PARSONS BRINCKERHOFF

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ELECTRICITY GENERATION COST MODEL - 2013 UPDATE OF NON-RENEWABLE TECHNOLOGIES

Department of Energy and Climate Change

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Final

Electricity Generation Cost Model - 2013 Update of Non-Renewable Technologies

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CONTENTS

LIST OF ABBREVIATIONS

ASC	Advanced Supercritical
CCGT	Combined Cycle Gas Turbine
CCS	Carbon Capture and Storage
CHP	Combined Heat and Power
CO_2	Carbon Dioxide
DECC	Department of Energy and Climate Change
EPC	Engineer, Procure and Construct
FEED	Front End Engineering Design
FGD	Flue Gas Desulphurisation
FOAK	First of a kind
FPM	Forward Pricing Model
GTPro	Gas turbine modelling software, part of Thermoflow software suite
HHV	Higher Heating Value
IGCC	Integrated Gasification Combined Cycle
kW	Kilowatt
LCM	Levelised Cost Model
LHV	Lower Heating Value
MW	Megawatt
NOAK	Nth of a kind
OCGT	Open Cycle Gas Turbine
O&M	Operation & Maintenance
PEACE	Cost estimation modelling software, part of Thermoflow software suite
PWR	Pressurised Water Reactor
TNUoS	Transmission Network Use of System
UK	United Kingdom
UoS	Use Of System

EXECUTIVE SUMMARY

Parsons Brinckerhoff was engaged by the Department of Energy and Climate Change (DECC) to update the cost assumptions and technical inputs of the "Levelised Electricity Cost Model" which was originally created and updated by a third party.

This report provides the supporting information to this (2013) update of the non-renewable cost assumptions and technical inputs for the DECC Levelised Electricity Cost Model. Parson Brinckerhoff also updated this information in 2012 (referred to throughout this report as "the 2012 update").

In order to update the 2012 values, Parsons Brinckerhoff considered data from recent UK and overseas reference plants, internal confidential information, opinions from prominent studies and the experience of technology experts within Parsons Brinckerhoff. Technical and cost modelling was undertaken where necessary using the Thermoflow software suite in order to corroborate input parameters. Parsons Brinckerhoff also invited a range of stakeholders to provide input to the cost estimates. Information received was also considered. Changes to the 2012 assumptions were made on the basis of this assessment. The draft data was reviewed by DECC, and a number of stakeholders, including operators, developers and industry bodies. The data was then adjusted as necessary and finalised.

The technologies investigated and evaluated were as follows:

- Combined Cycle Gas Turbine (CCGT) plant
- CCGT plant with Post-Combustion Carbon Capture and Storage (CCS)
- CCGT plant with Retrofitted Post-Combustion CCS
- CCGT plant with Pre-Combustion CCS
- CCGT plant with Oxy-Combustion CCS
- Advanced Supercritical (ASC) coal plant with Flue Gas Desulphurisation (FGD) and partial (300MW net) Post-Combustion (Amine) CCS
- ASC coal plant with FGD and Post-combustion (Amine) CCS
- ASC coal plant with FGD and Post-combustion (Ammonia) CCS
- ASC coal plant with FGD and Retrofitted Post-combustion (Amine) CCS
- ASC coal plant with FGD and Oxy-combustion CCS
- Integrated Gasification Combined Cycle (IGCC) and partial (300MW net) Pre-Combustion CCS
- IGCC with Pre-combustion CCS
- IGCC with Retrofitted Pre-combustion CCS
- Nuclear Pressurised Water Reactor (PWR) plant
- Large gas fired Combined Heat and Power (CHP) plant
- Open Cycle Gas Turbine (OCGT) plant
- Biomass plant with post-combustion CCS (evaluated as part of the renewable update, but included in both renewable and non-renewable reports)

The report gives an overview of each technology type.

The methods, assumptions and reasoning used to update the cost and technical inputs are described for each technology, for each of the main parameters of key timings, technical data, capital costs and operation and maintenance (O&M) costs. Changes from the data of the 2012 update are explained.

The updated cost assumptions and technical inputs have been included in the appendices of the report.

1 INTRODUCTION

1.1.1 Parsons Brinckerhoff was engaged by the Department of Energy and Climate Change (DECC) on December 17th 2012 to update the non-renewable cost assumptions and technical inputs of the Levelised Cost Model (LCM) which was originally created and updated in 2010 by a third party[1].

1.1.2 This report summarises the work carried out by Parsons Brinckerhoff and aims to provide context for and an explanation of modifications made to the dataset that forms the model inputs.

1.1.3 Open Cycle Gas Turbine (OCGT) plant in the 2012 update was assumed to be fast response plant, which has very short response times and is required to respond quickly to changes in load. The 2012 OCGT assumptions were therefore based on aeroderivative turbines, similar to those used in jet engines, which have very fast response times. No new information on the costs of aeroderivative engines is available, so OCGT costs were originally excluded from the scope of the study.

1.1.4 After discussion with DECC it was decided to include OCGT costs as an extension to the scope of the study. The updated OCGT costs may form part of the implementation of a Capacity Market under the Government's Electricity Market Reform program.

1.1.5 DECC advised that the type of plant selected should be the cheapest plant per unit capacity, in terms of its annual fixed costs and capital costs. This plant would be required to run if insufficient generation capacity was available, but would not be required to have such fast response times as aeroderivative plant. Parsons Brinckerhoff advised that large frame gas turbines, of the type also used in CCGT and CHP, would be the cheapest plant per unit capacity on this basis. The extension to the scope of the study was to produce updated assumptions for large frame gas turbines.

1.2 Background

1.2.1 Details of the LCM can be found in the '*UK Electricity Generation Costs Update'* report by Mott Macdonald for DECC.

1.2.2 The inputs to the Model require updating periodically in order to reflect the varying costs of generation technologies, market forces and changing attitudes to the predicted costs of new technologies as knowledge and experience increases. Parsons Brinckerhoff previously updated the non-renewable inputs on behalf of DECC in 2011 and 2012.

1.2.3 The dataset provided as part of this work represents the current (March 2013) view of non-renewable generation costs and performance and as such, the validity of the dataset shall decrease with time and require further updates in the future.

1.3 Report Structure

1.3.1 This report briefly describes the scope of work undertaken by Parsons Brinckerhoff in order to update the model inputs including the technologies covered, the input parameters investigated and the general limitations of the work.

[1] For further details, see: Mott Macdonald. *UK Electricity Generation Costs Update*. June 2010

1.3.2 Following this, an overview of the methodology is detailed and covers the general philosophy and approach to obtaining robust values for the input parameters and major data sources. The different technologies are described. The report then provides a more detailed commentary on specific inputs, explaining any assumptions made for specific technologies.

1.3.3 The updated cost assumptions are included in the appendices in a technology-by-technology format.

2 SCOPE OF WORK

2.1.1 Parsons Brinckerhoff's scope only included the update of the non-renewable cost assumptions to be inputted into the model, which was provided by DECC. Parsons Brinckerhoff was not responsible for the calculations or operation of the cost model.

2.2 Technologies

2.2.1 The technologies investigated and evaluated were as follows:

- Combined Cycle Gas Turbine (CCGT) plant
- CCGT plant with Post-Combustion Carbon Capture and Storage (CCS)
- CCGT plant with Retrofitted Post-Combustion CCS
- CCGT plant with Pre-Combustion CCS
- CCGT plant with Oxy-Combustion CCS
- Advanced Supercritical (ASC) coal plant with Flue Gas Desulphurisation (FGD) and partial (300MW net) Post-Combustion (Amine) CCS
- ASC coal plant with FGD and Post-combustion (Amine) CCS
- ASC coal plant with FGD and Post-combustion (Ammonia) CCS
- ASC coal plant with FGD and Retrofitted Post-combustion (Amine) CCS
- ASC coal plant with FGD and Oxy-combustion CCS
- Integrated Gasification Combined Cycle (IGCC) and partial (300MW net) Pre-Combustion CCS
- IGCC with Pre-combustion CCS
- IGCC with Retrofitted Pre-combustion CCS
- Nuclear PWR plant
- Large gas fired Combined Heat and Power (CHP) plant
- Open Cycle Gas Turbine (OCGT) plant
- Biomass plant with post-combustion CCS (evaluated as part of the renewable update, but included in both renewable and non-renewable reports)

2.3 Input Parameters

2.3.1 A range of cost and performance parameters were updated by Parsons Brinckerhoff and were classified within the model input sheets under the following areas:

- Timings – the development, construction and operational period

- Technical data – plant heat and power output, efficiency and forward profiles for availability, load factor and changes in efficiency due to degradation
- Capital costs[2] – design and development, regulatory and licensing, construction, infrastructure
- Operational and maintenance costs – fixed and variable maintenance costs, use of system charges and insurance.
- Cost of transport and storage of carbon dioxide (CO_2)

2.3.2 The model also contains input assumptions for the cost of waste disposal, decommissioning, fuel price projections, exchange rates and CO_2 price projections; however these parameters were outside the scope of the work undertaken by Parsons Brinckerhoff and have values as set by DECC.

2.4 General Limitations

2.4.1 The key challenge in assembling the model input data was to prepare cost estimates under consistent assumptions for a wide range of technologies, some of which are well understood and have extensive market presence whilst others are at an earlier stage of development or application and are less well understood. Inevitably the methods by which estimates were prepared for each of these technologies varied, presenting challenges to ensure that unavoidable discrepancies between the methods were minimised.

2.4.2 The range of inputs to the LCM are required to be based on what is technically feasible, rather than based on assumptions regarding economic constraints. In line with this the non-renewable inputs provided by Parsons Brinckerhoff are on the basis of baseload operation for all plant other than OCGT. A number of stakeholders commented that certain types of plant would not have such a high availability or load factor in reality. This is recognised by DECC and Parsons Brinckerhoff. It is in the nature of economic modelling to use technical limitations as inputs to a model and use the model as one of the tools to assess a realistic economic scenario. Making assumptions on values such as load factor would be to second guess the results of the modelling, and could risk double counting. Other economic information such as taxes and support mechanisms are also ignored in this analysis.

3 METHODOLOGY

3.1.1 Cost estimates and technical parameters used as inputs to the 2012 modelling were reviewed and compared against new data, where available. This new data was obtained from a number of sources. A number of stakeholders were invited to review and comment on the assumptions presented in the 2012 update. Where available, data from recent UK and overseas reference plants were considered, along with internal confidential information.

3.1.2 Estimates were also based on a combination of technical modelling, opinions from prominent studies and the experience of technology experts within Parsons Brinckerhoff. Technical and cost modelling was undertaken where necessary using the Thermoflow software suite in order to corroborate input parameters. The cost

[2] Capital costs include an item titled "EPC costs" which includes Engineering, Procurement and Construction (EPC) price, cost of commissioning, and owner's engineer costs. It does not include other owner's costs such as interest, other financing cost or any cost that is covered elsewhere in the assumptions, such as infrastructure, TNUoS, etc. This definition of EPC cost is consistent with the 2012 Update.

estimates from the software were used only to adjust the estimates for different circumstances than the original data rather than being used to derive new estimates.

3.2 General Approach

General Treatment of First Of A Kind (FOAK) and Nth Of A Kind (NOAK)

3.2.2 For established technologies that are well understood i.e. CCGT, CHP and OCGT, only NOAK costs were considered in this update. This is consistent with previous updates where parameters were assumed to be equal for FOAK and NOAK. Variation between sites and general uncertainty was represented through the variation of values across the high, central and low levels.

3.2.3 For new technologies or those with little commercial experience within the UK, inputs for FOAK and NOAK were differentiated where applicable. For CCS and nuclear technologies, FOAK was defined as the first plant within the UK, not including demonstration projects. This allowed for any experience gained from international projects, as well as the UK demonstration projects, to be accounted for within the FOAK numbers.

3.2.4 For new technologies or those with little commercial experience within the UK, NOAK inputs were generally defined as the estimated level that would be achieved when the addition of one new plant within the UK would not in itself have any significant impact on the forward price of the technology beyond long term market trends. Variation between sites was represented through the variation of values across the high, central and low levels, and general uncertainty is applied separately within the model, and shown separately in the values presented in this report.

General Treatment of Input Levels

3.2.5 High, central and low input levels were incorporated into the model for each parameter. These levels have been utilised to represent the variation in each parameter across specific example sites. Uncertainty in costs for immature technologies is shown separately.

3.2.6 The low, central and high cases are specific to each parameter. It is understood that a “high” cost case would have a “low” efficiency and availability. Each individual value is shown in its low-high range, regardless of impact on other values.

3.2.7 Costs are on a 2012 Great British Pound sterling (GBP) basis. Where necessary costs were adjusted to 2012 values using the Gross Domestic Product (GDP) deflator as published on the website of Her Majesty’s Treasury.

3.3 Data Sources

3.3.1 Where information such as publications, confidential data etc. had been reviewed for the 2012 update this information was not reviewed again, except as a comparator for new information. All information was adjusted as necessary, for example for inflation, timing, technical differences, currency, etc.

3.3.2 Data sources include:

- Information provided by operators for the purposes of this update[3].

- Information from industry experts, both Parsons Brinckerhoff and external experts
- Reference UK projects
- Reference International projects
- Indicative costs for projects under development – For CCS plant the best available cost information was used in each case, much of which is from projects still in development, both UK and overseas. Both public domain and confidential information was utilised.
- Cost databases and modelling software – The reference plant size for gas CHP was changed at DECC's request to reflect a plant size more likely to be built in the UK in the short term, and OCGT plant technology basis was changed. GTPro with PEACE modelling was performed for both of these technologies. This is industry recognised software, which uses the user design inputs to model the technical performance and relevant costs of different plant types. Technical values were informed by the model, and cost information was adjusted using cost data from the model. The absolute costs derived from the software were not used as cost results directly but as a means of scaling trusted costs e.g. for CCGT plant, to give more robust estimates of specific CHP and OCGT plant sizes.
- Studies and literature search – Relevant cost data published since the previous update, for projects under development and for new technologies at an earlier stage of demonstration, were analysed to prepare an assessment of the likely costs for such technologies when they become commercially available.
- Parsons Brinckerhoff experience – Parsons Brinckerhoff has drawn upon its own work and internal cost databases to contribute further data to the literature search which underpinned estimates.
- Parsons Brinckerhoff estimates – In some cases it was difficult to obtain any robust value from which input assumptions could be extrapolated from accessible or published data. Where necessary Parsons Brinckerhoff used its own cost estimating facilities to estimate the appropriate adjustment to make when an input was scaled.

3.3.3 When considering individual data sources, Parson Brinckerhoff also ensured consistency within the data set was conserved where possible. Many adjustments led to "knock-on" adjustments in other values, conserving the same methodology, link, or ratio of costs as in the 2012 values, as appropriate.

3.3.4 For new technologies, namely CCGT with oxy-combustion CCS and coal plant with 300MW of CCS, the best available information for each value was used. For some values e.g. timings, this was based on comparison and consistency with similar technologies in the dataset.

3.4 Peer Review

3.4.1 In accordance with the requirements of this project, an independent peer review of the key model inputs was undertaken. A range of stakeholders were asked to comment on the key draft values.

3.4.2 In general, changes were only made where two or more reviewers recommended a similar change and provided sufficient justification / source data. In some cases a change was made on the basis of one reviewer's comment, where that reviewer is considered to have particular expertise in that area. The expertise of each stakeholder in that area was also taken into account when deciding whether to act on the comment or not. Where peer reviewers disagreed on values the number and expertise of reviewers proposing increase or decrease was considered as well as the reasoning provided by each.

3.4.3 OCGT plant was not included in the peer review. This was partly due to time constraints and partly because no large scale OCGT plant is currently planned in the UK.

3.5 Accuracy

3.5.1 In general, the accuracy of capital costs for each technology can be said to fall into either a class 5 or class 4 estimate, as defined under AACE International Recommended Practice 18R-97, shown in Figure 1.

	Primary Characteristic	*Secondary Characteristic*			
ESTIMATE CLASS	**LEVEL OF PROJECT DEFINITION** Expressed as % of complete definition	**END USAGE** Typical purpose of estimate	**METHODOLOGY** Typical estimating method	**EXPECTED ACCURACY RANGE** Typical variation in low and high ranges [a]	**PREPARATION EFFORT** Typical degree of effort relative to least cost index of 1 [b]
Class 5	0% to 2%	Concept Screening	Capacity Factored, Parametric Models, Judgment, or Analogy	L: -20% to -50% H: +30% to +100%	1
Class 4	1% to 15%	Study or Feasibility	Equipment Factored or Parametric Models	L: -15% to -30% H: +20% to +50%	2 to 4
Class 3	10% to 40%	Budget, Authorization, or Control	Semi-Detailed Unit Costs with Assembly Level Line Items	L: -10% to -20% H: +10% to +30%	3 to 10
Class 2	30% to 70%	Control or Bid/ Tender	Detailed Unit Cost with Forced Detailed Take-Off	L: -5% to -15% H: +5% to +20%	4 to 20
Class 1	50% to 100%	Check Estimate or Bid/Tender	Detailed Unit Cost with Detailed Take-Off	L: -3% to -10% H: +3% to +15%	5 to 100

Figure 1 – Cost estimate classifications

3.5.2 The standard defines the expected accuracy of cost estimates as a function of the project stage and the way in which costs were derived.

3.5.3 The majority of capital costs were class 5 estimates as no specific project was defined and each technology was approached on a conceptual level. Estimates for immature technologies were towards the extreme limits of a class 5 estimate.

3.5.4 CCGT could be defined as a class 4 estimate as the concept has a relatively narrow definition and any cost variations caused by specific design choices are usually counter-acted by another variation, leading to an optimum design and converging costs.

3.5.5 Project cost data were often provided on the basis of specific costs per unit capacity, or as overall costs rounded to the nearest million units of currency for small plant, ten million units of currency for medium sized plant and 50 million units of currency for larger plant. This introduced an error of up to 5% into cost data supplied on this basis from rounding alone.

3.5.6 Additionally, the plant configuration, boundary and major components covered by the project costs were not always clear. Some quotes required modification in order to add or remove certain cost components to give a number of data points on a comparable basis.

3.5.7 Bottom up estimations were inherently less accurate than project costs due to the potential for the accumulation of errors; however they provided a more consistent approach across technologies.

4 TECHNOLOGY OVERVIEW

4.1 CCGT, CHP and OCGT

Combined Cycle Gas Turbine (CCGT)

4.1.1 CCGT plant is a mature technology that involves the generation of electricity from gas turbines. The waste heat from each gas turbine is then passed through a heat recovery steam generator to raise steam, which in turn generates additional electricity from a steam turbine. No major advances or technical changes are expected to affect the cost and performance of this technology in the near future; however incremental improvements in efficiency are expected to continue.

CCGT with Combined Heat and Power (CHP)

4.1.2 CCGT with CHP is a mature technology that involves the generation of electricity from gas turbines. The waste heat from each gas turbine is then passed through a heat recovery steam generator to raise steam, which in turn generates additional electricity from a steam turbine. Steam is also extracted at an appropriate pressure from the steam turbine to supply heat.

Open Cycle Gas Turbine (OCGT)

4.1.3 OCGT is a mature technology that involves the generation of electricity from gas turbines without any waste heat recovery. In the 2012 update the OCGT costs were based on aero-derivative turbines operating as fast response plant, however the 2013 assumptions are for large frame gas turbines which would be required to run if insufficient generation capacity was available, but would not be required to have such fast response times as aeroderivative plant. This basis is more appropriate to inform decisions concerning the implementation of a Capacity Market under the Government's Electricity Market Reform program.

4.2 ASC Coal and IGCC Coal

4.2.1 Advanced super-critical coal involves burning coal in a large boiler to produce steam above super-critical conditions. Super-critical conditions are defined scientifically as steam above 221.2 bar. The temperature is usually above 600 °C. The point at which steam is produced at a high enough pressure for the plant to be classed as advanced super-critical is arbitrary; some sources suggest over 240 bar, whereas some suggest over 270 bar and at temperatures of above 620 °C. For the purposes of this study, cost and technical data were based on a plant with steam conditions of

240 bar to 250 bar and 620 °C. The steam passes through a steam turbine which drives a generator to generate electricity.

4.2.2 IGCC involves the gasification of coal (or potentially biomass) to produce syngas that can fuel a CCGT plant.

4.3 CCS

Carbon Capture and Storage (CCS) Technologies

4.3.2 Carbon capture and storage technologies covered a range of methods for extracting carbon from fuel or flue gas in order to prevent the majority of its emission to atmosphere. This report covers the following technologies:

- CCGT plant with Post-Combustion Carbon Capture and Storage (CCS)
- CCGT plant with Retrofitted Post-Combustion CCS
- CCGT plant with Pre-Combustion CCS
- CCGT plant with Oxy-Combustion CCS
- Advanced Supercritical (ASC) coal plant with Flue Gas Desulphurisation (FGD) and partial (300MW net) Post-Combustion (Amine) CCS
- ASC coal plant with FGD and Post-combustion (Amine) CCS
- ASC coal plant with FGD and Post-combustion (Ammonia) CCS
- ASC coal plant with FGD and Retrofitted Post-combustion (Amine) CCS
- ASC coal plant with FGD and Oxy-combustion CCS
- Integrated Gasification Combined Cycle (IGCC) and partial (300MW net) Pre-Combustion CCS
- IGCC with Pre-combustion CCS
- IGCC with Retrofitted Pre-combustion CCS[4]
- Biomass plant with post-combustion CCS

4.3.3 It should be noted that the CCS costs are considered, as for other technologies, on a generic basis rather than a site-specific basis. They may therefore differ from the costs of particular planned projects in the UK. It also should be noted that the FOAK costs are for the first plant, excluding demonstration projects, so it is not expected that the FOAK values would be in line with current demonstration project estimates.

4.3.4 There are three types of carbon capture considered in this study, along with compression and pipeline transport of CO_2. These are post-combustion, pre-combustion and oxy-combustion. A brief description of each type is given below. Although pre-combustion and oxy-combustion can be applied to fuels other than gas and coal, these options are outside the scope of this study. There are a number of other methods of carbon capture, a number of other solvents available for pre and post-combustion capture, and carbon capture can also be applied to industrial plants

[4] It should be noted that the retro-fit of capture and compression equipment to an IGCC is highly unlikely to take place due to the technical difficulties associated with the modification of the syngas treatment process. A more likely solution is to retro-fit coal handling equipment, the gasifier and CO_2 capture equipment and modify an existing combined cycle plant, layout permitting.

such as cement or steel plant, but these options are also outside the scope of this study.

4.3.5 Post-combustion: The flue gases from a coal, biomass or CCGT plant are directed into an absorber vessel in which they react with liquid amine, which absorbs roughly 90% of the CO_2 in the flue gases. In a typical process the flue gas passes through a direct contact cooler which cools the flue gas to approximately 50°C. The amine solvent absorbs CO_2 from the flue gas, which is then cleaned with a water wash to remove harmful substances before being emitted to atmosphere. The CO_2 rich solvent is then pumped to a stripper, in which it is heated, causing the CO_2 to separate from the solvent. The concentrated CO_2 is then compressed and transported to a storage site while the solvent is returned to the absorber. Low pressure steam is extracted from the steam turbine to provide the required heat. This incurs an energy penalty (efficiency loss) in the steam cycle. The analysis for this study considered amine absorbers for both coal and gas with post-combustion, and ammonia absorbers for coal with post-combustion. Other methods such as dry sorbents are outside the scope of this study.

4.3.6 Pre-combustion: Synthetic gas produced from coal in an IGCC or from partial oxidation of natural gas is reacted with steam to convert the majority of the carbon monoxide to CO_2. The resulting mixture is mainly composed of hydrogen and CO_2. This type of mixture can also be produced by reforming natural gas using steam. The mixture is directed into an absorber vessel in which it reacts with a liquid solvent such as Selexol, which absorbs most of the CO_2 in the gas mixture. The cleaned gas, mainly composed of hydrogen with some carbon monoxide, CO_2 and other gases is then combusted in a CCGT cycle, with the flue gases emitted to the atmosphere. The solvent is heated in a re-boiler vessel using heat from steam which causes the CO_2 to desorb from the liquid. The overall capture rate is roughly 80% to 90%.

4.3.7 Oxy-combustion: pulverised coal is combusted with oxygen in a boiler to heat steam at a supercritical pressure, driving a steam turbine to produce electricity, or natural gas is combusted with oxygen in a CCGT. The oxygen is produced by a cryogenic Air Separation Unit and the flue gases are mainly composed of CO_2 and water vapour. Some of the flue gases are re-circulated to the combustion chamber or the gas turbine inlet, and the remainder are cooled to condense the water vapour, leaving a stream of CO_2 gas. The overall capture rate is roughly 95% to 98%. The oxygen may in the future be produced using membranes, and the NOAK low cost case assumes membranes are used to produce the oxygen.

4.3.8 Each capture technology is currently at a different stage of development from initial concept to numerous pilot plants with larger scale plants under development.

CO_2 transport and storage

4.3.9 Compression of CO_2 for pipeline transport was included in the capital cost estimates for all capture technologies.

4.3.10 The low case for storage was assumed to be offshore storage of CO_2 in a depleted oil or gas field, assuming some existing infrastructure e.g. offshore platform would be re-used if appropriate.

4.3.11 The central case for storage was assumed to be offshore storage of CO_2 in a depleted oil or gas field, with new infrastructure.

4.3.12 The high case for storage was offshore storage of CO_2 in a saline aquifer. This is more expensive as the pressure is higher.

4.3.13 All storage cases included abandonment expenditure and provision for a liability reserve account.

4.4 Nuclear

4.4.1 Various designs for large nuclear power plant are currently being offered or constructed around the world. The technology considered within this report is the pressurised water type reactor (PWR). The reactor generates heat from nuclear fission reaction which is utilised to raise steam to generate electricity in a steam turbine.

4.4.2 The plants include extensive safety systems and complex fuel and waste handling equipment.

4.4.3 It should be noted that the nuclear costs are considered, as for other technologies, on a generic basis rather than a site-specific basis. They may therefore differ from the costs of particular planned projects in the UK.

5 ANALYSIS OF COST INPUTS

5.1 General Changes to Cost Inputs

5.1.1 This section of the report describes the working behind the updated inputs. The updated assumptions can be found in Appendix A – Technology-By-Technology Assumptions.

5.1.2 Other than the changes described below, costs and other assumptions remained the same as in the 2012 update, or were adjusted to maintain consistency with other values and 2012 methodology.

5.1.3 Section 5.1 describes each assumption in more detail and highlights general high-level changes to the technology cost assumptions. Changes to each technology are then explored in more detail

Net Power Output

5.1.4 The quoted power output was selected to be representative of typical projects for the relevant technology type. These power outputs correlate with quoted costs and indicate the size of plant which the costs and performance inputs were based on. Although the actual value of power output is not represented in the levelised cost of a technology, it is significant due to the cost assumptions being based upon a plant of that size. Power outputs in general remained the same as in the 2012 update or were adjusted based on efficiency.

Net Efficiency

5.1.5 The efficiency figures chosen represent the reasonable variation in efficiency from site to site in the case of mature technologies such as CCGT, CHP, and OCGT. This variation is generally brought about by the economics of specific projects. For less mature technologies, the efficiency values represent the expected variation and uncertainty in this parameter.

Plant Availability

5.1.6 Availability includes estimates of the forced outage rate, outages due to a major overhaul and power degradation (where applicable). Although it is not usual to include power degradation within estimations of availability, it has been accounted for within the availability profile as there was no separate model input for power degradation (which is the decrease in total power output of a plant over time). Therefore for technologies that include power degradation (namely gas fired technologies) the availability may differ from the expected and more usual trends.

5.1.7 Please note that as in the 2012 update it is assumed that the addition of CCS does not significantly affect power plant availability, as the plant will be able to operate without CCS, and any temporary loss of power would be offset by the increase in power when operating without CCS. Therefore, outages in the downstream CO_2 transportation and storage system would not have a negative impact on power plant availability.

5.1.8 Infrastructure is assumed to be the cost of infrastructure that is charged directly to the project, i.e. overhead line to the grid connection point[5], and for gas pipelines the cost of building the pipeline. In the 2012 update these costs were estimated based on diameter and pressure of pipeline, and voltage of overhead lines. After discussion with operators and DECC, no change was made to the assumed length of overhead lines, which remain at 0, 5 and 10km. The overhead line costs are consistent with the IET transmission costing study undertaken by Parsons Brinckerhoff in 2012.

5.1.9 After discussion with suppliers and DECC, gas pipeline lengths were increased from 5 km for low, central and high to 5, 10 and 20 km for CCGT, CCGT CHP and OCGT. Both operators and experts within Parsons Brinckerhoff believed that 5 km is at the low end of the range, but various values for the high end of the range were suggested. 20 km was a reasonable compromise between the various values suggested.

5.1.10 Although steel prices have reduced outside of Europe in the last year, they have remained static in Europe. Expert opinion is that there should be no significant increase in costs per km for overhead line or gas pipeline.

For nuclear and coal plant, the cost of fuel supply infrastructure is not considered within the infrastructure cost. This is to maintain consistency with 2012 values. Nuclear plant will not require significant fuel supply infrastructure while coal plant is considered likely to be built adjacent to existing transport infrastructure providing access to shipped fuel.

Future Costs

5.1.11 Forward pricing is based on Parson Brinckerhoff's Forward Pricing Model (FPM), the output of which is an input to the LCM. Parsons Brinckerhoff updated the inputs to the FPM. No changes were made to learning rates or uncertainty bounds for existing technologies.

[5] Grid connection is said to be achieved when a power plant first supplies power outside of its own boundaries.

5.1.12 Build rates and global inputs were updated in line with information provided by DECC. Global Deployment scenarios were sourced from the IEA's 'Energy Technology Perspectives 2012'

5.1.13 For new estimates, uncertainty bounds for coal and IGCC plant with 300MW capture were consistent with uncertainty of the non-capture and capture portions of the plant. Uncertainty bounds for ammonia capture are assumed to be the same as those for amine capture.

Operational Costs

5.1.14 Insurance costs for retrofit capture plant are provided in the appendices for both the total plant (assumed to be the same per kW as newbuild plant) and for the retrofitted capture plant only (assumed to be the same percentage of capex as fullscale CCS).

5.1.15 The same methodology was used for Connection and Use of System (UoS) Charges as in the 2012 update. For each technology type the appropriate UoS charges were calculated, based on the 2013 updated information on all UoS charges from National Grid, including updated Generation Zones for Transmission Network UoS (TNUoS) charges. The likelihood of each technology being built in each zone was considered based on technical, permitting and network constraint, but ignoring economic constraints. The average charge of all the likely zones was used for each technology.

CO_2 Transport and Storage

5.1.16 In the 2012 update CO_2 transport costs were based on a central value per km per tonne with an assumed pipeline length providing the variation between low, central and high. This methodology underestimated central and high costs for transport, compared to costs per tonne. Transport costs have been adjusted to take account of per tonne low, central and high costs. These values are based on the same publications on which the transport costs were based last year. CO_2 storage assumptions remain as in the 2012 update. It should be noted that transport and storage costs are flatlined at NOAK values, as in the 2012 update.

Additional Inputs

5.1.17 Fuel costs and decommissioning costs were not considered as part of this project and will be updated by DECC separately.

5.2 CCGT and CCGT with CCS

5.2.1 In general for CCGT, assumptions were only changed where two or more operators or peer reviewers advised a change. Changes to CCGT impact the estimates for CCS as changes to the base plant (CCGT). We will firstly discuss changes to CCGT estimates and then CCS estimates.

CCGT

Timings

5.2.2 Most CCGT timings remained the same as in the 2012 update. The construction period was examined following information provided by operators for the purpose of this report. Parsons Brinckerhoff's view is that the length of time advised by operators is based on delays that are not caused by technical issues, however, and so the construction period remains the same.

5.2.3 The values for operating life represent the technical capability, not the economic life of the plant. The upper end of the range remains the same as in the 2012 update, as this is based on technical feasibility with appropriate maintenance. The technically feasible operating life is dependent on a number of factors including load factor. Many of the high-temperature plant components have a specified operating life of 200,000 hours. For the assumed availability range (91%-94%) this is 24-25 years before these parts are likely to need replacing. The central operating life value was reduced to 25 years in line with this and operator recommendation.

Technical Data

5.2.4 The low CCGT efficiency value was reduced to match a recent UK project. This had a knock-on effect on CCGT with capture. Although a number of operators and peer reviewers recommended increasing the high efficiency value in line with 61.5% gross for J class (roughly 60.5% net LHV), it was decided not to adjust this high value. 60% is as high as current technology is likely to achieve in real-world UK conditions.

The availability profile for CCGT was examined following information provided by operators for the purpose of this report. Based on knowledge of availability currently being contracted and achieved by new plant in other countries, Parsons Brinckerhoff's opinion is that the availability values proposed by the operators are not based on what is technically feasible for new plant, but rather are based on assumptions relating to operating regime. The inputs to the LCM should be based on technical feasibility rather than economic factors. Therefore the availability values remain the same as in the 2012 update.

Capital Costs

5.2.5 The range for the Pre-licensing, Technical and Design costs was considered following comments from operators for the purpose of this report. The low end was reduced in line with operator comments, but it was considered that the values given by operators for the high cost were not directly comparable to costs from the 2012 update, and most likely included some owner's costs or other costs not included in 2012 values. The high cost was increased slightly as a result. This had a knock-on effect on CCGT with retrofitted CCS costs. The range of the Regulatory, Licensing and Public enquiry costs scale was also examined in light of comments from operators, but it was considered that the values given were not directly comparable to costs from the 2012 update, and most likely included some owner's costs or other costs not included in 2012 values. The high cost was increased as a result. This had a knock-on effect on post-combustion and retrofitted post-combustion costs. Pre-combustion costs were adjusted to come into line with post-combustion costs.

5.2.6 The majority of EPC values received from operators were within the 2012 range for CCGT costs. The low, central and high values were all reduced very slightly to reflect market depression.

Operational Cost

5.2.7 The range for O&M was adjusted in light of comments received from operators for the purpose of this project and Parsons Brinckerhoff's professional judgement. Considering all values recommended, the decision was made to leave the low value the same, but increase the high and central values. The central cost was set to the middle of the range for both fixed and variable CCGT O&M. All peer reviewers stated CCGT O&M costs were reasonable apart from one who stated the high cost should be reduced and another who stated it should be increased.

5.2.8 The low cost for insurance was the lowest information provided (as a percentage of capex), and the central was the average of low and high. The same percentage of capex was used for insurance costs for both CCGT with and without capture. Peer review implied the insurance ranges are reasonable.

CCGT with CCS

5.2.9 In order to check continued validity of assumptions, all assumptions for CCS technologies were compared to a new source of data. The US Department of Energy National Energy Technology Laboratory has published an update of its costs for power plant including CCGT, CCGT with post-combustion capture, ASC Coal with post-combustion capture and IGCC with pre-combustion capture (NETL, 2012)[6]. For these technologies NETL's updated costs were converted to UK sterling on a 2012 basis and compared on the same basis to the final values in this report. The values compared were:

- Capital cost excluding owner's costs – compared to EPC cost
- Combined fixed and variable O&M costs excluding taxes and insurance – calculated assuming baseload operation – compared to combined fixed and variable O&M costs calculated assuming baseload operation.
- All of NETL's capital cost values fall within the range of uncertainty for both FOAK and NOAK for all four technologies. The combined fixed and variable O&M costs from the NETL report fall within the O&M range for both FOAK and NOAK for all technologies with two exceptions:
- NETL's combined O&M cost for IGCC with capture is 7% higher than the highest NOAK value, but is within the range for FOAK; and
- NETL's combined O&M cost for CCGT with post-combustion capture is 1% below the range for FOAK, but is within the range for NOAK.
- The ratios of CCS NOAK Operation and Maintenance (O&M) costs to FOAK O&M costs were adjusted based on the CRTF report. This report showed a potential reduction in operating cost of combined power and capture plant of 7%, but reduction included some economies of scale (ignoring non-technical and non-capture cost reductions).

Timings

5.2.10 Timings for CCGT with oxy-combustion capture (a new technology this year) were assumed to be the same as for post-combustion capture, as the technology should take a similar length of time to design, permit, procure, construct and commission, and the process equipment for producing oxygen and purifying the CO_2 should have a similar lifespan as the post-combustion capture equipment.

Technical data

5.2.11 Power output for CCGT with oxy-combustion CCS was based on a rounded estimate for a single gas turbine with a single steam turbine. The low value was based on peer review comment.

[6] National Energy Technology Laboratory (NETL, 2012), Updated Costs (June 2011 Basis) for Selected Bituminous Baseline Cases, *US Department of Energy*, http://www.netl.doe.gov/energy-analyses/pubs/BaselineCostUpdate.pdf

5.2.12 The low efficiency values for CCGT with newbuild and retrofitted post-combustion were reduced in line with peer review comments. The efficiency values for CCGT with oxy-combustion CCS were based on publications and peer review comment.

5.2.13 Pre-combustion capture rate was increased in line with peer review comments. CCGT with oxy-combustion capture rates are expected to be similar to coal with oxy-combustion capture rates.

Capital Costs

5.2.14 CCGT with pre-combustion costs for Pre-licensing, Technical and Design were adjusted slightly to come into line with post-combustion costs. Because technical issues associated with CCGT oxy-combustion technology are currently less well understood than post-combustion, design costs for CCGT with oxy-combustion CCS costs were assumed to be 5-10% higher than post-combustion for FOAK. For NOAK the design costs are expected to be similar to post-combustion.

5.2.15 The NOAK EPC costs for CCGT with capture were adjusted to maintain the same relative differences to non-capture CCS as in the 2012 update. In general for all CCS technologies developers stated in peer review that EPC costs should be increased, and industry / governmental bodies that costs should be reduced. Many of the costs proposed by peer reviewers were within or close to the range of uncertainty for CCS technologies. Where costs quoted were significantly outside the range of uncertainty, these were typically costs for small scale demonstration plant. In general therefore, no change was made to CCS capex values on the basis of peer review comments.

5.2.16 The ratios of CCS NOAK EPC costs to FOAK EPC costs were adjusted based on the CCS Cost Reduction Task Force interim report (CRTF report)[7]. This report showed a potential reduction in capital cost of combined power and capture plant of 5-10% (ignoring economies of scale, non-technical and non-capture cost reductions. One peer reviewer suggested a 20% drop in EPC costs. A 10% reduction in FOAK to NOAK central EPC cost was chosen for the final figures. As the NOAK values are based on more robust analysis (peer-reviewed report based on Aspen and Thermoflow modelling) than the FOAK values, the FOAK values were adjusted in line with this.

5.2.17 The EPC costs for CCGT with oxy-combustion capture were based on a range of publications, including the CRTF report expectations for FOAK to NOAK improvement.

Operational Costs

5.2.18 The range of NOAK O&M values for CCGT with capture was adjusted to encompass both the values from the 2012 update and this year's CCGT costs with incremental costs from the 2012 update. Peer review indicated that this range was reasonable. One demonstration project developer suggested that economic considerations such as when a CCS plant could operate in the market should be taken into consideration. As previously explained in this report (Section 2.4), the inputs to the LCM are based on what is technically feasible, not on economic decisions.

[7] UK Carbon Capture and Storage Cost Reduction Task Force (CRTF, 2012), The Potential for Reducing the Costs of CCS in the UK, Interim Report, *Department of Energy and Climate Change*, http://webarchive.nationalarchives.gov.uk/20121217152407/http:/www.decc.gov.uk/assets/decc/11/cutting-emissions/carbon-capture-storage/6987-the-potential-for-reducing-the-costs-of-cc-in-the-.pdf

5.2.19 The CRTF report indicates a 7% drop in O&M costs from FOAK to NOAK would be appropriate if economies of scale are included, implying the reduction should be less than 7% without economies of scale. However, in the 2012 update the reduction was greater than 7%. FOAK O&M values for CCGT with capture were adjusted in line with a 7% reduction.

5.3 ASC Coal and IGCC with CCS

5.3.1 For both ASC Coal and IGCC with partial capture, the fraction of the plant to which capture is applied is calculated to be the minimum required to achieve the 300MW requirement. This means that the high efficiency case corresponds to the low capture rate case, as less of the plant requires capture to meet 300MW. It also means that capture rates are lower for NOAK plant with higher efficiency.

5.3.2 The cost assumptions for ASC Coal and IGCC with CCS were also compared to the NETL (2012) data on CCS costs described in Section 5.2 above.

<u>Timings</u>

5.3.3 Although the capture plant will be largely built in parallel with the ASC Coal or IGCC plant, the capture plant will be slightly delayed and commissioning will be extended compared to an ASC Coal or IGCC plant without capture, as the capture plant cannot be commissioned until the power plant is operational. This applies regardless of the size of the capture plant. Therefore for a coal plant with 300MW of CCS, timings were assumed to be the same as coal plant with full scale CCS, for both post- and pre-combustion capture. Timings for ammonia capture were assumed to be the same as for amine capture as the technology should take a similar length of time to design, permit, construct and commission, and the process equipment should have a similar lifespan.

5.3.4 The central and high construction periods for ASC Coal with oxy-combustion capture were reduced. In 2012 a value from a confidential source was considered to be the central estimate but based on industry knowledge this is now considered to be at the high end of the scale. Some of the timings for IGCC with CCS were also adjusted based on industry experience.

<u>Technical Data</u>

5.3.5 For ASC Coal with post-combustion CCS, the FOAK power output was adjusted downwards, as it is considered the FOAK plant would be designed as a standard 1,600MW net (before CCS) plant with capture added, so that the net output would be less than 1,600MW. This was also assumed for FOAK and NOAK ASC Coal and IGCC with 300MW capture plant. The power outputs of coal plant with ammonia post-combustion capture were based on publications. The power outputs of IGCC with capture were adjusted in line with the efficiency, i.e. all IGCC plants would be expected to have the same total fuel intake.

5.3.6 Efficiencies for ASC Coal and IGCC with 300MW CCS were set to be consistent with full scale capture and non-capture efficiencies. The efficiency values for coal with post-combustion CCS were adjusted based on data from two recent publications and peer review comments. The efficiency values for ammonia capture were based on publications.

5.3.7 Availability for coal and IGCC with 300MW capture is expected to be the same as for full scale capture. Addition of capture is not expected to significantly impact on availability as the plant will be able to run without capture when necessary. In this case the output would increase, more than compensating for any temporary loss of power when switching from capture to non-capture mode. All plant with capture is now assumed to have the same availability as non-capture plant.

5.3.8 For the partial (300MW) capture cases, the capture rate has been stated on a whole-plant basis, consistent with capture rate for full scale capture plant. Capture rates for ASC Coal with post-combustion, ASC Coal with oxy-combustion and IGCC with pre-combustion capture were adjusted based on peer review comments. Ammonia capture rates are expected to be similar to amine capture rates. Pre-combustion capture rates were adjusted based on industry experience.

Capital Costs

5.3.9 Coal with 300MW of post-combustion CCS was assumed to have the same absolute cost for Pre-licensing, Technical and Design as full scale CCS, for both post- and pre-combustion. This is because these costs are expected to be largely independent of size of the plant. Design costs for retrofitted post-combustion capture were adjusted to have the same ratio for retrofitted to newbuild as for gas plant. Design costs for IGCC with 300MW capture, full scale capture and retrofitted capture were increased to 1.5% of the EPC cost to reflect the high cost of a Front End Engineering Design (FEED) study. This is based on the assumption that for an IGCC, a FEED study of the quality typical of the process sector would be necessary prior to financial close, since the technology required for an IGCC comes from the process sector, rather than being traditional power industry technology.

5.3.10 Regulatory, Licensing and Public enquiry for ASC Coal and IGCC with 300MW of capture are assumed to have the same absolute costs as full scale CCS. This is because these costs are expected to be largely independent of the size of the plant.

5.3.11 EPC and O&M costs for the 300MW capture cases are set to be consistent with the capture and non-capture costs, and the relevant portion of the plant to which capture is applied.

5.3.12 Coal with post-combustion amine capture EPC costs were reduced slightly on the basis of two new publications. Coal with post-combustion ammonia costs found in publications were typically lower than amine costs, however these publications were based on very high level designs. One source of ammonia cost information was considered a worst case as it was based on a retrofit, small scale, FOAK demo plant. This was the only source that provided values for an ammonia capital cost, which, when appropriately adjusted, were higher than amine – in this case by 7%. A more recent and robust publication than the high level studies did not give values for costs but stated that capital costs for ammonia are higher and operating costs lower than amine. On this basis ammonia capital costs were set to be 0%, 3.5% and 7% higher than amine. IGCC with pre-combustion CCS EPC costs were increased based on industry knowledge.

5.3.13 Capital cost information for IGCC has been acquired from a number of sources. This has included a number of published cost reports including figures generated by the Electric Power Research Institute, NETL and the Global CCS Institute, reported costs for the Duke Energy Edwardsport project, confidential data from a project at FEED stage development and in-house modelling. All of these costs have been converted to a common basis, both in terms of timeframe and UK location basis. Analysis of the resultant data indicates a significant increase in the capital cost of IGCC projects, which is reflected in our updated figures.

5.3.14 The CRTF report indicates a 5-10% drop in EPC costs from FOAK to NOAK would be appropriate. One peer reviewer indicated a 5% drop for FOAK to NOAK is appropriate. A value of 10% is assumed for IGCC FOAK to NOAK reduction, in line with CRTF report and industry expertise. In 2012 the values showed a 6% reduction in FOAK to NOAK central EPC cost for coal with post-combustion. This ratio was maintained in 2013, and a 6% reduction was also assumed for ammonia post-combustion EPC central cost. As the FOAK values are based on more robust analysis (including FEED studies) than the NOAK values, the NOAK values were adjusted in line with this.

5.3.15 Coal with retrofit post-combustion capture EPC costs were adjusted to maintain the same relative values to new build as in the 2012 update.

Operational costs

5.3.16 A recent publication based on a FEED study indicated O&M costs for post-combustion capture should be reduced. The values were reduced in line with this publication and Parsons Brinckerhoff judgement.

5.3.17 The CRTF report indicates a 7% drop in O&M costs from FOAK to NOAK would be appropriate if economies of scale are included, implying the reduction should be less than 7%. In the 2012 update the reduction in O&M costs for ASC Coal with oxy-combustion capture was 7%, but for post-combustion capture, the reduction was greater than 7%. NOAK O&M values for ASC Coal with post-combustion capture were adjusted to show a 7% reduction in line with this report.

5.3.18 The range of publications considered for the coal with post-combustion ammonia capture included values from 57% of amine O&M cost to higher than amine O&M cost. However a more recent FEED study indicated that ammonia O&M cost is lower than amine O&M cost, though values were not provided. The range of ammonia costs are based on the range of publications and consideration of the CRTF report. The values selected are 57%-87% per unit of amine costs.

5.3.19 IGCC with pre-combustion capture O&M was increased to 4% of EPC cost per annum in line with industry knowledge. The reduction in O&M cost from FOAK to NOAK is in line with the CRTF report.

5.3.20 Low and central insurance costs are the same percentage of EPC cost as in the 2012 update. High insurance cost for coal with CCS was assumed to be the same percentage of EPC cost as central insurance cost for CCGT, on the basis that capture plant may be considered a higher risk.

5.4 Nuclear PWR

5.4.1 The values for which changes were proposed by peer reviewers and operators are discussed below. It should be noted that although some peer reviewers quoted values for other nuclear technologies, the costs discussed in this report are for PWR plant only.

5.4.2 It should be noted that the nuclear costs are considered, as for other technologies, on a generic basis rather than a site-specific basis. They may therefore differ from the costs of particular planned projects in the UK.

Technical Data

5.4.3 The availability figures for nuclear were revisited. The low value was reduced slightly in light of a comment that the availability figures should be reduced. The high and central cases from the 2012 update were retained, however, as it is considered that the high and central cases reflect what is technically feasible. The inputs to the LCM should be based on technically achievable availability, not economic considerations as discussed in section 2.4 above.

5.4.4 For nuclear technologies, fuel prices are quoted per unit of electrical energy output and therefore the efficiency is not required to calculate the fuel consumed. Therefore, no assumption for nuclear plant efficiency has been provided. Rather, the efficiency figure to be included in the LCM to be consistent with the fuel prices is 100%.

Capital Costs

5.4.5 Stakeholder feedback indicated that nuclear capital costs should be increased. The NOAK values were increased for low, central and high. The FOAK values were also increased for low, central and high in line with operator and peer reviewer information, discussion with DECC and Parsons Brinckerhoff's judgement.

Operational costs

5.4.6 O&M and insurance costs were not adjusted as almost all stakeholders were in agreement with the values.

5.5 Large Scale CHP

5.5.1 Small (5MW and 50MW scale) CHP was not updated in 2013. Large scale CHP plant in the 2012 update was based on a 750MW electrical output, 380MW steam output plant. In 2013 DECC requested that the large scale CHP plant be changed to a smaller scale unit, of the size that DECC believes is likely to be built in the UK in the short term. The new size is a 215MW electrical, 220MW steam CHP plant. This type of plant was modelled using GTPro and PEACE, both part of the Thermoflow industry standard software package.

5.5.2 It should be noted that the updated CHP costs are not directly comparable to the 2012 costs, as the plant is a different type.

Timings

5.5.3 As in the 2012 update, pre-construction and construction timings for CCGT CHP plant are identical to CCGT plant, as the plant is very similar. Operational life has been increased to the technical life of the plant, again expected to be the same as CCGT,

Technical Data

5.5.4 Power output, efficiency and steam output are based on the range of GTPro modelling carried out.

5.5.5 Availability for CCGT CHP plant is assumed to be the same as for CCGT plant as the technology is very similar. There is no technical reason why a gas turbine, steam turbine or Heat Recovery Steam Generator should have significantly different forced outage rates or maintenance requirements when used as part of a CHP plant instead of a CCGT plant. A small modification to the steam turbine may be required to accommodate extraction steam but this is an established technology with no availability implications.

Capital costs

5.5.6 CHP was assumed to have the same absolute cost for Pre-licensing, Technical and Design as a CCGT. Although the plant is smaller it is not sufficiently smaller to significantly reduce the costs.

5.5.7 CHP was assumed to have the same absolute Regulatory, Licensing and Public enquiry cost for permitting as a CCGT. The issues are the same and although the plant is smaller it is not sufficiently smaller to significantly reduce the costs.

5.5.8 EPC values for CHP plant were based on market knowledge of CCGT plant, adjusted by reference to PEACE modelling. PEACE modelling of both CCGT plant and the specific CCGT CHP scenario required provided information on the relative costs of these two plant types. This allowed the CCGT costs based on market knowledge and stakeholder information to be adjusted to provide a price for CHP plant. This method is considered to be the most robust method of producing CHP capital costs bearing in mind that the CCGT values are based on knowledge of the current market and have been corroborated by information from stakeholder and there are no relevant recent or current CHP projects from which to market pricing information is available.

Operational Costs

5.5.9 No O&M costs from comparative projects were available for the CHP plant size chosen. As an indicative range O&M costs from 2011 (based on a 500MW plant) were used, adjusted for inflation. The low value is the same per kW as the low 2011 cost, the high value is the same overall cost as the high 2011 cost, and the central value is the average. This provides a range within which the costs can be reasonably expected to fall.

5.5.10 CHP insurance costs are the same percentage of EPC cost as CCGT.

5.6 OCGT

5.6.1 The OCGT values in the 2012 update were based on aeroderivative turbines, whereas the 2013 values are based on large frame turbines. The updated OCGT assumptions are based on large frame “F-class” turbines, which are the most modern type of large frame gas turbine suitable for use in open cycle. Parsons Brinckerhoff considers it unlikely that “E-class” machines would be built as these are outdated, and newer technology (“G-class”, “H-class” and “J-class”) are not suitable for operation in open cycle.

5.6.2 It should be noted that the updated OCGT costs are not directly comparable to the 2012 costs, as the plant is a different type.

Timings

5.6.3 The time taken to design, permit, construct and commission large frame OCGT plant has been adjusted slightly based on expert knowledge. The operating life of the plant is expected to be similar to CCGT, as the OCGT is essentially a CCGT without a bottoming steam cycle, so these values are identical to CCGT operating life.

Technical data

5.6.4 F-class OCGT plant was modelled using GTPro, industry standard software. Three turbines from three different suppliers were modelled. The capacity and efficiency ranges of the plant are based on these models.

5.6.5 Availability js expected to be similar for large frame and aeroderivative turbines, so the availability figures remain as in the 2012 update.

5.6.6 As previously stated, the inputs to the LCM are based on technical assumptions rather than economic assumptions. Other non-renewable technologies are assumed to have a 100% load factor in these inputs. DECC will carry out dynamic dispatch modelling at a later stage, which will consider different load factor scenarios for the various plant types. However OCGT will not run baseload in any scenario, so the load factor is not assumed to be 100%. In recognition of the change from peaking to standby plant, the range for load factors have been changed from 5% - 20% to 5%-10%. In reality the load factor will depend on a wide range of factors and could be higher or lower than these values.

Capital costs

5.6.7 Pre-licensing, Technical, Design, Regulatory, Licensing and Public enquiry costs are expected to be similar for aeroderivative and large frame engines, so these costs remain the same as in the 2012 update.

5.6.8 EPC values for OCGT plant were based on market knowledge of CCGT plant, adjusted by reference to PEACE modelling, the cost estimate software associated with GTPro. The PEACE costs for the three suppliers were compared to PEACE costs for CCGT plant. It was found that the EPC cost of the OCGT plant is between 44.5% and 50.9% of the CCGT plant and consequently the same ratios have been applied to the low and high CCGT costs. This method is considered to be the most robust method of producing OCGT capital costs bearing in mind that the CCGT values are based on knowledge of the current market and have been corroborated by information from stakeholders and there are no relevant recent or current OCGT projects from which to obtain market pricing levels.

Operational Costs

5.6.9 Based on expert opinion, operating costs for OCGT are also expected to be slightly under half those of CCGT. The OCGT plant will benefit from avoiding the O&M costs associated with the bottoming cycle but these are in any case relatively low compared to the gas turbine maintenance costs. Furthermore, the OCGT plant is expected to have a low utilisation and consequently a low accumulation of operating hours which will also tend to reduce the annual maintenance costs. On the other hand, gas turbine maintenance will need to be carried out on an elapsed time basis and it is more likely that this factor would determine the frequency of maintenance than actual operating hours. Ultimately, the operating costs for OCGT plant will be determined by the operating regime (including hours and number and type of starts) as well as the suppliers recommendations for maximum time intervals between inspections.

5.6.10 OCGT insurance costs are the same percentage of EPC cost as CCGT.

5.7 Biomass with CCS

5.7.1 Biomass technology and biomass with CCS are covered in the renewable costs update. Biomass with CCS also appears in this report to enable comparison with other CCS Technologies.

5.7.2 The evidence base for Biomass plants with CCS is highly limited due to the technology being relatively new. However, the CCS portion from coal plants with post combustion CCS was remodelled with large scale biomass data to provide an indicative price.

5.7.3 Using the capture rate of CO_2 of 269.4 t/h taken for a 300MW Biomass plant with CCS, the capture rate was levelised on the net power output of the Biomass with CCS plant to produce the flow rate for CCS.

5.7.4 The incremental increase in capital and O&M costs, both fixed and variable, were calculated using data from ASC Coal with post combustion CCS and coal without CCS. This data was levelised on flow rate of CCS in a coal plant.

5.7.5 The flow rate for biomass CCS and levelised costs of CCS were then multiplied together to produce the approximate capital and O&M costs for CCS.

5.7.6 The costs attributed to CCS were added to the Biomass data to give an approximation of the costs for Large scale Biomass with CCS projects.

5.7.7 For the FOAK data, the low, central and high EPC cost was calculated as £3512/KW, £4055/KW and £6357/KW respectively.

5.7.8 The fixed O&M costs for FOAK were calculated as £96031/MW/yr, £96052/MW/yr and £96071/MW/yr for the low, central and high respectively.

5.7.9 The variable O&M costs were estimated at £4/MWh for the high, central and low values.

5.7.10 With regards to the NOAK data, the low, central and high capital cost data was calculated as £3054/KW, £3663/KW and £5909/KW respectively.

5.7.11 The fixed O&M costs for NOAK were calculated as £96021/MW/yr, £96037/MW/yr and £96061/MW/yr for the low, central and high respectively.

5.7.12 The variable O&M costs for NOAK were estimated at £4/MWh for the high, central and low values.

5.7.13 Due to the limited evidence available and the basic nature of the analysis undertaken, a significant margin of uncertainty should be placed on all parameters.

6 PEER REVIEWERS

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APPENDIX A – TECHNOLOGY-BY-TECHNOLOGY ASSUMPTIONS

Gas - CCGT		Nth OF A KIND		
		Low	**Med**	**High**
Key Timings				
Total Pre-development Period (including pre-licensing, licensing & public enquiry)	years	2.0	2.3	5.0
Construction Period	years	2.0	2.5	3.0
Plant Operating Period	years	20.0	25.0	35.0
Technical data				
Net Power Output	MW	900	900	900
Net LHV Efficiency	%	57.4%	58.8%	60.0%
Average Steam Output	MW (thermal)	0	0	0
Average Availability	%	91.9%	92.8%	93.7%
Average Load Factor	%	100.0%	100.0%	100.0%
CO2 Removal	%	0.0%	0.0%	0.0%
Capital costs				
Pre-licencing costs, Technical and design	£/kW	6.0	12.0	15.0
Regulatory + licencing + public enquiry	£/kW	0.36	0.42	4.00
EPC cost (excluding interest during construction) – variability only	£/kW	490	569	648
EPC cost (excluding interest during construction) – variability and uncertainty	£/kW	490	569	648
Infrastructure cost	£'000	7,000	17,500	36,000
Operating costs				
O&M fixed fee	£/MW/yr	18,026	21,954	25,882
O&M variable fee	£/MWh	0.00	0.08	0.15
Insurance	£/MW/yr	930	1,992	3,276
Connection and UoS charges	£/MW/yr	6,842	6,842	6,842
CO2 transport and storage costs	£/t	0.0	0.0	0.0

Gas - CCGT with post comb. CCS		1st OF A KIND				Nth OF A KIND		
		Low	Med	High		Low	Med	High
Key Timings								
Total Pre-development Period (including pre-licensing, licensing & public enquiry)	years	4.0	5.0	6.0		3.0	4.0	5.5
Construction Period	years	3.9	4.5	5.5		3.5	4.0	4.5
Plant Operating Period	years	20.0	25.0	30.0		20.0	25.0	30.0
Technical data								
Net Power Output	MW	736	779	795		767	786	802
Net LHV Efficiency	%	48.0%	50.8%	51.8%		50.0%	51.3%	52.3%
Average Steam Output	MW (thermal)	0	0	0		0	0	0
Average Availability	%	91.9%	92.8%	93.7%		91.9%	92.8%	93.7%
Average Load Factor	%	100.0%	100.0%	100.0%		100.0%	100.0%	100.0%
CO2 Removal	%	85.0%	87.5%	90.0%		90.0%	90.6%	90.6%
Capital costs								
Pre-licencing costs, Technical and design	£/kW	25.0	30.0	40.0		20.0	25.0	40.0
Regulatory + licencing + public enquiry	£/kW	0.48	0.53	4.98		0.46	0.52	4.94
EPC cost (excluding interest during construction) – variability only	£/kW	1,138	1,321	1,505		1,024	1,189	1,355
EPC cost (excluding interest during construction) – variability and uncertainty	£/kW	1,057	1,321	1,586		951	1,189	1,427
Infrastructure cost	£'000	7,000	17,500	36,000		7,000	17,500	36,000
Operating costs								
O&M fixed fee	£/MW/yr	21,762	25,045	29,046		19,417	23,087	26,775
O&M variable fee	£/MWh	1.37	1.67	2.09		1.23	1.54	1.93
Insurance	£/MW/yr	2,158	4,625	7,606		1,942	4,163	6,845
Connection and UoS charges	£/MW/yr	6,842	6,842	6,842		6,842	6,842	6,842
CO2 transport and storage costs	£/t	8.2	19.6	32.2		8.2	19.6	32.2

Gas - CCGT retro post comb. CCS		1st OF A KIND				Nth OF A KIND		
		Low	Med	High		Low	Med	High
Key Timings								
Total Pre-development Period (including pre-licensing, licensing & public enquiry)	years	3.0	4.0	5.5		2.0	3.0	4.0
Construction Period	years	3.5	4.0	5.5		3.0	3.5	4.5
Plant Operating Period	years	8.8	17.5	26.3		8.8	17.5	26.3
Technical data								
Net Power Output	MW	733	773	789		767	785	801
Net LHV Efficiency	%	48.0%	50.6%	51.7%		50.2%	51.4%	52.5%
Average Steam Output	ЛW (therma	0	0	0		0	0	0
Average Availability	%	91.9%	92.8%	93.7%		91.9%	92.8%	93.7%
Average Load Factor	%	100.0%	100.0%	100.0%		100.0%	100.0%	100.0%
CO2 Removal	%	85.0%	87.5%	90.0%		90.0%	90.6%	90.6%
Capital costs								
Pre-licencing costs, Technical and design	£/kW	14.0	22.1	30.1		9.0	19.6	30.1
Regulatory + licencing + public enquiry	£/kW	0.05	0.05	0.50		0.05	0.05	0.49
EPC cost (excluding interest during construction) – variability only	£/kW	842	978	1,114		694	806	918
EPC cost (excluding interest during construction) – variability and uncertainty	£/kW	782	978	1,174		645	806	967
Infrastructure cost	£'000	0	0	0		0	0	0
Operating costs								
O&M fixed fee	£/MW/yr	21,762	25,045	29,046		19,417	23,087	26,775
O&M variable fee	£/MWh	1.37	1.67	2.09		1.23	1.54	1.93
Insurance	£/MW/yr	2,158	4,625	7,606		1,942	4,163	6,845
Connection and UoS charges	£/MW/yr	6,842	6,842	6,842		6,842	6,842	6,842
CO2 transport and storage costs	£/t	8.2	19.6	32.2		8.2	19.6	32.2
Insurance - retrofit portion only	£/MW/yr	1,597	3,423	5,629		1,317	2,822	4,640

Gas - CCGT with pre comb. CCS		1st OF A KIND				Nth OF A KIND		
		Low	Med	High		Low	Med	High
Key Timings								
Total Pre-development Period (including pre-licensing, licensing & public enquiry)	years	4.0	5.0	6.0		3.0	4.0	5.5
Construction Period	years	3.9	4.5	5.5		3.5	4.0	4.5
Plant Operating Period	years	20.0	25.0	30.0		20.0	25.0	30.0
Technical data								
Net Power Output	MW	862	883	1018		876	897	1018
Net LHV Efficiency	%	40.7%	41.7%	48.0%		41.3%	42.3%	48.0%
Average Steam Output	/W (therma	0	0	0		0	0	0
Average Availability	%	91.9%	92.8%	93.7%		91.9%	92.8%	93.7%
Average Load Factor	%	100.0%	100.0%	100.0%		100.0%	100.0%	100.0%
CO_2 Removal	%	81.6%	88.3%	95.0%		81.6%	88.3%	95.0%
Capital costs								
Pre-licencing costs, Technical and design	£/kW	23.5	29.6	47.9		22.8	28.5	45.6
Regulatory + licencing + public enquiry	£/kW	0.40	0.53	4.98		0.46	0.52	4.94
EPC cost (excluding interest during construction) – variability only	£/kW	1,296	1,506	1,715		1,166	1,355	1,543
EPC cost (excluding interest during construction) – variability and uncertainty	£/kW	1,054	1,506	1,957		948	1,355	1,761
Infrastructure cost	£'000	7,000	17,500	36,000		7,000	17,500	36,000
Operating costs								
O&M fixed fee	£/MW/yr	20,809	31,681	45,030		19,056	28,986	38,915
O&M variable fee	£/MWh	1.05	1.35	1.35		0.96	1.24	1.52
Insurance	£/MW/yr	2,459	5,269	8,665		2,213	4,742	7,799
Connection and UoS charges	£/MW/yr	6,842	6,842	6,842		6,842	6,842	6,842
CO_2 transport and storage costs	£/t	8.2	19.6	32.2		8.2	19.6	32.2

Gas - CCGT with oxy comb. CCS		1st OF A KIND				Nth OF A KIND		
		Low	Med	High		Low	Med	High
Key Timings								
Total Pre-development Period (including pre-licensing, licensing & public enquiry)	years	4.5	5.8	7.0		3.0	4.0	5.5
Construction Period	years	4.0	4.5	5.5		3.5	4.0	4.5
Plant Operating Period	years	20.0	25.0	30.0		20.0	25.0	30.0
Technical data								
Net Power Output	MW	250	400	400		250	400	400
Net LHV Efficiency	%	34.0%	40.0%	45.0%		46.2%	50.0%	58.9%
Average Steam Output	/IW (therma	0	0	0		0	0	0
Average Availability	%	89.9%	91.8%	93.7%		89.9%	91.8%	93.7%
Average Load Factor	%	100.0%	100.0%	100.0%		100.0%	100.0%	100.0%
CO2 Removal	%	90.0%	93.0%	98.0%		93.0%	95.0%	98.0%
Capital costs								
Pre-licencing costs, Technical and design	£/kW	26.3	32.3	44.0		20.0	25.0	40.0
Regulatory + licencing + public enquiry	£/kW	1.03	1.42	9.90		1.03	1.42	9.90
EPC cost (excluding interest during construction) – variability only	£/kW	1,303	1,513	1,724		1,172	1,362	1,551
EPC cost (excluding interest during construction) – variability and uncertainty	£/kW	908	1,513	2,119		817	1,362	1,907
Infrastructure cost	£'000	7,000	10,922	18,164		7,000	10,922	18,164
Operating costs								
O&M fixed fee	£/MW/yr	18,697	78,907	139,118		17,388	73,384	129,380
O&M variable fee	£/MWh	1.05	0.53	0.00		0.94	0.47	0.00
Insurance	£/MW/yr	2,471	5,296	8,710		2,224	4,767	7,839
Connection and UoS charges	£/MW/yr	6,673	6,673	6,673		6,673	6,673	6,673
CO2 transport and storage costs	£/t	8.2	19.6	32.2		8.2	19.6	32.2

Coal - ASC with FGD and 300MW post-comb capture		1st OF A KIND				Nth OF A KIND		
		Low	Med	High		Low	Med	High
Key Timings								
Total Pre-development Period (including pre-licensing, licensing & public enquiry)	years	4.0	5.3	7.0		3.0	4.5	6.5
Construction Period	years	4.5	5.0	6.0		4.0	4.5	5.0
Plant Operating Period	years	20.0	25.0	30.0		20.0	30.0	35.0
Technical data								
Net Power Output	MW	1486	1506	1535		1530	1523	1554
Net LHV Efficiency	%	38.3%	41.4%	43.9%		39.5%	41.9%	44.7%
Average Steam Output	MW (therma	0	0	0		0	0	0
Average Availability	%	94.9%	95.8%	96.8%		94.9%	95.8%	96.8%
Average Load Factor	%	100.0%	100.0%	100.0%		100.0%	100.0%	100.0%
CO2 Removal	%	21.0%	21.9%	22.0%		20.6%	20.8%	21.2%
Capital costs								
Pre-licencing costs, Technical and design	£/kW	15.6	20.2	33.3		18.8	24.2	30.9
Regulatory + licencing + public enquiry	£/kW	0.16	0.20	1.43		0.22	0.25	1.77
EPC cost (excluding interest during construction) – variability only	£/kW	1,788	1,932	2,139		1,751	1,877	2,079
EPC cost (excluding interest during construction) – variability and uncertainty	£/kW	1,736	1,932	2,179		1,688	1,877	2,115
Infrastructure cost	£'000	0	7,500	15,000		0	7,500	15,000
Operating costs								
O&M fixed fee	£/MW/yr	27,157	45,670	63,359		23,617	40,597	57,470
O&M variable fee	£/MWh	1.22	1.38	1.53		1.04	1.21	1.38
Insurance	£/MW/yr	1,788	2,899	7,485		1,751	2,815	7,277
Connection and UoS charges	£/MW/yr	9,022	9,022	9,022		9,022	9,022	9,022
CO2 transport and storage costs	£/t	8.2	19.6	32.2		8.2	19.6	32.2

Coal - ASC with post comb. CCS		1st OF A KIND				Nth OF A KIND		
		Low	Med	High		Low	Med	High
Key Timings								
Total Pre-development Period (including pre-licensing, licensing & public enquiry)	years	4.0	5.3	7.0		3.0	4.5	6.5
Construction Period	years	4.5	5.0	6.0		4.0	4.5	5.0
Plant Operating Period	years	20.0	25.0	30.0		20.0	30.0	35.0
Technical data								
Net Power Output	MW	1158	1218	1279		1600	1600	1600
Net LHV Efficiency	%	29.9%	33.5%	37.0%		33.5%	35.0%	39.0%
Average Steam Output	MW (therma	0	0	0		0	0	0
Average Availability	%	94.9%	95.8%	96.8%		94.9%	95.8%	96.8%
Average Load Factor	%	100.0%	100.0%	100.0%		100.0%	100.0%	100.0%
CO_2 Removal	%	85.0%	89.0%	92.0%		90.0%	90.0%	95.0%
Capital costs								
Pre-licencing costs, Technical and design	£/kW	20.0	25.0	40.0		18.0	23.0	30.0
Regulatory + licencing + public enquiry	£/kW	0.21	0.24	1.72		0.21	0.24	1.72
EPC cost (excluding interest during construction) – variability only	£/kW	2,674	2,950	3,319		2,674	2,773	3,120
EPC cost (excluding interest during construction) – variability and uncertainty	£/kW	2,360	2,950	3,540		2,218	2,773	3,328
Infrastructure cost	£'000	0	7,500	15,000		0	7,500	15,000
Operating costs								
O&M fixed fee	£/MW/yr	43,230	71,638	100,046		40,204	66,623	93,043
O&M variable fee	£/MWh	2.16	2.35	2.54		2.01	2.19	2.36
Insurance	£/MW/yr	2,674	4,425	11,616		2,674	4,160	10,919
Connection and UoS charges	£/MW/yr	9,022	9,022	9,022		9,022	9,022	9,022
CO_2 transport and storage costs	£/t	8.2	19.6	32.2		8.2	19.6	32.2

Ammonia Coal - ASC with post comb. ammoniaCCS		1st OF A KIND				Nth OF A KIND		
		Low	Med	High		Low	Med	High
Key Timings								
Total Pre-development Period (including pre-licensing, licensing & public enquiry)	years	4.0	5.3	7.0		3.0	4.5	6.5
Construction Period	years	4.5	5.0	6.0		4.0	4.5	5.0
Plant Operating Period	years	20.0	25.0	30.0		20.0	30.0	35.0
Technical data								
Net Power Output	MW	235	235	475		560	560	560
Net LHV Efficiency	%	26.6%	30.5%	34.3%		28.0%	33.7%	39.4%
Average Steam Output	/W (therma	0	0	0		0	0	0
Average Availability	%	94.9%	95.8%	96.8%		94.9%	95.8%	96.8%
Average Load Factor	%	100.0%	100.0%	100.0%		100.0%	100.0%	100.0%
CO2 Removal	%	85.0%	87.5%	90.0%		90.0%	90.0%	90.0%
Capital costs								
Pre-licencing costs, Technical and design	£/kW	20.0	25.0	40.0		18.0	23.0	30.0
Regulatory + licencing + public enquiry	£/kW	0.21	0.24	1.72		0.21	0.24	1.72
EPC cost (excluding interest during construction) – variability only	£/kW	2,674	3,053	3,557		2,674	2,870	3,344
EPC cost (excluding interest during construction) – variability and uncertainty	£/kW	2,443	3,053	3,664		2,296	2,870	3,444
Infrastructure cost	£'000	0	7,500	15,000		0	7,500	15,000
Operating costs								
O&M fixed fee	£/MW/yr	35,104	70,667	106,230		32,647	65,720	98,794
O&M variable fee	£/MWh	0.00	0.00	0.00		0.00	0.00	0.00
Insurance	£/MW/yr	2,674	5,336	12,450		2,674	4,305	11,703
Connection and UoS charges	£/MW/yr	8,656	8,656	8,656		8,656	8,656	8,656
CO2 transport and storage costs	£/t	8.2	19.6	32.2		8.2	19.6	32.2

Coal - ASC ret post comb. CCS		1st OF A KIND				Nth OF A KIND		
		Low	Med	High		Low	Med	High
Key Timings								
Total Pre-development Period (including pre-licensing, licensing & public enquiry)	years	3.5	4.5	6.0		2.0	3.0	4.0
Construction Period	years	3.5	4.0	5.5		3.0	3.5	4.5
Plant Operating Period	years	7.5	15.0	22.5		11.3	22.5	33.8
Technical data								
Net Power Output	MW	1297	1297	1297		1297	1297	1297
Net LHV Efficiency	%	29.9%	33.2%	36.5%		33.2%	34.7%	38.6%
Average Steam Output	⁄IW (therma	0	0	0		0	0	0
Average Availability	%	94.9%	95.8%	96.8%		94.9%	95.8%	96.8%
Average Load Factor	%	100.0%	100.0%	100.0%		100.0%	100.0%	100.0%
CO2 Removal	%	85.0%	89.0%	92.0%		90.0%	90.0%	95.0%
Capital costs								
Pre-licencing costs, Technical and design	£/kW	11.2	18.4	30.1		8.1	18.0	22.6
Regulatory + licencing + public enquiry	£/kW	0.03	0.03	0.21		0.03	0.03	0.21
EPC cost (excluding interest during construction) – variability only	£/kW	1,591	1,755	1,975		1,470	1,525	1,716
EPC cost (excluding interest during construction) – variability and uncertainty	£/kW	1,404	1,755	2,106		1,220	1,525	1,830
Infrastructure cost	£'000	0	0	0		0	0	0
Operating costs								
O&M fixed fee	£/MW/yr	43,230	71,638	100,046		40,204	66,623	93,043
O&M variable fee	£/MWh	2.16	2.35	2.54		2.01	2.19	2.36
Insurance	£/MW/yr	2,674	4,425	11,616		2,674	4,160	10,919
Connection and UoS charges	£/MW/yr	8,825	8,825	8,825		8,825	8,825	8,825
CO2 transport and storage costs	£/t	8.2	19.6	32.2		8.2	19.6	32.2
Insurance - retrofit portion only	£/MW/yr	1,591	2,633	6,911		1,470	2,288	6,005

Coal - ASC with oxy comb. CCS		1st OF A KIND				Nth OF A KIND		
		Low	Med	High		Low	Med	High
Key Timings								
Total Pre-development Period (including pre-licensing, licensing & public enquiry)	years	4.5	6.0	7.0		3.0	4.5	6.5
Construction Period	years	5.0	5.5	6.0		4.0	4.5	5.0
Plant Operating Period	years	20.0	25.0	30.0		20.0	30.0	35.0
Technical data								
Net Power Output	MW	800	800	800		800	800	800
Net LHV Efficiency	%	30.9%	34.5%	38.0%		32.6%	36.0%	39.3%
Average Steam Output	/W (therma	0	0	0		0	0	0
Average Availability	%	89.9%	93.4%	96.8%		89.9%	93.4%	96.8%
Average Load Factor	%	100.0%	100.0%	100.0%		100.0%	100.0%	100.0%
CO2 Removal	%	90.0%	93.0%	98.0%		93.0%	95.0%	98.0%
Capital costs								
Pre-licencing costs, Technical and design	£/kW	21.0	26.9	44.0		18.0	23.0	30.0
Regulatory + licencing + public enquiry	£/kW	0.42	0.49	3.43		0.42	0.49	3.43
EPC cost (excluding interest during construction) – variability only	£/kW	2,031	2,285	2,538		2,133	2,399	2,665
EPC cost (excluding interest during construction) – variability and uncertainty	£/kW	1,371	2,285	3,198		1,439	2,399	3,359
Infrastructure cost	£'000	0	7,500	15,000		0	7,500	15,000
Operating costs								
O&M fixed fee	£/MW/yr	21,297	56,906	92,514		19,362	52,586	85,810
O&M variable fee	£/MWh	1.88	2.41	2.93		1.77	2.27	2.77
Insurance	£/MW/yr	2,031	3,427	8,883		2,133	3,599	9,328
Connection and UoS charges	£/MW/yr	8,825	8,825	8,825		8,825	8,825	8,825
CO2 transport and storage costs	£/t	8.2	19.6	32.2		8.2	19.6	32.2

Coal - IGCC with 300MW pre-comb capture		1st OF A KIND				Nth OF A KIND		
		Low	Med	High		Low	Med	High
Key Timings								
Total Pre-development Period (including pre-licensing, licensing & public enquiry)	years	4.0	5.0	6.0		4.0	5.0	6.0
Construction Period	years	4.5	5.0	6.0		4.5	5.0	6.0
Plant Operating Period	years	20.0	25.0	35.0		20.0	25.0	35.0
Technical data								
Net Power Output	MW	774	821	884		809	854	916
Net LHV Efficiency	%	35.4%	37.5%	40.4%		37.0%	39.0%	41.8%
Average Steam Output	MW (therma	0	0	0		0	0	0
Average Availability	%	88.8%	89.8%	90.7%		88.8%	89.8%	90.7%
Average Load Factor	%	100.0%	100.0%	100.0%		100.0%	100.0%	100.0%
CO2 Removal	%	35.8%	36.2%	36.3%		32.6%	32.9%	34.1%
Capital costs								
Pre-licencing costs, Technical and design	£/kW	36.3	43.0	50.2		35.0	40.8	46.2
Regulatory + licencing + public enquiry	£/kW	0.37	0.43	3.03		0.40	0.46	3.22
EPC cost (excluding interest during construction) – variability only	£/kW	2,418	2,865	3,348		2,337	2,722	3,079
EPC cost (excluding interest during construction) – variability and uncertainty	£/kW	1,719	2,865	4,011		1,633	2,722	3,810
Infrastructure cost	£'000	0	7,500	15,000		0	7,500	15,000
Operating costs								
O&M fixed fee	£/MW/yr	96,732	114,590	133,936		92,600	108,053	122,692
O&M variable fee	£/MWh	0.00	0.00	0.00		0.00	0.00	0.00
Insurance	£/MW/yr	2,418	4,297	11,719		2,337	4,082	10,776
Connection and UoS charges	£/MW/yr	8,825	8,825	8,825		8,825	8,825	8,825
CO2 transport and storage costs	£/t	8.2	19.6	32.2		8.2	19.6	32.2

Coal - IGCC with CCS		1st OF A KIND				Nth OF A KIND		
		Low	Med	High		Low	Med	High
Key Timings								
Total Pre-development Period (including pre-licensing, licensing & public enquiry)	years	4.0	5.3	7.0		3.0	4.5	6.5
Construction Period	years	4.5	5.0	6.0		4.5	5.0	6.0
Plant Operating Period	years	20.0	25.0	30.0		20.0	25.0	35.0
Technical data								
Net Power Output	MW	704	743	796		780	820	875
Net LHV Efficiency	%	31.8%	33.6%	36.0%		35.3%	37.1%	39.6%
Average Steam Output	MW (therma	0	0	0		0	0	0
Average Availability	%	88.8%	89.8%	90.7%		88.8%	89.8%	90.7%
Average Load Factor	%	100.0%	100.0%	100.0%		100.0%	100.0%	100.0%
CO2 Removal	%	85.0%	90.0%	95.0%		88.6%	90.0%	95.0%
Capital costs								
Pre-licencing costs, Technical and design	£/kW	42.7	50.6	59.1		41.2	48.0	54.3
Regulatory + licencing + public enquiry	£/kW	0.41	0.48	3.37		0.41	0.48	3.37
EPC cost (excluding interest during construction) – variability only	£/kW	2,845	3,370	3,939		2,749	3,202	3,622
EPC cost (excluding interest during construction) – variability and uncertainty	£/kW	2,022	3,370	4,718		1,921	3,202	4,482
Infrastructure cost	£'000	0	7,500	15,000		0	7,500	15,000
Operating costs								
O&M fixed fee	£/MW/yr	113,802	134,812	157,572		101,300	120,002	140,261
O&M variable fee	£/MWh	0.00	0.00	0.00		0.00	0.00	0.00
Insurance	£/MW/yr	2,845	5,055	13,788		2,749	4,803	12,678
Connection and UoS charges	£/MW/yr	8,825	8,825	8,825		8,825	8,825	8,825
CO2 transport and storage costs	£/t	8.2	19.6	32.2		8.2	19.6	32.2

Coal - IGCC with retrofit CCS		1st OF A KIND				Nth OF A KIND		
		Low	Med	High		Low	Med	High
Key Timings								
Total Pre-development Period (including pre-licensing, licensing & public enquiry)	years	3.5	4.5	6.0		2.0	3.0	4.0
Construction Period	years	3.5	4.0	5.5		3.0	3.5	4.5
Plant Operating Period	years	7.5	15.0	22.5		8.8	17.5	26.3
Technical data								
Net Power Output	MW	686	724	776		716	757	811
Net LHV Efficiency	%	29.9%	31.6%	33.8%		31.2%	33.0%	35.4%
Average Steam Output	/IW (therma	0	0	0		0	0	0
Average Availability	%	88.8%	89.8%	90.7%		88.8%	89.8%	90.7%
Average Load Factor	%	100.0%	100.0%	100.0%		100.0%	100.0%	100.0%
CO2 Removal	%	84.3%	87.2%	88.6%		87.2%	88.6%	90.0%
Capital costs								
Pre-licencing costs, Technical and design	£/kW	21.2	24.4	28.0		20.0	22.1	23.4
Regulatory + licencing + public enquiry	£/kW	0.04	0.05	0.36		0.04	0.05	0.36
EPC cost (excluding interest during construction) – variability only	£/kW	1,415	1,628	1,867		1,336	1,476	1,559
EPC cost (excluding interest during construction) – variability and uncertainty	£/kW	977	1,628	2,279		885	1,476	2,066
Infrastructure cost	£'000	0	0	0		0	0	0
Operating costs								
O&M fixed fee	£/MW/yr	113,802	134,812	157,572		101,300	120,002	140,261
O&M variable fee	£/MWh	0.00	0.00	0.00		0.00	0.00	0.00
Insurance	£/MW/yr	2,845	5,055	13,788		2,749	4,803	12,678
Connection and UoS charges	£/MW/yr	8,825	8,825	8,825		8,825	8,825	8,825
CO2 transport and storage costs	£/t	8.2	19.6	32.2		8.2	19.6	32.2
Insurance - retrofit portion only	£/MW/yr	1,415	2,442	6,535		1,336	2,213	5,457

Nuclear - PWR		1st OF A KIND				Nth OF A KIND		
		Low	Med	High		Low	Med	High
Key Timings								
Total Pre-development Period (including pre-licensing, licensing & public enquiry)	years	5.0	5.0	7.0		5.0	5.0	7.0
Construction Period	years	5.0	6.0	8.0		5.0	5.0	8.0
Plant Operating Period	years	60.0	60.0	60.0		60.0	60.0	60.0
Technical data								
Net Power Output	MW	3300	3300	3300		3300	3300	3300
Net LHV Efficiency	%	100.0%	100.0%	100.0%		100.0%	100.0%	100.0%
Average Steam Output	MW (therma	0	0	0		0	0	0
Average Availability	%	89.1%	91.1%	92.0%		89.1%	91.1%	92.0%
Average Load Factor	%	100.0%	100.0%	100.0%		100.0%	100.0%	100.0%
CO_2 Removal	%	0.0%	0.0%	0.0%		0.0%	0.0%	0.0%
Capital costs								
Pre-licencing costs, Technical and design	£/kW	110.0	207.4	461.5		99.5	180.8	391.7
Regulatory + licencing + public enquiry	£/kW	2.24	2.86	3.79		2.24	2.86	3.79
EPC cost (excluding interest during construction) – variability only	£/kW	3,741	4,206	4,653		3,390	3,673	3,955
EPC cost (excluding interest during construction) – variability and uncertainty	£/kW	3,741	4,206	4,653		3,390	3,673	3,955
Infrastructure cost	£'000	0	11,500	23,000		0	11,500	23,000
Operating costs								
O&M fixed fee	£/MW/yr	60,000	72,000	84,000		50,000	60,000	70,000
O&M variable fee	£/MWh	2.59	2.59	2.59		2.50	2.50	2.50
Insurance	£/MW/yr	8,000	10,000	12,000		8,000	10,000	12,000
Connection and UoS charges	£/MW/yr	7,449	7,449	7,449		7,449	7,449	7,449
CO_2 transport and storage costs	£/t	0.0	0.0	0.0		0.0	0.0	0.0

CCGT CHP		Nth OF A KIND		
		Low	Med	High
Key Timings				
Total Pre-development Period (including pre-licensing, licensing & public enquiry)	years	2.0	2.3	5.0
Construction Period	years	2.0	2.5	3.0
Plant Operating Period	years	20.0	25.0	35.0
Technical data				
Net Power Output	MW	206	215	224
Net LHV Efficiency	%	38.2%	38.4%	38.6%
Average Steam Output	MW (thermal)	210	220	229
Average Availability	%	91.9%	92.8%	93.7%
Average Load Factor	%	100.0%	100.0%	100.0%
CO2 Removal	%	0.0%	0.0%	0.0%
Capital costs				
Pre-licencing costs, Technical and design	£/kW	26.2	50.2	60.3
Regulatory + licencing + public enquiry	£/kW	1.56	1.74	16.07
EPC cost (excluding interest during construction) – variability only	£/kW	482	559	637
EPC cost (excluding interest during construction) – variability and uncertainty	£/kW	482	559	637
Infrastructure cost	£'000	4,500	7,000	15,500
Operating costs				
O&M fixed fee	£/MW/yr	23,000	46,250	69,500
O&M variable fee	£/MWh	0.00	0.11	0.23
Insurance	£/MW/yr	914	1,958	3,220
Connection and UoS charges	£/MW/yr	6,655	6,655	6,655
CO2 transport and storage costs	£/t	0.0	0.0	0.0

OCGT		Nth OF A KIND		
		Low	Med	High
Key Timings				
Total Pre-development Period (including pre-licensing, licensing & public enquiry)	years	1.5	1.8	4.5
Construction Period	years	1.5	1.8	2.0
Plant Operating Period	years	20.0	25.0	35.0
Technical data				
Net Power Output	MW	561	565	608
Net LHV Efficiency	%	37.3%	39.0%	39.1%
Average Steam Output	MW (thermal)	0	0	0
Average Availability	%	93.8%	94.7%	95.7%
Average Load Factor	%	5.0%	7.5%	10.0%
CO2 Removal	%	0.0%	0.0%	0.0%
Capital costs				
Pre-licencing costs, Technical and design	£/kW	16.3	18.9	24.6
Regulatory + licencing + public enquiry	£/kW	2.00	2.40	3.10
EPC cost (excluding interest during construction) – variability only	£/kW	218	274	330
EPC cost (excluding interest during construction) – variability and uncertainty	£/kW	218	274	330
Infrastructure cost	£'000	7,000	9,050	11,100
Operating costs				
O&M fixed fee	£/MW/yr	8,112	9,879	11,647
O&M variable fee	£/MWh	0.00	0.03	0.07
Insurance	£/MW/yr	414	959	1,667
Connection and UoS charges	£/MW/yr	3,440	3,440	3,440
CO2 transport and storage costs	£/MWh	0.0	0.0	0.0

Biomass with CCS		1st OF A KIND			Nth OF A KIND		
		Low	Med	High	Low	Med	High
Key Timings							
Total Pre-development Period (including pre-licensing, licensing & public enquiry)	years	3.5	4.5	5.5	3.5	4.5	5.5
Construction Period	years	3.0	3.5	4.0	3.0	3.5	4.0
Plant Operating Period	years	20.0	20.0	20.0	20.0	20.0	20.0
Technical data							
Net Power Output	MW	210	210	210	210	210	210
Net LHV Efficiency	%	25.0%	26.1%	27.20%	27.2%	27.3%	28.4%
Average Steam Output	MW (thermal)	N/A	N/A	N/A	N/A	N/A	N/A
Average Availability	%	88.5%	90.0%	90.9%	88.5%	90.0%	90.9%
Average Load Factor	%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
CO2 Removal	%	85.0%	89.0%	92.0%	90.0%	90.0%	95.0%
Capital costs							
Pre-licencing costs, Technical and design	£/kW	48.2	61.6	61.6	48.2	61.6	80.3
Regulatory + licencing + public enquiry	£/kW	1.02	1.18	8.32	1.02	1.18	8.32
EPC cost (excluding interest during construction) – variability only	£/kW	3,512	4,055	6,357	3,054	3,663	5,909
EPC cost (excluding interest during construction) – variability and uncertainty	£/kW	2,433	4,055	5,677	2,198	3,663	5,128
Infrastructure cost	£'000	Not considered			Not considered		
Operating costs							
O&M fixed fee	£/MW/yr	96,031	96,052	96,071	96,021	96,037	96,061
O&M variable fee	£/MWh	4.00	4.00	4.00	4.00	4.00	4.00
Insurance	£/MW/yr	Not considered			Not considered		
Connection and UoS charges	£/MW/yr	Not considered			Not considered		
CO2 transport and storage costs	£/MWh	8	20	32	8	20	32