Programme Area: Carbon Capture and Storage

Project: Next Gen Capture Tech Benchmarking and Performance Analysis

Title: Executive Summary

Abstract:

The vision for the ETI's CCS Next Generation Capture Technologies focus area is to support the development of a transformational capture technology to a stage where it is ready for incorporation into a full scale demonstration or first of a kind build by 2015. To support selection of the most appropriate technology, the ETI commissioned a series of projects, with Foster Wheeler Energy Limited (FW), to produce outline designs and technoeconomic assessments of power generation plant with different capture technologies. This report summarises the key findings from the first of these: the Capture Benchmarking project. The primary aim of this project was to establish a set of techno-economic performance benchmarks, based on 'best available technology', against which the performance of potential 'Next Generation' technologies could be objectively measured. These benchmarks covered the three key capture technologies for power generation applications (pre-combustion, post-combustion (for coal and gas) and oxyfuel), based on a 'typical' UK application. The key deliverables for the project were a comprehensive technical report (Ref 1) and spreadsheet economic model, which allows 'what if' calculations to be undertaken (Ref 2).

Context:

This project provided ETI with an objective view of the techno-economic performance of a range of current and next generation CO2 capture technologies including pre and post combustion and oxyfuel CCS plant. The analysis that underpins these benchmarking studies was based on coal and gas fired power station designs typical of those found in the UK and considered parameters such as power station capital cost, efficiency and levelised cost of electricity (with and without CCS).

ETI Executive Summary

Programme: Carbon Capture and Storage

Project Name: CCS – Next Generation Capture: Benchmarking

Introduction

The vision for the ETI's CCS Next Generation Capture Technologies focus area is that the ETI will have supported the development of a transformational capture technology to a stage where it is ready for incorporation into a full scale demonstration or first of a kind (FOAK) build by 2015, enabling such a plant to be complete and operational by 2020. This will enable the technology to catch the 'second wave' of CCS implementation in the 2020s (the 'first wave' will be plant built in 2015 – 2020 following the planned demonstration projects).

To support selection of the most appropriate technology, the ETI commissioned a series of projects, with Foster Wheeler Energy Limited (FW), to produce outline designs and techno-economic assessments of power generation plant with different capture technologies. This report summarises the key findings from the first of these: the Capture Benchmarking FRP (Flexible Research Programme) Project.

The primary aim of the Benchmarking Project was to establish a set of techno-economic performance benchmarks, based on 'best available technology', against which the performance of potential 'Next Generation' technologies could be objectively measured. These benchmarks covered the three key capture technologies for power generation applications (pre-combustion, post-combustion (for coal and gas) and oxyfuel), based on a 'typical' UK application.

The key deliverables for the project were a comprehensive technical report (Ref 1) and spreadsheet economic model, which allows 'what if' calculations to be undertaken (Ref 2). These are available to ETI members.

In this work there was close interaction with the ETI CCS Strategy Advisory Group (SAG), including several iterations of the final report and spreadsheet to incorporate SAG input.

Basis of Designs

FW produced outline designs for four 'benchmark' power generation technologies:

- Integrated Gasification Combined Cycle (IGCC) coal with solvent capture ('Pre-combustion');
- Ultrasupercritical Pulverised Coal (USCPC) with post-combustion amine system capture;
- Combined Cycle Gas Turbine (CCGT) with post-combustion amine system capture;
- Pulverised coal recirculation oxy-fuel plant.

For each benchmark, designs were produced both with and without capture so the effect of CCS on performance could be seen. A detailed Basis of Design (BoD) was agreed with the CCS SAG, based on a new build, nominal 800MWe station, on a green field, NE England coastal location (see Appendix 1 for further information and Reference 1 for full details). For coal-fired designs, a capture rate of 90% was specified: for gas, capture rates of 90% and 75% were considered (the latter gives equivalent CO_2 emissions per kWh to coal-fired stations with 90% capture).

For all of the benchmark cases FW adopted a consistent estimating methodology using equipment costs and cost factors developed using cost estimating tools along with in-house data and experience. Where available estimates were supported with data from previous work undertaken by FW for similar plant designs. For all of the cases any historic source estimate data was adjusted to provide figures on a consistent and comparable 1st quarter 2009 UK Basis. Estimates prepared at this level of technical definition and initial study phase of project development using the above methodology and associated qualifications/ exclusions are considered to have an accuracy of +/-40%, although given the consistent approach and assumptions, better relative accuracy between cases would be expected.

Costs are for delivery up to the station boundary fence (CO_2 at 150 bar pressure). These include contingency, land fees and owners costs, but do not include costs of transport and storage. In other studies, capture has been shown to make up ~ 70% of total CCS costs.

Results Summary

Figure 1 shows the capital costs and power generation efficiency (LHV) of the different technologies.

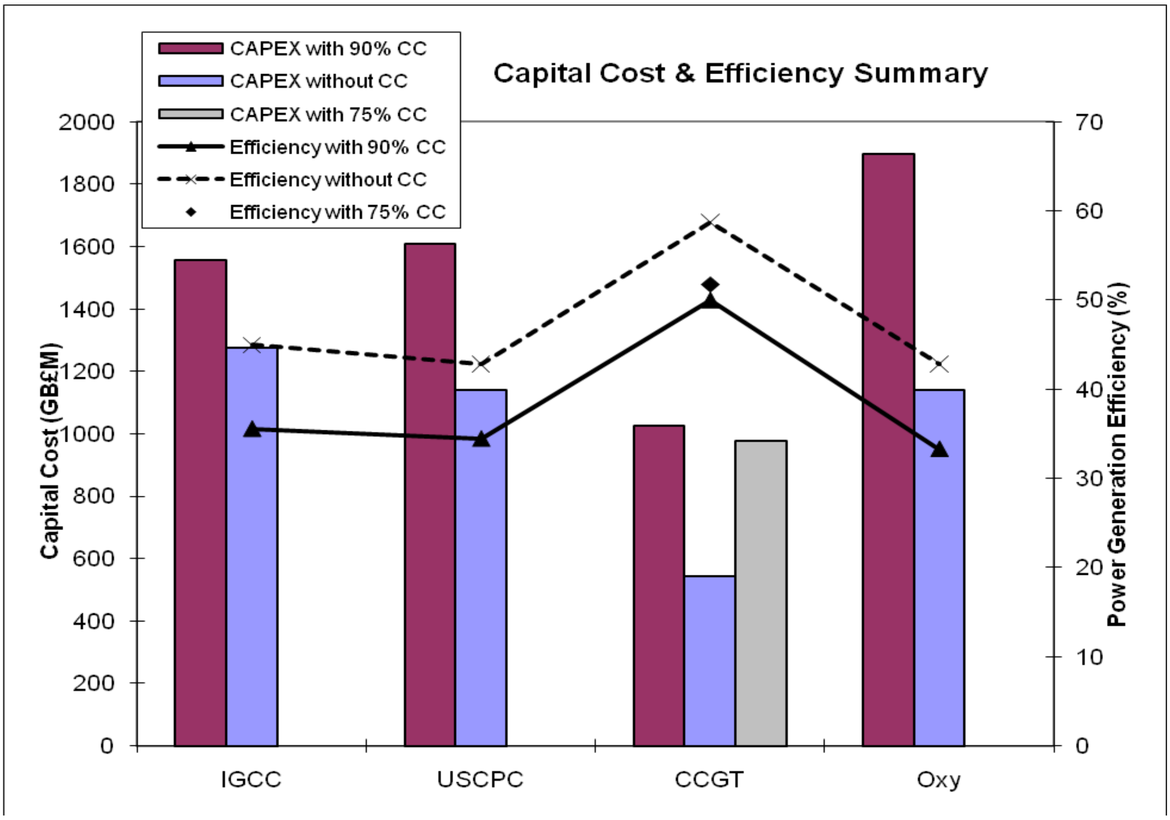

Figure 1 Summary Economic Figures

The Levelised Cost of Electricity for each design is given below in Table 1. It should be noted that these costs are based on the particular assumptions used in the study (see Appendix 2), and in practice will be highly dependent on factors such as plant availability & load factor, fuel cost and discount factor. The spreadsheet tool provided by FW can be used to readily carry out sensitivity analyses.

		IGCC		USCPC		Natural Gas CCGT			Oxyfuel
		with CC	no CC	with CC	no CC	75% CC	90% CC	no CC	with CC
Levelised Cost of Electricity	**£ / MWh_{Net}**	**76.2**	**59.5**	**87.3**	**56.2**	**65.9**	**69.6**	**47.9**	**96.9**
Increase in LCOE from addition of CCS	**%**	**28%**	**-**	**55%**	**-**	**38%**	**45%**	**-**	**72%**

Table 1 Levelised Cost of Electricity

Further performance information is provided in Appendix 2, with full details in Reference 1.

Key Findings

Key findings of the study are:

- The results provide ETI members with a set of benchmark techno-economic performance measures for new build coal and gas power stations with all key capture types, for typical UK-based applications;
- The spreadsheet produced by FW provides a tool to undertake sensitivity analyses on the effect of cost and operational assumptions made in this study;
- For each design, addition of CCS (with 90% capture) resulted in around 8 - 10 percentage points reduction in plant efficiency;
- Dependent on design, addition of CCS increases LCOE by between 28% and 72%;
- For coal fired stations, IGCC (pre-combustion) came out as lowest cost with capture fitted, in terms of capital cost and levelised cost of electricity (LCOE), followed by pulverised coal (post combustion), with oxyfuel being the most expensive;
- Even with CCS, gas stations showed the lowest LCOE.

However, it should be stressed that the comparisons between benchmarks are only strictly valid for the benchmarks selected and assumptions made. In particular, comparisons between gas and coal are highly dependent on assumptions of gas price and cost of capital. The study used a Q1/09 gas price which was relatively low (2.058p/kWh) and a relatively high cost of capital (discount factor of 10%). For example, increasing the cost of gas by 30 – 50% ***or*** reducing cost of capital to 5% brings LCOE close to parity with the two fuels. Differences should also be viewed in the light of typical estimating accuracies for such studies (ie +/- 40%).

The results of the study were closely scrutinised by the CCS SAG, in particular the relative costs between IGCC and USCPC. A number of SAG members (including Shell) considered that the IGCC capital costs were underestimated. Detailed unit-by-unit comparisons to further understanding of where differences might occur were not possible, due to commercial sensitivities around the underlying data. Foster Wheeler provided comparisons between the results of this study and other published studies: these broadly supported the absolute and relative costs, although some differences were apparent (see Appendix 2 for further information).

Further Work

Subsequent to the Benchmarking Study, a series of analyses was undertaken on six potential 'Next Generation' capture technologies, using the same methodology. Results from these analyses were kept confidential between FW, the ETI and the relevant technology provider. The results of these studies, as referenced to the appropriate benchmark study, were used as a primary source of information for the ETI's Technology Selection Panel, held on 1st February 2010, which made recommendations on the future direction of the ETI's Next Generation Capture Technology focus area.

A Request for Proposals (RfP) was issued on 31st March 2010 for projects based on the technology recommended by the Panel (Pre-combustion CO_2 capture, primarily by synthesis gas compression, cooling and liquid CO_2 removal by phase separation). Minimum performance targets were set based on the analysis, namely:

- Specific carbon emissions of <100 g CO_2/kWh net electricity export via transmission connection point (equivalent to ~90% capture for a coal-fired station);
- At least 1 percentage point improvement in overall plant efficiency and at least 6% reduction in capital cost efficiency (£/kW net power) compared to benchmark design or alternative efficiency/cost improvement which demonstrably provides equivalent overall impact on Levelised Cost of Electricity (LCOE).

The analyses and Selection Panel also identified opportunities which the ETI should consider and track for 'Wave 3' technologies with higher potential benefits but longer (and higher risk) development pathways (solid sorbents and enzyme-enhanced carbonates for CO_2 separation).

References

1. Benchmarking and Performance Analysis of Future CO_2 Capture Technologies: Work Package 1 (WP1) – Benchmarking Study. Foster Wheeler Report, February 2010
2. ETI Performance Cost and Economic Model v2.00, February 2010 (Excel spreadsheet).

Appendix 1: basis of Design and Analysis Approach

The key features were as follows:

- New Build, nominal 800 MWe scale power station (note: depending on the designs, actual outputs varied from 620 – 990 MWe);
- Green field, English North East coast location, with sea water cooling;
- Coal specification based on an open-cut coal from Eastern Australia;
- 2009 'State of the Art' plant designs:
  - IGCC: Shell gasifier with water gas shift Selexol solvent capture and 'F' Class Gas Turbines.
  - USCPC: 600 – 620^{o}C steam, with generic MEA capture unit (Fluor Econamine or similar)
  - CCGT: G Class turbine with generic MEA capture unit (Fluor Econamine or similar)
  - Oxyfuel: similar to USCPC. Oxygen supplied by Air Separation Unit with 12 hours bottled back up;
- CO_2 dehydrated and compressed to 150 bar;
- 90% capture rate (coal designs). Gas designs were produced for 90% and 75% capture (75% gives the same specific CO_2 production (g CO2 per kWh output) as coal with 90% capture).

For the purposes of comparing 'with' and 'without' capture, different approaches were taken between pulverised coal and gas turbine based technologies:

- For gas turbine technologies (IGCC & CCGT), the 'front end' technology was resized to ensure that the turbine's fuel appetite was fully met with and without capture;
- For pulverised coal technologies (USCPC and Oxyfuel), the same coal feed rate and burner/ boiler size was maintained.

Based on the BoD, FW developed a process configuration and heat and material balance (HMB) for each of the Benchmark cases, using process simulators as the primary tool. From the individual HMBs, FW produced the required Benchmark deliverables, including block level process flow scheme drawings, equipment lists, overall and unit level performance summaries.

For all of the benchmark cases FW adopted a consistent estimating methodology using equipment costs and cost factors developed using cost estimating tools along with in-house data and experience. Where available estimates were supported with data from previous work undertaken by FW for similar plant designs. For all of the cases any historic source estimate data was adjusted to provide figures on a consistent and comparable 1st quarter 2009 (1Q2009) UK Basis. Estimates prepared at this level of technical definition and initial study phase of project development using the above methodology and associated qualifications / exclusions are considered to have an accuracy of +/-40%.

Cost of electricity was calculated assuming a base-load plant (ie equivalent to 100% loaded for 85% of the time through all but the initial plant life).

Further details of the methodology used and results are given in Reference 1: a summary of results is given below.

Appendix 2: Benchmark Results

Figure A2-1 Summary Performance Figures

		IGCC		USCPC		Natural Gas CCGT			Oxyfuel
Capture Level		with CC	no CC	with CC	no CC	with CC (75% capture)	with CCS (90% capture)	no CC	with CC
Total gross installed capacity	MWe	923.8	878.1	745.7	836.2	970.7	955.3	1038	855.4
Total auxiliary loads	MWe	223.9	132.0	119.0	57.0	98.4	113.0	46.8	230.8
Net Power Export	MWe	699.9	746.1	626.7	779.2	872.3	842.3	990.8	624.6
Net Efficiency (LHV)	**%**	**35.5**	**45.0**	**34.4**	**42.8**	**51.7**	**49.9**	**58.8**	**34.3**
Carbon capture rate	%	90.0	0.0	90.0	0.0	75.2	90.1	0.0	90.4
Total CO_2 captured	tpd	13976	0	13124	0	6265	7504	0	13182
Total CO_2 emitted	tpd	1557	13150	1465	14590	2063	825	8329	1408
CO_2 emissions	g CO_2/ kWh_{Net}	92.7	734.4	97.4	780.2	98.5	40.8	350.2	93.9

Figure A2-2 Summary Economic Figures

		IGCC		USCPC		Natural Gas CCGT			Oxyfuel
		with CC	no CC	with CC	no CC	75% CC	90% CC	no CC	with CC
Total CAPEX	GB£M	1556	1274	1607	1140	976	1024	544	1897
CAPEX efficiency	GB£ / kW_{Net}	2223	1708	2565	1463	1119	1216	549	3132
Total OPEX – incl. fuel	GB£M p.a.	208.1	175.8	211.8	187.3	296.0	297.7	279.6	205.9
Total OPEX – excl. fuel	GB£M p.a.	75.9	64	87.4	62.9	43.4	45.1	27	81.5
OPEX – incl. fuel	GB£ p.a. / kW_{Net}	297.3	235.6	338.0	240.4	339	354	282.2	340.0
OPEX – excl. fuel	GB£ p.a. / kW_{Net}	108.5	85.8	139.5	80.7	50	54	27.3	134.6
Levelised Cost of Electricity	**£ / MWh_{Net}**	**76.2**	**59.5**	**87.3**	**56.2**	**65.9**	**69.6**	**47.9**	**96.9**
Cost of CO_2 Avoided	£ / te CO_2	26.0		45.5		70.0			59.5

Notes:

1. OPEX figures based on fuel costs: Coal £65/tonne, Natural Gas £0.02058/kWh.
2. OPEX figures calculated on the basis of [Load Factor x Availability] = 0.65 (Year 1), 0.75 (Year 2) and 0.85 (balance of operation)
3. 30 years operation assumed for coal fed plants, 20 years operation for natural gas fed plants.
4. Levelised cost of electricity figures are based upon a discount rate of 10%.
5. Total CAPEX figures include Total Installed Cost, 5% land costs, 10% owner's costs and 25% contingency.
6. Economic figures are based on cost of capture and compression (to 150bar) only, and exclude transport and storage costs.

Comparison with other Studies

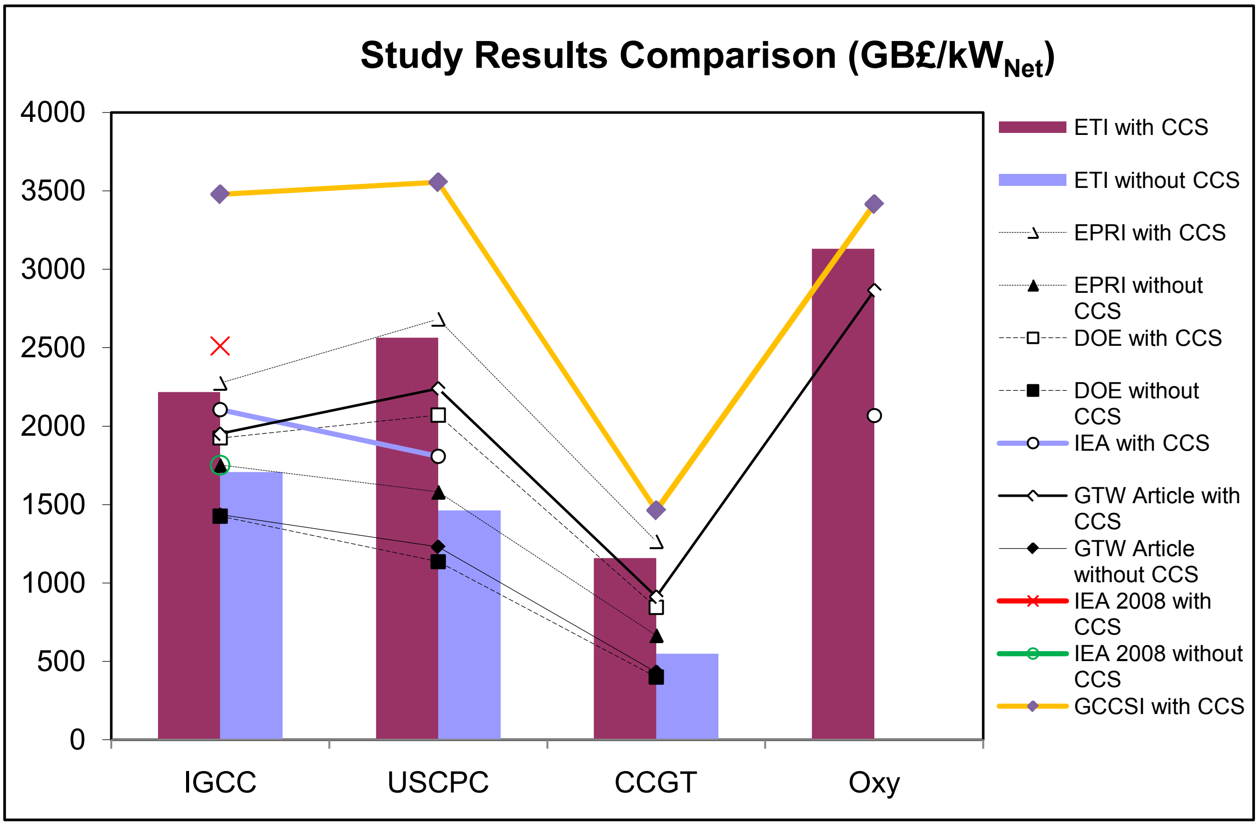

Figure A2-3 Capital Cost Comparison with Previous Studies

Studies used for comparison:

- "Evaluation of Innovative Fossil Fuel Power Plants with CO_2 Removal", by EPRI, December 2000.
- "Cost and Performance Baseline for Fossil Energy Plants, Volume 1: Bituminous Coal and Natural Gas to Electricity, Final Report", by the DOE and NETL, May 2007.

- "Fossil Fuel Fired Power Generation", IEA Clean Coal Centre, 2007.
- "CO_2 Capture in Low Rank Coal Power Plants", IEA Greenhouse Gas R&D Programme, November 2005.
- "Gas Turbine World" articles published in early 2009, in the IGCC Reference Guide.
- "Co-Production of Hydrogen and Electricity by Coal Gasification with CO_2 Capture – updated economic analysis", IEA Greenhouse Gas R&D Programme, August 2008.
- "Strategic Analysis of the Global Status of Carbon Capture and Storage, Report 5: Synthesis Report, Final Report", Global CCS Institute, September 2009.