation, 2008

40 MWt full size OxyCoal burner test at Doosan Babcock

2009

100 - 250 MWe full power plant demonstration by 2012/2014

Target is "Commercialised by 2020"

By the end of 2009 there will have been at least two industrial scale demonstrations of the full process and the Doosan Babcock full size burner demonstration which should give a high level of confidence in going to the next step

Oxyfuel Technology – Coal-Fired Demonstration Projects

Real projects give us the essential experience to commercialise oxyfuel

- It is only by undertaking real plant projects that we learn to make the hard decisions
  - It is too easy to put off decisions in paper studies
  - From Doosan Babcock's perspective, we have gained valuable practical experience during the engineering of our test facility oxyfuel retrofit, construction, commissioning and testing.

- It is only by undertaking real plant projects that we can commercialise the technology
  - No matter how much information and experience we gain from reduced scale facilities, there is always a degree of uncertainty in the performance of the "first-of-kind" full scale plant
  - Until we are fully confident in our design process it is impossible to deliver a plant under truly commercial conditions with performance guarantees

Oxyfuel Technology – R&D Needs

- First and foremost, we need a full-scale demonstration of the oxyfuel process (i.e. >100MW$_e$) to:

- Demonstrate
  - The operation of the process elements at full-scale
  - The integration of the process elements
  - The operation of the plant, and its ability to respond to grid requirements
  - Selection of optimal materials in oxyfuel service

- Validate
  - The engineering software / design methods, and refine them
  - The performance predictions

- Learn
  - The lessons of real experience, to make the next plant better

Oxyfuel Technology – R&D Needs

Equipment suppliers are capable of engineering a credible oxyfuel power plant today, but further R&D work is required to arrive at better designs and to have greater confidence in the performance

- From the APGTF Cleaner Fossil Power Generation in the 21st Century strategy document
  - Process optimisation, including start-up / shut-down / flexibility
  - Combustion chemistry and kinetics
  - Heat transfer prediction
  - Materials for the oxyfuel environment, corrosion
  - Ash properties – impact of oxyfuel on mineralogy, deposition, ash sales
  - Product gas clean-up
  - Safety
  - ASU – selection, cycle optimisation
  - Novel processes such as gas separation membranes to reduce energy penalty

Concluding Remarks

- Considerable progress has been made in the development of oxyfuel technology
  - The process is technically viable
  - The process is well understood
  - The process has been demonstrated at pilot scale
  - The process is being demonstrated at large scale (40MW_t)
  - Most of the individual components are in commercial operation at the required scale

- Oxyfuel combustion is economically competitive with alternative CO_2 capture technologies

- Several utilities are making or planning significant investments in oxyfuel technology
  - Large-scale plant demonstration

- The time is right for the full scale demonstration of oxyfuel
  - Equipment manufacturers are ready to supply the technology

Concluding Remarks

Doosan Babcock is developing the capability to provide competitive oxyfuel firing technology suitable for full plant application post-2010.

- Doosan Babcock has established a dedicated Carbon Capture Business Group to commercialise Carbon Capture technologies.

- We aim to design, supply and construct a $100MW_e$ oxyfuel power plant for a utility client before 2015, and a $1000MW_e$ oxyfuel power plant by 2020.