Electricity Generation Cost Model - 2012 Update of Non Renewable Technologies

Department of Energy and Climate Change

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NOMENCLATURE

AACE	Association for the Advancement of Cost Engineering
AC	Alternating current
ASC	Advanced super critical
Capex	Capital expenditure
CO_2	Carbon dioxide
CCGT	Combined cycle gas turbine
CCS	Carbon capture and storage
CHP	Combined heat and power
CHPQA	Quality Assurance for Combined Heat and Power
DC	Direct current
DECC	Department for Energy and Climate Change
DNUoS	Distribution network use of system
FGD	Flue gas de-sulphurisation
FOAK	First of a kind
GDP	Gross domestic product
GIS	Gas insulated switchgear
GT	Gas turbine
GW	Giga Watts
HRSG	Heat recovery steam generator
HV	High voltage
HVDC	High voltage direct current
IC	Internal combustion
IEA	International Energy Agency
IGCC	Integrated gasification combined cycle
Kt	Kilo tonnes
Km	Kilometres
kV	Kilo Volts
kW	Kilo Watts
kWe	Kilo Watts electrical
kWh	Kilo Watt hours
LHV	Lower heating value
LCOE	Levelised cost of electricity
M	Metres
MW	Mega Watts
MWe	Mega Watts electrical
MWh	Mega Watt hours
NOAK	Nth of a kind

OCGT	Open cycle gas turbine
OEM	Original equipment manufacturer
OHL	Overhead line
Opex	Operational expenditure
PWR	Pressurised water reactor
SCADA	Supervisory control and data acquisition
SCR	Selective catalytic reduction
SNCR	Selective non catalytic reduction
t	Tonnes
TNUoS	Transmission network use of system
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.

Following the completion of the input data sheets, the levelised cost of electricity for each technology was calculated by DECC using the Levelised Electricity Cost Model. The methodology behind the utilisation of the model and levelised cost outputs are the responsibility of DECC.

The inputs to the model require updating periodically in order to reflect the varying costs of generation technologies, market forces and changing perceptions of the predicted costs of new technologies as knowledge and experience increases. The dataset provided as part of this work represents the current view of generation costs and performance and as such, the validity of the dataset shall decrease with time and require further updates in the future.

The technologies covered within this report for which a full inputs sheet[1] was delivered are:

- CCGT
- OCGT
- CCGT with post combustion CCS
- CCGT with retro-fitted post combustion CCS
- CCGT with pre combustion CCS
- CCGT with oxyfuel CCS
- ASC coal with FGD
- ASC coal with post combustion CCS
- ASC coal with retro-fitted post combustion CCS
- ASC coal with oxyfuel CCS
- CCGT CHP
- GT and back pressure steam turbine CHP
- GT CHP
- Retro-fit of SCR / SNCR
- IGCC
- IGCC with CCS
- IGCC with retro-fit CCS
- Nuclear
- Pumped storage

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 were well understood and have extensive market presence whilst others were at an earlier stage of development or application and were less well understood.

The initial stage of this study involved the definition of each technology in terms of major equipment, requirements for infrastructure and major development and operations and maintenance activities. The relative importance of each parameter was also documented and confirmed through sensitivity analysis.

Cost estimates and technical parameters were obtained using a staged approach that began with recently completed UK reference projects. Where reference plants were unavailable, estimates were based on a combination of data from older or global projects, 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 and Aspen in order to corroborate input parameters.

A view of the construction costs for projects with a start date from 2012 to 2030 was modelled and derived through a Forward Pricing Model, the results from which were transposed into the levelised cost inputs sheets.

[1] Model input data is available in Appendix A.

Key cost inputs were peer reviewed. Parsons Brinckerhoff and DECC wishes to extend acknowledgements and thanks all those who supported this project as peer reviewers for their involvement in this project.

1 INTRODUCTION

Parsons Brinckerhoff was engaged by the Department of Energy and Climate Change (DECC) on December 12th 2011 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 summarises the work undertaken by Parsons Brinckerhoff and aims to provide the context for and an explanation of modifications made to the dataset that forms the model inputs.

1.1 Background

Details of the "Levelised Electricity Cost Model" can be found in the 'UK Electricity Generation Costs Update' report by Mott MacDonald, commissioned for DECC in 2010.

In 2011, inputs to the "Levelised Electricity Cost Model" were updated by Parsons Brinckerhoff and Arup.

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. The dataset provided as part of this work represents the current view of generation costs and performance and as such, the validity of the dataset shall decrease with time and require further updates in the future.

1.2 Report Structure

This report briefly describes the scope of work undertaken by Parsons Brinckerhoff in order to update the model inputs, including the technologies covered and the input parameters investigated. This Section also notes the information and guidance provided by DECC. Following this, an overview of the methodology is detailed and covers the general philosophy, data sources and the approach to obtaining robust values for the input parameters.

The following section aims to provide a comprehensive level of guidance for the interpretation of the model inputs, the effects of key assumptions and the effects on outputs resulting from model and data limitations.

The report then provides a more detailed commentary on specific technologies, explaining any assumptions made. This Section also identifies cost inputs that were considered sufficiently different from previous estimates to require a qualitative and high level explanation of the differences.

The appendices contain supplementary information giving specific details on specific technology assumptions and interpretation guidance. A summary of the updated cost assumptions for all technologies are also included in Appendix A.

2 SCOPE

2.1 Technologies

Separate input sheets were developed for the technologies listed below as part of this project. Some technologies were sub-divided to allow the costs and technical parameters of various scales, plant configurations and fuel types to be evaluated fairly. The technologies covered within the scope of this report included unabated fossil fuelled plant, fossil fuelled plant with carbon capture and storage, gas fired combined heat and power plant and nuclear plant. These technologies were largely in line with the technologies covered by the 2011 updates to the inputs to the Levelised Electricity Cost Model.

The technologies covered within this report for which a full inputs sheet was delivered are:

- CCGT
- OCGT
- CCGT with post combustion CCS
- CCGT with retro-fitted post combustion CCS
- CCGT with pre combustion CCS
- CCGT with oxyfuel CCS
- ASC coal with FGD
- ASC coal with post combustion CCS
- ASC coal with retro-fitted post combustion CCS
- ASC coal with oxyfuel CCS
- CCGT CHP
- GT and back pressure steam turbine CHP
- GT CHP
- Retro-fit of SCR / SNCR
- IGCC
- IGCC with CCS
- IGCC with retro-fit CCS
- Nuclear
- Pumped storage

2.2 Parameters

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, operational and decommissioning periods
- Technical data – plant heat and power output, efficiency and forward profiles for availability, load factor and changes in efficiency and capacity due to degradation
- Capital costs – design and development, regulatory and licensing, construction, infrastructure and phasing of each technology across the appropriate time period
- Operational and maintenance costs – fixed and variable operations and maintenance costs, use of system charges, insurance and CO_2 disposal and decommissioning where appropriate.

2.3 Information Supplied by DECC

The following cost items were beyond Parsons Brinckerhoff's scope and were provided by DECC:

- Fuel cost projections
- CO_2 cost projections
- Exchange rates
- GDP deflator[2]

[2] GDP deflators as of March 2012 – HM Treasury, "GDP DEFLATORS AT MARKET PRICES, AND MONEY GDP", March 2012. http://www.hm-treasury.gov.uk/data_gdp_fig.htm

- Forward build rate projections (on which an assessment of forward market conditions was based)
- Avoided gas boiler methodology for the evaluation of potential heat revenues from CHP plant

2.4 Forward Pricing Model

As part of the scope of this project, DECC requested a view of the construction costs for projects with a start date[3] from 2010 to 2030. These estimates were derived through a Forward Pricing Model, the results from which were transposed into the levelised cost inputs sheets.

2.5 Comparison to Previous Input Data

As part of the scope of this year's update, Parsons Brinckerhoff was requested to offer suggestions as to why cost estimates differed from update work undertaken previously. Section 5 highlights for each technology any known changes in inputs that can at least qualitatively be attributed to a known and understood event such as a significant change in build rate, new pilot project or new study. Such technologies were identified by screening for cases where the levelised capital cost had changed by +/- 30%. Any smaller changes were assumed to be a function of the natural variation expected when undertaking this kind of costing exercise caused by differing approaches and interpretation of raw data.

[3] "Start date" referred to the beginning of the pre-development period.

3 METHODOLOGY

3.1 General Approach

Parsons Brinckerhoff approached the derivation of inputs for the Levelised Electricity Cost Model from an analytical perspective, relying on expert interpretation of raw market and project data, plant modelling and bottom up costings (where possible). This was required due to the complexity of the information sought and the often sparse availability of data. The approach is in contrast to previous studies, which in general had employed a more empirical approach. Parsons Brinckerhoff employed this approach in this study to minimise the risk of simplifying the highly complex picture of generation costs by an over-reliance upon traditional statistical analysis techniques. For example, the inclusion of costs for plants of different sizes within the same analysis, the utilisation of costs from projects at different stages of development or the utilisation of one off annual figures as compared to representative lifetime averages. Further details on the effects of data limitations for specific technologies can be found in Section 5.

The initial stage of this study involved the definition of each technology in terms of major equipment, requirements for infrastructure and major development activities and operations and maintenance activities[4]. This facilitated a cross-check across all technologies to ensure consistency in approach to the split between equipment and costs classed as "infrastructure" and those classed as "construction" and to the activities included within the development period.

The relative importance of each parameter was also documented and confirmed through sensitivity analysis. Construction cost was the major driver behind most technologies. Fuel costs were also critical and resulted in a reduced relative contribution from operations and maintenance costs.

Load factors were also a critical driver of the levelised cost output. To ensure a consistent modelling approach, dispatchable technologies with a secure and constant fuel source were assumed to operate at base load and therefore would be unconstrained by dispatch (except for OCGT, which was assumed to operate at a 20% load factor as peaking plant).

Cost estimates and technical parameters were obtained using a staged approach that began with recently completed UK reference projects. Where reference plants were unavailable, estimates were based on a combination of data from older or global projects, data from projects under development, technical modelling, opinions from prominent studies and the experience of technology experts within Parsons Brinckerhoff. Further details on the hierarchal approach to obtaining robust source data can be found in Section 3.3.

3.2 Input Parameters

The following Section describes the general approach to each group of input parameters. Any deviations from this for specific technologies are detailed in Section 5.

3.2.1 Key Timings

The timings for each technology were generally based on past reference projects and expected durations within the industry. Appendix C indicates the activities included within the "Pre-licensing, technical and design" and "Regulatory, licensing and public enquiry" periods.

3.2.2 Power, Heat and Efficiency

Net power was presented for all technologies. Net LHV efficiencies were therefore presented.

[4] Major equipment, requirements for infrastructure, major development activities and operations and maintenance activities are given in Appendices B, C and D respectively.

A single value was presented across the high, medium and low input levels. The power output given was assumed to be representative of the costed projects, however in general, experience shows that the costs over the ranges presented may also be applicable to plant sizes between 50% and 200% of the stated power output. The exception to this is nuclear, where a narrow power output was dictated by reactor manufacturers.

Heat was also presented as plant net output values and calculated according to an assumed characteristic load. Further details can be found in Section 3.6 and Section 4.4.

3.2.3 Availability and Forward Efficiency Profiles

Availability trends for thermal dispatchable technologies included 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 trend 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 turbine technologies) the availability may differ from the expected and more usual trends.

3.2.4 Capital and Operations and Maintenance Costs

Capital costs were split within the model into Pre-licensing, Technical and design costs, Regulatory, licensing and public enquiry costs and EPC costs exclusive of interest during construction. The model facilitated the entry of Operations and Maintenance costs either on a per MW of capacity basis or on a per MWh of electricity produced basis.

Capital and operations and maintenance cost data represented either observed market costs relating to each technology for mature technologies with reasonable data availability, or estimated costs for immature technologies with limited data availability.

3.2.5 Use of System Charges

A consistent approach to the evaluation of use of system charges that applied either an aggregate transmission system charge (TNUoS) or a distribution system charge (DNUoS) was implemented.

Due to the more complex nature of the distribution charges, a representative distribution system charge of £2500 per MW per year was derived from the charges levied by each DNO[5] and applied to technologies sized such that the appropriate connection voltage would be below 132 kV. No use of system charge was applied to technologies with outputs below 5 MW, as it was assumed that these would connect to a private wire network, or that any use of system charges would be covered by the O&M costs.

For technologies sized such that the appropriate connection voltage would be at or above 132 kV, a view was taken as to which system tariff zones the technology may exist within[6]. The average charge for these zones was calculated.

[5] Energy Networks Association, "Distribution Use of System Charges Final Tariffs April 2012", February 2012. http://www.energynetworks.org/electricity/regulation/distribution-use-of-system-charges-final-tariffs-april-2012.html

[6] System tariff zones and charges from: National Grid, "The Statement of Use of System Charges", April 2011. http://www.nationalgrid.com/NR/rdonlyres/0F5FBFA1-A94C-45DD-BAC0-C9A676737176/46235/UoSCI7R0Draft_Issued_FINAL.pdf

In order to provide a consistent approach across technologies and because of the relatively small contribution that use of system charges make to the overall levelised cost, the same value was assumed for the high, medium and low input values and for FOAK and NOAK. There was no consideration of the potential future changes to the use of system costs that could be brought about by Project TransmiT because of the relatively small contribution that use of system costs make to the overall levelised cost.

3.2.6 CO_2 Transport and Storage

Unlike the 2011 update, the costs for the transport and storage of carbon dioxide were entered into the model in £ per tonne of carbon dioxide stored. Inputs were derived from the analysis of the cost of onshore pipeline, offshore pipeline and potential storage solutions with a break-down as follows:

- Onshore pipeline cost = 5.20 £ / kt / km (pipeline lengths of 5 km, 20 km and 50 km)
- Offshore pipeline cost = 6.24 £ / kt / km (pipeline length of 70 km)
- Low storage cost, based on offshore depleted oil and gas with re-use of appropriate offshore infrastructure = 7.43 £ / t
- Medium storage cost, based on offshore depleted oil and gas field = 11.19 £ / t
- High storage cost, based on offshore saline = 16.16 £ / t

3.3 Input Data and Sources

3.3.1 Sources

The following hierarchy of data sources was employed to ensure that the most up to date information was obtained:

- UK projects of appropriate size commissioned in 2012, 2011 or 2010
- UK projects of appropriate size currently under construction
- European projects of appropriate size commissioned in 2012, 2011 or 2010
- European projects of appropriate size currently under construction
- UK projects currently under development
- UK projects commissioned in 2009, 2008 and 2007
- Modelling and bottom up cost estimation using OEM quotes
- Recent publications

Modelling and bottom up costing were also used to validate data from sources higher up the hierarchy. The modelling software utilised was the Thermoflow software suit including PEACE (for cost modelling) and Aspen.

3.3.2 Technical and Cost Modelling

Technical and cost modelling was undertaken where necessary using the Thermoflow software suite and Aspen. The Thermoflow software suite facilitates the thermal modelling of various plant types and configurations and includes a comprehensive equipment cost database that is updated approximately every six months. Multipliers adjust the base cost information to the UK market.

Technical and cost modelling was used to corroborate cost and performance data gathered from both internal and external sources. It's most powerful use however was to facilitate the evaluation of a number of technically similar technologies on a consistent basis to increase the validity of any comparisons drawn between these technologies by removing any variation due to site conditions, market fluctuations and design differences. This approach was particularly important for utility scale GT based plant. The example configuration of two gas turbines supplying a single steam turbine was modelled for CCGT, CCGT CHP, CCGT with pre-combustion CCS and CCGT with post combustion CCS. The use of the same gas turbine and configuration across all models for these technologies removed any cost variation due to the choice of gas turbine. Modelled cost and performance values were utilised as medium values, and high and low values were derived using reference project data or values from literature.

Technical and cost modelling also provided a valuable data source without constraints of confidentiality imposed from real project data. A much greater level of detail can therefore be disclosed relating to modelled technologies.

3.3.3 Peer Review

In accordance with the requirements of this project, an independent peer review of the key model inputs was undertaken. Peer reviewers were requested to comment on net power, efficiency, construction costs (exclusive of infrastructure) and development costs. Peer reviewers were also requested to comment on the appropriateness of the technology descriptions and main items of equipment presented in Appendix B. Operations and maintenance costs were not peer reviewed partly because these provided a relatively small contribution to the levelised costs compared to the construction costs and partly because it was felt that these may vary significantly between sites.

A number of stakeholders within the UK power industry were approached and engaged with during the peer review process. Peer review organisations provided qualitative and quantitative feedback in the form of a survey which was utilised to update and amend the input parameters where necessary.

Parsons Brinckerhoff and DECC wishes to extend acknowledgements and thanks all those who supported this project as peer reviewers for their involvement in this project.

3.4 Treatment of Input Levels

The Levelised Electricity Cost Model required three levels for each input, i.e. a high, medium and low level.

3.4.1 Construction costs

This year, an attempt was made to differentiate between variation and uncertainty in relation to construction costs. The difference in high, medium and low construction costs presented in the inputs sheets therefore represented the variability in costs caused by variation in design, risk mitigation, physical site characteristics and choice of contractor or manufacturer. Uncertainty was portrayed within the Forward Price Model (Section 3.7) and represented a bound and measure of the current and future uncertainty in construction costs.

Should the full potential range of construction costs for immature technologies be required (as opposed to the narrower range of site to site variation) the high and low curves from the forward pricing model with uncertainty should be used.

This approach also provided the facility to increase the uncertainty envelope that would be applied to future predicted costs. This approach is displayed graphically in Figure 1.

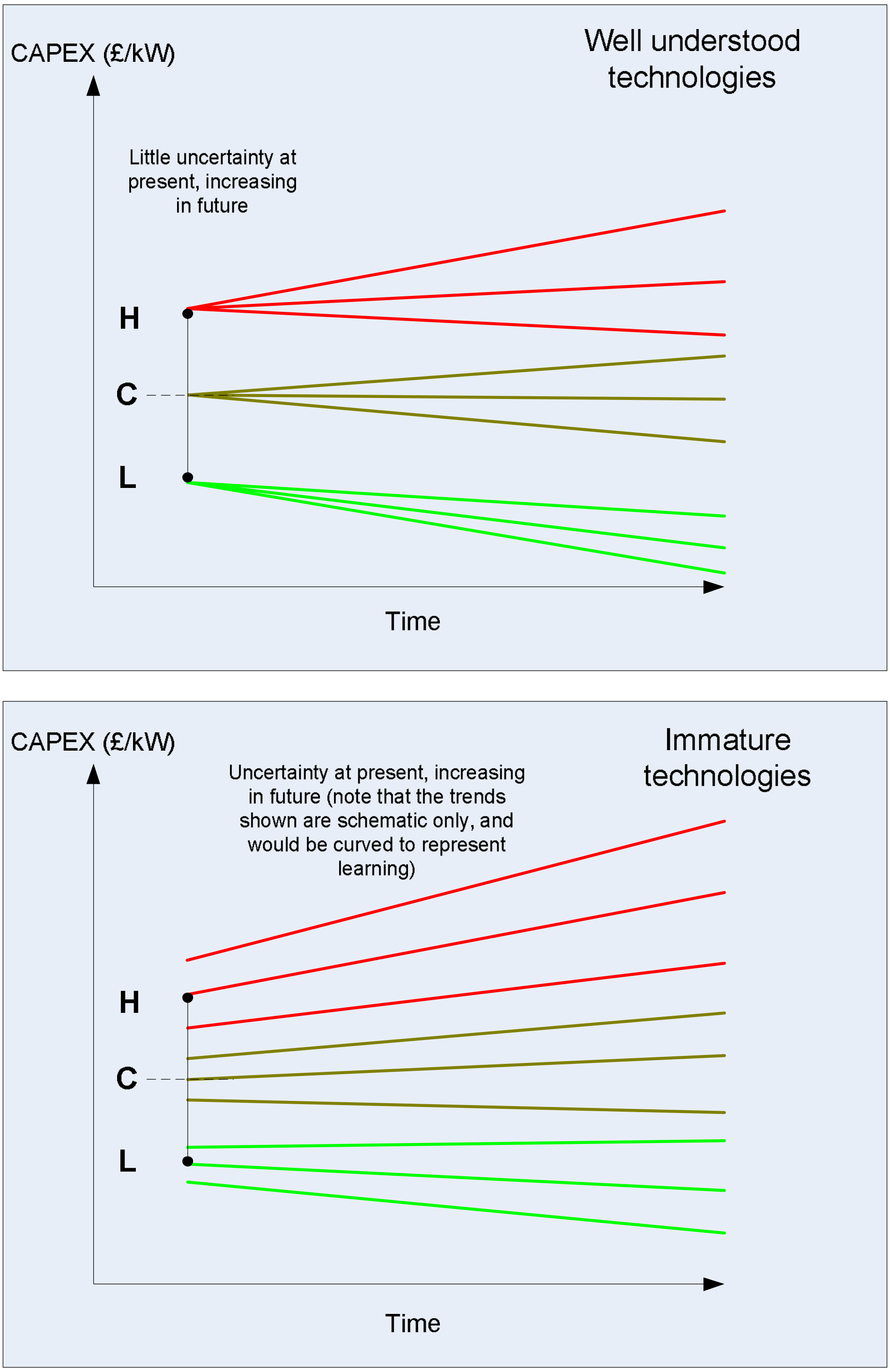

Figure 1 – Graphical representation of construction cost variation and uncertainty.

Note that the above curves are intended for illustrative purposes only.

For CCS technologies, site to site variation was estimated using the relative ranges of non CCS technologies (as shown in Figure 2) as there are no commercial CCS projects in the UK from which a range could be derived.

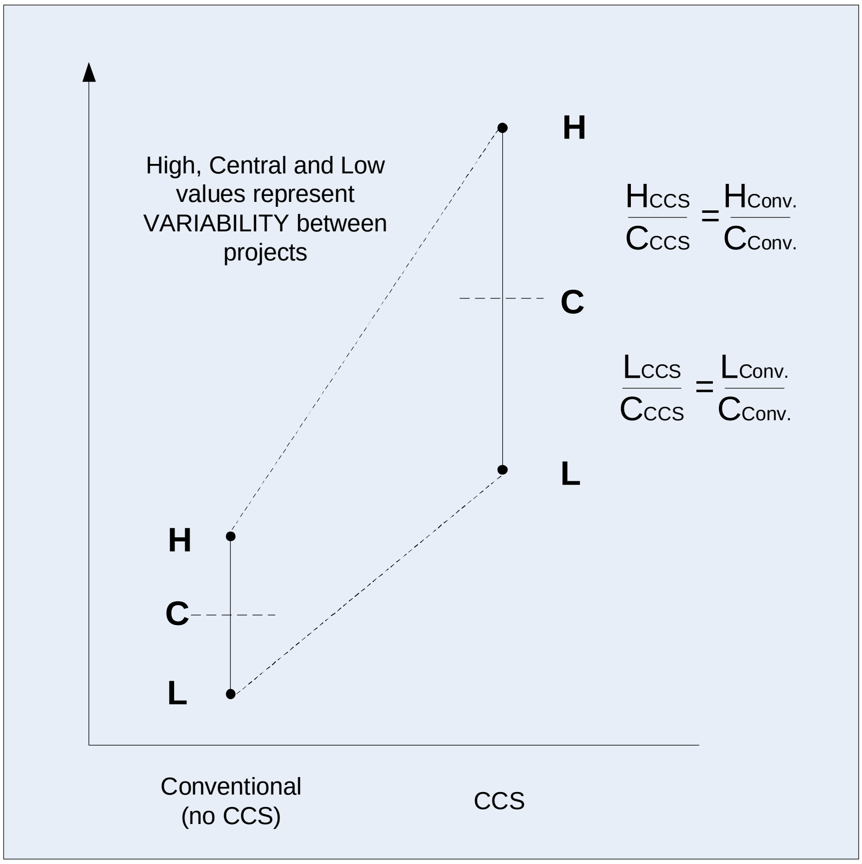

Figure 2 – Graphical representation of the calculation of variability in construction costs for CCS technologies.

Forward uncertainty for CCS included expected cost variation due to the choice of capture technology as these are currently evolving and a convergent solution for each type of CCS is not yet apparent. The value of uncertainty for each type of CCS was estimated using the range of costs reported in recent literature and expert opinion.

For nuclear technologies, there was no basis on which to estimate the distinction between variation and uncertainty. Therefore the range given within the input sheets represented the uncertainty in 2012. The forward price trends only included an increasing envelope of uncertainty going forward.

3.4.2 Other Cost and Technical Parameters

High, medium and low variation for other parameters represented the expected variation in each parameter as reflected by the state of the technology.

3.5 Treatment of FOAK and NOAK

For all established technologies that are well understood such as CCGT, OCGT, coal ASC with FGD, IGCC, gas CHP and pumped storage, all parameters reflect NOAK projects, and therefore FOAK and NOAK values for all parameters were presented as equal within the inputs sheets.

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 and demonstration projects to be accounted for.

NOAK inputs were defined as the estimated level of each parameter when the forward price of the technology and key technical parameters such as efficiency or availability would not be significantly affected by the addition of one more new plant within the UK

The period in which the price moves from FOAK to NOAK was entirely dependent on the assumed learning rate and the assumed build rate.

3.6 Heat Revenues Methodology

In order for the cost of electricity from CHP technologies to be evaluated, the cost and effect on performance of generating heat had to be identified and accounted for. Whilst it would be possible to attribute the costs of various components to either heat or power, the splitting of performance parameters to give an accurate portrayal of the performance of the plant on the basis of electricity only would be impossible.

The value of heat was therefore accounted for within the overall levelised cost by reducing the construction cost by the cost of a gas boiler designed to supply the assumed heat load. Details on the assumed characteristics of the heat load for each technology are presented in Section 4.4. Additionally, the approximate fuel and operations and maintenance cost of the gas boiler were calculated over a ten year period and removed from the overall levelised costs. A ten year period was chosen to represent a reasonable contract lifespan for a typical heat load.

The performance parameters presented were those of the CHP plant as a whole.

This methodology was consistent with the approach adopted for the analysis undertaken for the Renewables Obligation Banding Review.

3.7 Forward Pricing Model

The approach to the Forward Pricing Model was developed to provide consistency in the derivation of future construction costs across technologies by linking into a coherent set of UK and global build rates. Build rates, learning and tuning inputs can be modified by DECC in the future as forward projections are amended.

The resulting trends are indicative only and were based on assumed future build rates.

3.7.1 Scope

Forward price adjustments were required as inputs to the Levelised Electricity Cost Model to give an estimate of the construction cost of each technology for each year from 2012 to 2030. The provision of forward adjustments for parameters other than construction costs (such as O&M costs, use of system charges and technical parameters) was beyond the scope of the project.

The Forward Pricing Model had the functionality to estimate the effect of market conditions or constraints, learning, inflation and commodity price variation on the forward construction cost of each technology. Each factor could be switched on or off to investigate its effects.

The forward price trends include market conditions and learning where appropriate.

Whilst the Forward Pricing Model included the functionality to investigate the effects of inflation, this was switched off so that the resulting trends were in real terms. Commodity prices were also switched off because it was assumed that any price change that may have an effect on forward costs could not be predicted (for example, recession or economic boom) and that the impact on construction costs would be low and within the bounds of forward uncertainty. This was consistent with the approach to previous estimates published by DECC.

The forward price trends were based on the current assumed plant configuration and did not account for any cost changes either up or down that would result in the change of another parameter such as increased efficiency or reduced O&M costs because there was no ability within the model to represent these potential changes.

Uncertainty bounds were also implemented within the high and low forward price trends. These could be switched on or off when calculating levelised cost bounds.

3.7.2 Functionality

The Forward Pricing Model ensured consistency across technologies through the utilisation of the following sub-set of technology areas:

- Gas Turbines / Combined Cycle
- Conventional[7]
- Carbon Capture
- Nuclear
- Hydro

All build rates, learning rates and tuning parameters were transposed onto this sub-set before any calculation took place. Interactions and inter-dependence between similar technologies, for example, CCS technologies partly tracked the Carbon Capture price trend and partly tracked the price trend of the base technology (either “Conventional” or “Gas Turbines”). The split was based on analysis of the component costs of each technology.

The annual cost change due to market constraints and learning were derived as detailed below. If switched on, inflation, commodity price projections and uncertainty bounds were then applied.[8] The final calculation step related each annual change to a change relative to the 2012 market level.

Appendix E shows a flow diagram illustrating the calculation steps for the analysis of market constraints and learning.

3.7.2.1 Build Rates

The Forward Pricing Model utilised UK based build rate scenarios that were provided by DECC to meet future predicted demand. A global build rate for each technology was also derived from the IEA BlueMap scenario for global installed capacity. The use of a consistent and coherent set of build rates as opposed to taking the build rate of each technology in isolation resulted in more consistent forward prices.

3.7.2.2 Market Capacity

The forward pricing model estimated the market’s capacity to supply a technology in each year as the average historical deployment of the technology. This was done both at a global scale and at a UK scale. The length of the averaging period was set to the operational life of a specific technology for the global market to reflect an estimate of the period in which each industry on a global scale could fully adjust to demand. However, the UK market was assumed to react quicker, and as such a lower averaging period of 5 years was assumed.

7 The term “conventional” covers plants that incorporate a boiler and a steam turbine within a Rankine steam cycle.
8 Inflation and commodity price variation were switched off in line with the methodology used for previous reports.

This estimated supply capacity was then compared to projected deployment in each year to give an intermediary value relating to the over or under capacity in the market. A linear relationship between the over or under capacity and the corresponding cost impact was assumed. For mature technologies, this was calibrated against observed relationships between historical cost impacts and market changes. For immature technologies, a conservative relationship was modelled to avoid spurious variations in future costs that would be unsubstantiated. The projected price impacts were then smoothed over three years to account for some market foresight.

The global and UK estimates were amalgamated together using a weighted average of the global and UK market cost impacts.

3.7.3 Learning Rates

Potential cost reductions due to learning were evaluated based on published learning rates or those thought appropriate by experts within Parsons Brinckerhoff.

Learning rates, assumed current capacity and build rate base (UK or global) for each technology are tabulated in Table 1. Further discussion on the derivation of learning rates for each technology is presented in Section 5.

Technology area	Learning rate (% cost reduction for doubling capacity) and source	Current capacity assumed (GW)[9]	Based on UK or Global
Gas turbines / combined cycle	0%	NA	NA
Conventional	0%	NA	NA
Carbon capture	2.2%[10]	0	Global
Nuclear	5%[11]	13.6[12]	Global
Hydro	10%[13]	1004.4	Global

Table 1 – Input parameters for the Forward Price Model

Learning rates were derived from recent and prominent literature sources. The general issue with the application of learning rates however was that if the technology on which the rate was based was considered too similar to that under investigation then the risk is that the learning has already taken place. If the technology was considered too different however then there would be no guarantees that the learning rate would transpose onto the technology under investigation.

9 If global build rate used, start capacity is approximate 2012 global capacity. If UK build rate used, start capacity is approximate 2012 UK capacity.
10 E S Rubin, "Estimating the Future Trends in the Cost of CO2 Capture Technologies", February 2006. http://steps.ucdavis.edu/People/slyeh/syeh-resources/IEA%202006-6%20Cost%20trends.pdf
11 Due to the unavailability of a robust source on learning rates for new nuclear, an indicative rate of 5% was utilised.
12 New global capacity from 2007 onwards – older capacity assumed to have no affect on new build learning.
13 A learning rate of 10% was advised by DECC, although due to current large installed capacity, forward learning has no impact

3.7.4 Interpretation

The forward price model was based on estimates of global and UK build rates. Changes due to market constraints and learning were therefore sensitive to these build rates. If the actual build rates diverge from the predicted build rates, actual cost trends may also diverge from the predicted costs.

Tuning parameters such as estimated cost changes and averaging periods within the model were not highly evidence based due to a lack of robust data. The tuning parameters however provided a consistent approach across technologies as they were derived relative to each other.

3.8 Derivation of Levelised Costs

The methodology behind the utilisation of the model and levelised cost outputs are the responsibility of DECC.

4 GENERAL ASSUMPTIONS AND LIMITATIONS

This Section describes the major assumptions and limitations in relation to the derivation of input data. Input data and model outputs should therefore be reviewed within the context of the following section. Appendix F provides guidance on specific issues where either limitations or the modelling approach has had a specific effect on results of certain technology groups. The technology by technology discussions offer suggestions and guidance as to how the assumptions and limitations may affect conclusions.

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 were well understood and have extensive market presence whilst others were at an earlier stage of development or application and were 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.

4.1 Data Availability

The work described in this report was generally limited by the availability of reliable and accurate data suitable for transposition into the model. Specific issues arising from this and any assumptions that were required in order to overcome these limitations are described in Section 5 and Appendix F.

Traditional statistical analysis techniques require a minimum of five data points. Even for mature technologies like CCGT, where site design choices fall within a comparatively limited and understood range, obtaining at least five reliable data points that could be compared on a consistent basis was a challenge. Costs for projects that were completed over the last five years would vary due to changes in the economy and costs from across Western Europe varied due to country specific factors. For mature and well understood technologies, these factors were stripped out; however for immature technologies where there was greater uncertainty about the intrinsic costs and cost variation, the disentanglement of the short term effects of the global economy and location based factors from underlying technology costs and variation resulted in large margins of uncertainty.

Data was therefore used from the highest category in the data sources hierarchy (presented in Section 3.3) in which projects with robust information existed. This resulted in a small number (sometimes two or three) data points; however this was deemed acceptable if corroborated by modelling and expert opinion. The approach avoided any potential misinterpretation of data that may have been skewed by the changing economy.

4.2 Data Accuracy

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 3.

	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 3 – Cost estimate classifications

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

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.

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.

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.

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.

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.

4.3 Interpretation of Raw Data

Perhaps the greatest source of uncertainty within this kind of analysis was the interpretation of raw data. This was often unconscious and shaped by the experience and viewpoint of the individual undertaking the analysis. Traceability could have been lost leading to misinterpretation of results. Parsons Brinckerhoff has for this reason ensured that each technology was dealt with by an engineer with considerable experience in the development of projects within each technology and recorded raw data. Any unconscious data processing or amendments which cannot be expressed through analytical or numerical means therefore resulted in the exclusion of biased data or costs for projects that have some unique aspect that may skew results, or to amend cost data to reflect general industry or expert views.

4.4 Heat Load Characteristics

The levelised cost of electricity from CHP technologies as evaluated using the Levelised Electricity Cost Model and the avoided gas boiler method (introduced in Section 3.6) was highly sensitive to the characteristics of the heat load. These characteristics are bespoke to each consumer.

Parameters for CHP technologies were therefore based on thermal models. Each was modelled to meet the requirements of accreditation as “good quality CHP” under the CHP QA, which in itself was not sufficient to derive a determinate plant model. Therefore the characteristics of the heat and power load were further defined by assigning a representative industrial or commercial customer such as a hospital, paper mill or petrochemical works to each CHP technology, as displayed in the following table.

CHP technology	Representative heat customer assumed	Assumed heat characteristics
Small GT based	Hospital	IP extraction at 3.5 bar, 200 °C - for large scale space heating Heat to power ratio of 2 aimed for
Medium GT and back pressure steam turbine	Paper mill / small chemical plant	IP extraction at 3.5 bar, 200 °C - for process heat Heat to power ratio of 1 aimed for
CCGT CHP	Petrochemical plant	IP extraction at 20 bar, 237 °C - for process heat Heat to power ratio of 1 aimed for

Table 2 – Heat load characteristics

The heat to power ratios assumed were advised by DECC and based on statistical analysis of pipeline projects. In reality however, the minimum heat required either to meet the heat load or the CHP QA would be delivered due to the relatively low value of heat compared to the lost revenues from electricity.

Further discussion on the implications of the choice of heat load and the avoided gas boiler methodology are discussed in Appendix F.

4.5 Global Assumptions

The following global assumptions were established to facilitate a consistent starting point or default approach to various aspects of modelling. Deviations from these were allowed if justified by the technology or market. This approach insured that each technology was treated fairly in its own right and that inconsistencies were minimised.

4.5.1 Price Basis

Costs were presented in 2012 prices. Historical project or equipment costs were inflated to 2012 prices. Literature sourced cost parameters dated in the last two years were reviewed within the context of the current market and were not inflated due to the inherent uncertainty of the source.

4.5.2 Site Boundaries

Site boundaries were generally defined as the area that housed all equipment from the fuel delivery point to the high voltage metering point of the grid connection. Equipment within the site boundary was assumed to be part of the construction cost.

4.5.3 Infrastructure

Infrastructure was generally defined as equipment beyond the site boundary that was assumed to be required for the purposes of fuel delivery or electricity export. Such equipment would be funded as a capital expense then transferred to a third party without payment to the developer or owner. Effectively such items included a gas supply pipeline where required and an overhead line and substation of the appropriate voltage (the grid connection).

The gas supply pipeline and grid connection were sized according to the calculated gas demand and electrical load. The length of the OHL and pipeline was varied within practical and economic limits for the size of project. The medium and high cost estimates also included a tee-off substation for technologies large enough to export at 132 kV or above. The onsite substation was included within the capital construction costs.

4.5.4 Fuel Processing and Delivery

Fuel processing and delivery costs were assumed to be accounted for within the fuel price trends supplied by DECC. Therefore, the only onsite fuel processing required was for the purposes of protecting the plant and modifying the fuel should the delivered fuel fall outside of specified limits.

5 TECHNOLOGY DISCUSSIONS

The following Section provides an overview of the inputs and interpretation for each technology covered within the study. A high level equipment list, assumed site boundaries and required infrastructure for each technology can be found in Appendix B. Activities assumed to be covered during the development stage of the project are given in Appendix C. Operations and Maintenance activities for each technology are displayed in Appendix D.

5.1 CCGT

5.1.1 Technology Description

Combined cycle gas turbine 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.

5.1.2 Main Data Sources

Parameter	Comment
Key timings	Well understood with little variation between sites. Therefore indicative figures were provided with no specific plant references.
Technical parameters	Power output was chosen as representative of the size of plant that is likely to be built in the UK in the future (800 MW to 1000 MW). Larger plants are feasible at comparative specific costs; however land availability and transmission network capacity usually limit the deployment within the UK. Smaller plants are also feasible. The low and medium efficiency values were the design points for recently commissioned UK plants. The high efficiency value represented the capability of the latest gas turbines.
Pre-development costs	Development costs were derived from a range of European projects currently under development or construction. These costs were revised following peer review as more reliable source information was provided.
Construction costs	Construction costs were gathered from two recently commissioned UK projects and two recent European projects. The capital costs were revised following peer review as peer review evidence was from recent UK projects.
Operational costs	Operational costs were gathered from three UK projects.

Table 3 – Main data sources

5.1.3 Effects of Limitations and Assumptions

The technology is mature and well understood and thus the input data was considered to be reliable.

5.1.4 Changes from 2011

The plant capacity was increased from the 2011 update, thus resulting in a higher overall capital cost. As a result of the peer review, the development costs were revised downwards from last year's estimates. However, this was not a significant cost component and the overall effect on the levelised cost was not significant.

5.1.5 Market Conditions and Forward Pricing

The recent economic climate had a noticeable downward effect on the capital cost per unit capacity of CCGT and caused a drop in demand. As the data gathered for this study was required to reflect current costs then this cost reduction was reflected. It is however expected that as the economy recovers and investment in major infrastructure follows, specific costs would return to 2008 levels. This was reflected in the Forward Pricing Model.

5.1.6 Other Comments

In order to provide a consistent approach across technologies, the same base power plant configuration was assumed for CCGT, CCGT CHP, CCGT with post combustion capture and CCGT with pre-combustion capture.

5.2 OCGT

5.2.1 Technology Description

Open cycle gas turbine plant is a mature technology that involves the generation of electricity from gas turbines. This type of plant is operated as peaking units due the lower capital costs and greater operational flexibility than CCGT and coal plant.

No major advances or technical changes are expected to affect the cost and performance of this technology in the near future.

5.2.2 Main Data Sources

Parameter	Comment
Key timings	Well understood with little variation between sites. Therefore indicative figures were provided with no specific plant references.
Technical parameters	Power output was chosen as representative of the size of plant that is likely to be built in the UK in the future (around 300 MW) and corresponds to two E class industrial turbines. Larger plants are technically feasible at comparable specific costs and smaller plants are also feasible, although at a diminished economic value. Efficiency values correspond to published values for E class machines.
Pre-development costs	Development costs were derived as a percentage of the capital costs. Due to the lack of recent open cycle projects in the UK, the percentage used was that suggested by the Thermoflow PEACE software for UK plant.

Parameter	Comment
Construction costs	Again due to the lack of recent UK projects, the capital costs were derived from Thermoflow PEACE software.
Operational costs	Operational costs were gathered from UK projects.

Table 4 – Main data sources

5.2.3 Effects of Limitations and Assumptions

The technology is mature and well understood and thus the input data was considered to be reliable.

5.2.4 Changes from 2011

The plant capacity was increased significantly from the 2011 update, thus resulting in a higher overall capital cost. The specific capital cost however was lower than in 2011 due to the increased economies of scale implied by assuming a larger plant size. There may also have been some decrease in costs due to the contraction of the gas turbine market within Europe in general.

5.2.5 Market Conditions and Forward Pricing

A lack of recent projects has resulted in difficulty in evaluating how the cost of OCGT would vary in the future. Costs are therefore assumed to follow the gas turbine technology price trend.

5.3 Small GT Based CHP

5.3.1 Technology Description

Gas fired combined heat and power of a small scale is a mature technology that involves the generation of electricity from a gas turbine. The waste heat from each gas turbine is then passed through a heat recovery steam generator to raise steam, which is utilised for large space heating or industrial processes.

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, driven by rising gas prices.

5.3.2 Main Data Sources

Parameter	Comment
Key timings	Well understood with little variation between sites. Therefore indicative figures were provided with no specific plant references.
Technical parameters	Power and heat outputs were derived from the thermal modelling of a suitable plant configuration supplying an assumed heat and power load for a hospital. It was also assumed that such plants would be designed to achieve “good quality CHP”. Electrical efficiency was calculated using thermal modelling and the high to low range was assumed to be that of the CCGT technology.
Pre-development costs	Development costs were derived from a range of UK projects.

Parameter	Comment
Construction costs	Construction costs were obtained from cost modelling based on the plant thermal model. The range was estimated using UK projects with similar heat loads to that which was modelled.
Operational costs	Operational costs were gathered from UK projects.

Table 5 – Main data sources

5.3.3 Effects of Limitations and Assumptions

The technology is mature and well understood and thus the input data were considered to be reliable.

5.3.4 Changes from 2011

This year's configuration was more representative of existing plant and utilised a gas turbine that was more expensive yet more efficient that that assumed for the 2011 update.

The heat and power was amended and therefore a comparison with last year's results is invalid; however there has been no significant market change.

5.4 GT with Back Pressure Steam Turbine CHP

5.4.1 Technology Description

Gas fired combined heat and power of a medium scale 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. The steam exhausted from the steam turbine is then utilised as process heat. A steam extraction can also be incorporated.

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, driven by rising gas prices.

5.4.2 Main Data Sources

Parameter	Comment
Key timings	Well understood with little variation between sites. Therefore indicative figures were provided with no specific plant references.
Technical parameters	Power and heat outputs were derived from the thermal modelling of a suitable plant configuration supplying an assumed heat and power load for a paper mill or small chemical plant. It was also assumed that such plants would be designed to achieve "good quality CHP". Electrical efficiency was calculated using thermal modelling and the high to low range was assumed to be that of the CCGT technology.
Pre-development costs	Development costs were derived from a range of UK projects.

Parameter	Comment
Construction costs	Construction costs were obtained from cost modelling based on the plant thermal model. The range was estimated using UK projects with similar heat loads to that which was modelled.
Operational costs	Operational costs were gathered from three UK projects.

Table 6 – Main data sources

5.4.3 Effects of Limitations and Assumptions

The technology is mature and well understood and thus the input data were considered to be reliable.

5.4.4 Changes from 2011

This year's configuration was more representative of existing plant and utilised a gas turbine that is more expensive yet more efficient that that assumed for the 2011 update.

The capital cost per unit capacity was also higher than in the 2011 update due to the larger heat to power ratio.

5.5 CCGT CHP

5.5.1 Technology Description

CCGT with combined heat and power 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.

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, driven by raising gas prices.

5.5.2 Main Data Sources

Parameter	Comment
Key timings	Well understood with little variation between sites. Therefore indicative figures were provided with no specific plant references.
Technical parameters	Power and heat output were derived from the thermal modelling of the CCGT plant configuration supplying an assumed heat and power load for a large petrochemical plant. It was also assumed that such plants would be designed to achieve "good quality CHP". Electrical efficiency was calculated using thermal modelling and the high to low range was assumed to be that of the CCGT technology.
Pre-development costs	Development costs were derived from a range of UK projects.

Parameter	Comment
Construction costs	Construction costs were obtained from cost modelling based on the plant thermal model. The range was estimated using UK projects with similar heat loads to that which was modelled.
Operational costs	Operational costs were gathered from UK projects.

Table 7 – Main data sources

5.5.3 Effects of Limitations and Assumptions

The technology is mature and well understood and thus the input data were considered to be reliable.

5.5.4 Changes from 2011

The plant capacity was increased from the 2011 update, thus resulting in a higher absolute capital cost. This was done to allow a fair comparison between CCGT based technologies such that all were assumed to utilise the same configuration.

The capital cost per unit electrical capacity was also higher due to the larger heat to power ratio.

5.5.5 Market Conditions and Forward Pricing

The forward price of CCGT with CHP is expected to follow that of CCGT since the technologies are essentially the same.

5.6 ASC Coal with FGD

5.6.1 Technology Description

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.

Future improvements in this technology may be driven by increasing the temperature and pressure of the steam leaving the boiler. This would increase the efficiency of the plant but also drive up costs as the design of the boiler, steam turbine and pipework would be required to cope with increased thermal and mechanical stresses. Such variations were presented within the high, medium and low parameter levels.

5.6.2 Main Data Sources

Parameter	Comment
Key timings	Due to the scale of this technology, key timings can be susceptible to site specific delays, resulting in a reasonable variation in key timings. These were estimated from a range of similar global projects, due to a lack of UK and European projects.

Parameter	Comment
Technical parameters	Power output was chosen as representative of the size of plant that is likely to be built in the UK in the future (around 1600 MW). Larger plants are feasible and exist in other parts of the world, however land availability and transmission network capacity usually limit the deployment within the UK. Smaller plants are also feasible although unit sizes below 600 MW are thought to be uneconomical. The efficiency values were originally based on thermal modelling of ASC plant with varying steam conditions, however this was updated to reflect a real project.
Pre-development costs	Development costs were derived from a range of global projects currently under development or construction as there are few UK or European projects.
Construction costs	Construction costs were gathered from two global reference plants currently under construction and were validated using cost modelling based on plant thermal models.
Operational costs	Operational costs were based on two global projects currently under construction and were corroborated with data from UK sub-critical coal plants of a similar capacity.

Table 8 – Main data sources

5.6.3 Effects of Limitations and Assumptions

Coal ASC with FGD is a maturing technology with no current deployment in the UK. There was therefore some uncertainty in how the capital costs from global projects would relate to the UK.

5.6.4 Changes from 2011

Costs and technical parameters have changed little from the 2011 update.

5.6.5 Market Conditions and Forward Pricing

Due to the lack of recent UK projects and difficulties in resolving various factors affecting the cost of ASC coal plants across the world, the forward price projections developed were uncertain and should be utilised with caution. Calibration and tuning factors were chosen conservatively such that the resulting trends did not fluctuate wildly. There was no strong basis for any other projection.

5.7 Retro-fit of SCR or SNCR onto Coal

5.7.1 Technology Description

SCR or SNCR is a process for controlling emissions of nitrogen oxides within the waste gases from burners through catalytic or non catalytic reduction reactions. The type of catalyst required is highly dependent on the exhaust conditions of the boiler and the constituents of the flue gas.

Whilst this technology is not novel in itself, the retro-fitting of the technology is currently unusual, although it is expected to become more widespread as environmental regulations become more demanding. Costs are also highly site specific which resulted in a wide variation.

5.7.2 Main Data Sources

Parameter	Comment
Key timings	Indicative key timings were provided based on estimates derived from an internal Parsons Brinckerhoff study into retro-fitting SCR to a number of UK coal plants.
Technical parameters	Power output indicates the post retro-fit output of a 1000 MW coal plant.
Pre-development costs	Indicative estimate of the design and procurement costs for major modification works were provided.
Construction costs	Derived from an internal Parsons Brinckerhoff study into retro-fitting SCR to a number of UK coal plants.
Operational costs	Derived from an internal Parsons Brinckerhoff study into retro-fitting SCR to a number of UK coal plants.

Table 9 – Main data sources

5.7.3 Effects of Limitations and Assumptions

The levelised cost represented the capital costs of undertaking the retro-fit and the additional operations and maintenance costs post retro-fit, levelised on the basis of the electricity output of the entire plant. The evaluation did not account for the lost revenues caused by the post-retro-fit reduction in plant output.

5.7.4 Changes from 2011

This technology was new for 2012 and so a direct comparison was not possible.

5.8 IGCC

5.8.1 Technology Description

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

Future improvements in this technology may be driven by efficiency improvements in the gasification process and incremental improvements in the efficiency of the gas turbines. Such variations were presented within the high, medium and low parameter levels.

5.8.2 Main Data Sources

Parameter	Comment
Key timings	Due to the scale of this technology, key timings can be susceptible to site specific delays, resulting in a reasonable variation in key timings. These were estimated from a range of similar global projects, due to a lack of UK projects.

Parameter	Comment
Technical parameters	Power output was chosen as representative of the size of plant that is likely to be built in the UK in the future. Larger plants are technically feasible and exist in other parts of the world; however land availability and transmission network capacity usually limit the deployment within the UK. Smaller plants are also technically feasible, however may prove to be less economic due to the lack of economies of scale. The efficiency values were based on thermal modelling.
Pre-development costs	Development costs were derived from a range of global projects currently under development as there are no UK projects without CCS. The costs were cross-checked with those for ASC coal.
Construction costs	Construction costs were estimated using cost modelling based on the thermal model of the plant.
Operational costs	Operational costs were based on literature quotes and corroborated through comparison with the operations and maintenance costs of CCGT plant and coal plant

Table 10 – Main data sources

5.8.3 Effects of Limitations and Assumptions

IGCC is a maturing technology with no current deployment in the UK. Due to the lack of complete UK projects, there was some uncertainty in how the capital costs from global projects would relate to the UK.

5.8.4 Changes from 2011

Technical parameters have changed little from the 2011 update. The approach to capital costs was however changed from a project cost approach to a bottom up cost evaluation using industry standard modelling software. The change in approach was due to the uncertainty in how costs from global projects would relate to the UK and because a lack of visibility of various project details (such as equipment costs, configuration, extent of supply, site characteristics etc.) that would be required in order to better relate costs to the UK. It was assumed that this change in approach accounted for the significant difference in capital costs compared to previous updates because there was little change in the technical parameters and no significant movement within the UK market.

5.8.5 Market Conditions and Forward Pricing

Due to the lack of UK projects and difficulties in resolving various factors affecting the cost of IGCC plants across the world, the forward price projections developed were uncertain and should be utilised with caution. The forward price trend was therefore assumed to partly track that of conventional technologies and partly that of gas turbine based technologies because of the inclusion of similar components within an IGCC plant.

5.9 CCS and Retro-fit CCS

5.9.1 Technology Description

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

- Pre-combustion capture with CCGT
- IGCC with pre-combustion capture
- Post combustion capture with CCGT
- Post combustion capture with ASC coal
- Post combustion capture with biomass
- Oxyfuel with CCGT
- Oxyfuel with ASC coal

Additionally, inputs were derived for the retro-fit of post combustion capture to ASC coal and CCGT, and the retro-fit of the capture and compression equipment to an IGCC plant. 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.

There are three types of carbon capture considered in this study, along with compression and pipeline transport of CO_2. A brief description of each type is given below. Although pre-combustion can be applied to fuels other than gas and coal, and oxyfuel can be applied to fuels other than 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 such as cement or steel plant, but these options are also outside the scope of this study.

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 carbon dioxide (CO_2) in the flue gases. In a typical process the flue gas passes through a direct contact cooler (DCC) 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 only considered amines as absorbers. Other methods such as ammonia or dry sorbents were not considered.

Pre-combustion: Synthetic gas produced from coal in an IGCC 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 carbon dioxide (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%.

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. The oxygen is produced by a cryogenic Air Separation Unit (ASU) 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, 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.

Each capture technology is currently at a different stage of development from initial concept, such as oxyfuel with CCGT, to numerous pilot plants with larger scale plants under development, such as post combustion capture.

5.9.2 CO_2 transport and storage

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

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.

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

The high case for storage was offshore storage of CO_2 in a saline aquifer.

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

5.9.3 Main Data Sources

Parameter	Comment
Key timings	Based on the key timings of the base plant and adjusted for the approximate additional design and development time for CCS.
Technical parameters	Power output and efficiency were based on plant modelling using estimates for steam extractions and auxiliary power or on published values.
Pre-development costs	These were derived using an assumed percentage of capital costs and compared to approximate design and development costs from literature.
Construction costs	Due to the lack of commercial plants, cost information was taken from a mixture of confidential sources, economic modelling using thermal models and updates with estimates for CCS equipment and literature. These were corroborated with a comparison to the base plant construction costs with additions for the CCS plant.
Operational costs	Due to the lack of commercial plants, cost information was taken from a mixture of confidential sources and literature. These were corroborated with a comparison to the base plant operational costs with additions for the CCS plant.
CO_2 transport and storage costs	Transport and storage costs were based on published information from the first carbon capture and storage competition FEED studies.

Table 11 – Main data sources

5.9.4 Effects of Limitations and Assumptions

The Levelised Electricity Cost Model was appropriate for the evaluation of thermal technologies and was therefore appropriate for the evaluation of thermal technologies with CCS. When dealing with the retro-fit of CCS technologies however, the model did not attribute any value to the base plant or the electricity lost as a result of the retro-fit.

The levelised cost for the retro-fit of CCS represented the additional capital cost of carrying out the retro-fit and the operational and maintenance costs of the entire plant.

5.9.5 Changes from 2011

For the 2011 update, post combustion capture on ASC coal, post combustion capture on CCGT and IGCC with CCS were included. Technical parameters for these technologies were updated to represent modelled values as opposed to those quoted in literature sources, as in the 2011 update. This increased the accuracy and certainty of the data set.

Costs were also updated using confidential data, information from published sources including the first carbon capture competition (post combustion capture) and modelling (other CCS technologies) using Aspen, Thermoflow and economic modelling. Some variation in specific capital costs for post combustion capture technologies was therefore attributed to the advancement in knowledge from the first carbon capture competition.

The significant change to IGCC with CCS costs could partly be attributed to a change in technical parameters assumed; however similar to IGCC, it was assumed that the change in approach accounted for the significant difference in capital costs compared to previous updates because there was little change in the technical parameters and no significant movement within the UK market.

5.9.6 Market Conditions and Forward Pricing

The Forward Pricing Model provided the same forward cost curve regardless of capture type. This was because the build rates on which the model was based did not distinguish between capture types. Forward prices were therefore only valid on a technology by technology basis under the assumption that the given build rates were of that specific capture type only. There may be some inter-linked effects due to similarities in the technology; however the derivation of analytical expressions and therefore the modelling of such relationships would be extremely difficult and time consuming and was therefore not attempted.

5.10 Nuclear

5.10.1 Technology Description

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

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

5.10.2 Main Data Sources

Parameter	Comment
Key timings	Indicative key timings are provided due to a lack of commercial plants in operation or under construction.
Technical parameters	Power output was based on quoted and well understood figures. There may be some variation in the quoted power values across literature which may come from rounding or varying assumptions on the size of auxiliary loads. Efficiency was not required as fuel prices were given per MWh of plant output.
Pre-development costs	Derived from literature and updated following peer review.

Parameter	Comment
Construction costs	Derived from global projects under development and updated following peer review.
Operational costs	Derived from global projects under development cross-checked with the operational costs of existing nuclear plant in the UK sourced partly from literature and partly from confidential sources.

Table 12 – Main data sources

5.10.3 Effects of Limitations and Assumptions

Nuclear technology in its broader sense is mature, however uncertainties exist around the delivery schedule of the relatively new reactor design and how costs quoted for projects in other countries (mainly France and USA) would relate to the UK.

5.10.4 Changes from 2011

Technical parameters have not changed significantly since 2011. Capital costs were revised towards the higher end of the range given in 2011, although the highest construction cost remained unchanged. Development costs were also increased such that the low, medium and high levels represented 3%, 5% and 10% of the capital cost. Due to the complexities of the nuclear technology and the sensitivity of the overall cost to the reactor cost, a bottom up comparison was not feasible for this project.

5.10.5 Market Conditions and Forward Pricing

There was uncertainty surrounding the forward price of nuclear in relation to the way in which developments and resulting cost changes from global projects are likely to impact upon UK projects.

Due to the current low levels of deployment of the PWR designs especially in the UK, a robust historical cost trend does not exist. Historical costs simply represent the view of what the costs were thought to be at a point in time. Currently this is generally an upward trend which does not reflect any potential learning from experience gained.

An indicative learning rate of 5% was calculated to give a drop in price from FOAK to NOAK in a reasonable timescale. This approach was required due to a limited availability of robust historical cost information on which a learning rate calculation could be based.

5.11 Pumped Storage

5.11.1 Technology Description

Pumped storage is a mature technology that involves using electricity bought at low prices (usually over night) to pump water from a low level reservoir to a higher level reservoir. At times of high price and peak demand, water is allowed to flow back to a low level reservoir through turbines that generate electricity.

No major advances or technical changes are expected to affect the cost and performance of this technology in the near future. However, the capital cost of pumped storage is highly site specific due to the extent of civil works required.

5.11.2 Main Data Sources

Parameter	Comment
Key timings	All parameters from the 2011 update were reviewed and accepted as current.
Technical parameters	All parameters from the 2011 update were reviewed and accepted as current.
Pre-development costs	All parameters from the 2011 update were reviewed and accepted as current.
Construction costs	All parameters from the 2011 update were reviewed and accepted as current.
Operational costs	All parameters from the 2011 update were reviewed and accepted as current.

Table 13 – Main data sources

5.11.3 Effects of Limitations and Assumptions

Under the current analysis, no fuel cost has been attributed to pumped storage. The fuel input is electricity and costs should be derived through analysis of the over-night electricity purchase cost.

5.11.4 Changes from 2011

All parameters from the 2011 update were reviewed and accepted as current. There have been no significant events that would result in discernible parameter changes beyond general market conditions.

6 APPENDIX A – DATA INPUTS

Gas - CCGT

		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	2.0	2.3	5.0	2.0	2.3	5.0
Construction Period	years	2.0	2.5	3.0	2.0	2.5	3.0
Plant Operating Period	years	20.0	30.0	35.0	20.0	30.0	35.0
Technical data							
Net Power Output	MW	900	900	900	900	900	900
Net Efficiency	%	57.9%	58.8%	60.0%	57.9%	58.8%	60.0%
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%
CO_2 Removal	%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Capital costs							
Pre-licensing costs, Technical and design	£/kW	11.0	12.0	13.0	11.0	12.0	13.0
Regulatory + licensing + public enquiry	£/kW	0.4	0.4	2.9	0.4	0.4	2.9
EPC cost (excluding interest during construction) –variability only	£/kW	495.1	575.1	655.1	495.1	575.1	655.1
EPC cost (excluding interest during construction) –variability and uncertainty	£/kW						
Infrastructure cost	£'000	7,000	14,500	22,000	7,000	14,500	22,000
Operating costs							
O&M fixed fee	£/MW/yr	18,026	18,884	19,742	18,026	18,884	19,742
O&M variable fee	£/MWh	0	0	0	0	0	0
Insurance	£/MW/yr	1,485	2,300	3,276	1,485	2,300	3,276
Connection and UoS charges	£/MW/yr	3,070	3,070	3,070	3,070	3,070	3,070
CO_2 transport and storage costs	£/MWh	0	0	0	0	0	0

OCGT

		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	1.5	2.1	4.5	1.5	2.1	4.5
Construction Period	years	1.7	1.9	2.5	1.7	1.9	2.5
Plant Operating Period	years	35.0	40.0	45.0	35.0	40.0	45.0
Technical data							
Net Power Output	MW	290	290	290	290	290	290
Net Efficiency	%	33.3%	35.0%	36.8%	33.3%	35.0%	36.8%
Average Steam Output	MW (thermal)	0	0	0	0	0	0
Average Availability	%	93.8%	94.7%	95.7%	93.8%	94.7%	95.7%
Average Load Factor	%	5.0%	20.0%	20.0%	5.0%	20.0%	20.0%
CO_2 Removal	%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Capital costs							
Pre-licensing costs, Technical and design	£/kW	16.3	18.9	24.6	16.3	18.9	24.6
Regulatory + licensing + public enquiry	£/kW	2.0	2.4	3.1	2.0	2.4	3.1
EPC cost (excluding interest during construction) –variability only	£/kW	417.3	472.5	567.0	417.3	472.5	567.0
EPC cost (excluding interest during construction) – variability and uncertainty	£/kW	417.3	472.5	567.0	417.3	472.5	567.0
Infrastructure cost	£'000	7,000	9,050	11,100	7,000	9,050	11,100
Operating costs							
O&M fixed fee	£/MW/yr	18,000	23,000	28,000	18,000	23,000	28,000
O&M variable fee	£/MWh	0	0	0	0	0	0
Insurance	£/MW/yr	1,252	1,890	2,835	1,252	1,890	2,835
Connection and UoS charges	£/MW/yr	1,884	1,884	1,884	1,884	1,884	1,884
CO_2 transport and storage costs	£/MWh	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	30.0	35.0
Technical data							
Net Power Output	MW	786	786	786	786	786	786
Net Efficiency	%	50.0%	50.8%	51.8%	50.8%	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%
CO_2 Removal	%	85.0%	87.5%	90.0%	90.6%	90.6%	90.6%
Capital costs							
Pre-licensing costs, Technical and design	£/kW	25.0	30.0	40.0	20.0	25.0	40.0
Regulatory + licensing + public enquiry	£/kW	0.5	0.5	3.7	0.5	0.5	3.7
EPC cost (excluding interest during construction) –variability only	£/kW	1218.4	1415.3	1612.2	1034.6	1201.7	1368.9
EPC cost (excluding interest during construction) – variability and uncertainty	£/kW	1132.2	1415.3	1698.4	961.4	1201.7	1442.0
Infrastructure cost	£'000	7,000	14,500	22,000	7,000	14,500	22,000
Operating costs							
O&M fixed fee	£/MW/yr	23,301	24,021	24,763	19,417	20,017	20,636
O&M variable fee	£/MWh	1	2	2	1	2	2
Insurance	£/MW/yr	3,655	5,661	8,061	3,104	4,807	6,844
Connection and UoS charges	£/MW/yr	3,070	3,070	3,070	3,070	3,070	3,070
CO_2 transport and storage costs	£/MWh	8	12	17	8	12	17

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	785	785	785	785	785	785
Net Efficiency	%	49.9%	50.6%	51.7%	50.6%	51.4%	52.5%
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%
CO_2 Removal	%	85.0%	87.5%	90.0%	90.6%	90.6%	90.6%
Capital costs							
Pre-licensing costs, Technical and design	£/kW	14.0	23.0	27.0	9.0	18.0	27.0
Regulatory + licensing + public enquiry	£/kW	0.0	0.1	0.4	0.0	0.1	0.4
EPC cost (excluding interest during construction) –variability only	£/kW	940.3	1092.3	1244.2	701.3	814.6	927.9
EPC cost (excluding interest during construction) – variability and uncertainty	£/kW	873.8	1092.3	1310.8	651.7	814.6	977.5
Infrastructure cost	£'000	0	0	0	0	0	0
Operating costs							
O&M fixed fee	£/MW/yr	23,301	24,021	24,763	19,417	20,017	20,636
O&M variable fee	£/MWh	1	2	2	1	2	2
Insurance	£/MW/yr	2,105	3,260	4,642	1,787	2,768	3,941
Connection and UoS charges	£/MW/yr	3,070	3,070	3,070	3,070	3,070	3,070
CO_2 transport and storage costs	£/MWh	8	12	17	8	12	17

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	30.0	35.0
Technical data							
Net Power Output	MW	897	897	897	897	897	897
Net Efficiency	%	41.0%	41.7%	42.5%	41.7%	42.3%	43.2%
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%
CO_2 Removal	%	81.6%	81.6%	81.6%	81.6%	81.6%	81.6%
Capital costs							
Pre-licensing costs, Technical and design	£/kW	23.5	29.6	47.9	22.8	28.5	45.6
Regulatory + licensing + public enquiry	£/kW	0.4	0.5	3.2	0.4	0.5	3.2
EPC cost (excluding interest during construction) –variability only	£/kW	1388.1	1612.4	1836.7	1178.7	1369.1	1559.5
EPC cost (excluding interest during construction) – variability and uncertainty	£/kW	1128.7	1612.4	2096.1	958.4	1369.1	1779.8
Infrastructure cost	£'000	7,000	14,500	22,000	7,000	14,500	22,000
Operating costs							
O&M fixed fee	£/MW/yr	22,867	30,184	39,331	19,056	25,154	32,776
O&M variable fee	£/MWh	1	1	2	1	1	2
Insurance	£/MW/yr	4,164	6,450	9,184	3,536	5,476	7,798
Connection and UoS charges	£/MW/yr	3,070	3,070	3,070	3,070	3,070	3,070
CO_2 transport and storage costs	£/MWh	8	12	17	8	12	17

Coal - ASC with FGD

		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	2.0	3.5	5.0	2.0	3.5	5.0
Construction Period	years	2.8	3.0	4.0	2.8	3.0	4.0
Plant Operating Period	years	25.0	35.0	45.0	25.0	35.0	45.0
Technical data							
Net Power Output	MW	1600	1600	1600	1600	1600	1600
Net Efficiency	%	41.3%	44.0%	45.0%	41.3%	44.0%	45.0%
Average Steam Output	MW (thermal)	0	0	0	0	0	0
Average Availability	%	91.9%	92.8%	93.8%	91.9%	92.8%	93.8%
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-licensing costs, Technical and design	£/kW	20.0	25.0	35.0	16.0	20.0	30.0
Regulatory + licensing + public enquiry	£/kW	0.2	0.2	1.6	0.2	0.2	1.6
EPC cost (excluding interest during construction) –variability only	£/kW	1450.0	1600.0	1800.0	1450.0	1600.0	1800.0
EPC cost (excluding interest during construction) – variability and uncertainty	£/kW	1450.0	1600.0	1800.0	1450.0	1600.0	1800.0
Infrastructure cost	£'000	0	7,500	15,000	0	7,500	15,000
Operating costs							
O&M fixed fee	£/MW/yr	20,000	35,000	50,000	20,000	35,000	50,000
O&M variable fee	£/MWh	1	1	1	1	1	1
Insurance	£/MW/yr	1,450	2,400	3,600	1,450	2,400	3,600
Connection and UoS charges	£/MW/yr	4,513	4,513	4,513	4,513	4,513	4,513
CO_2 transport and storage costs	£/MWh	0	0	0	0	0	0

Coal - retrofit SCR or NSCR

		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	1.0	2.0	3.0	1.0	2.0	3.0
Construction Period	years	0.5	0.8	1.0	0.5	0.8	1.0
Plant Operating Period	years	2.0	5.0	15.0	2.0	5.0	15.0
Technical data							
Net Power Output	MW	988	988	988	988	988	988
Net Efficiency	%	32.0%	34.0%	36.0%	32.0%	34.0%	36.0%
Average Steam Output	MW (thermal)	0	0	0	0	0	0
Average Availability	%	91.9%	92.8%	93.8%	91.9%	92.8%	93.8%
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-licensing costs, Technical and design	£/kW	0.0	0.1	0.1	0.0	0.1	0.1
Regulatory + licensing + public enquiry	£/kW	0.0	0.0	0.0	0.0	0.0	0.0
EPC cost (excluding interest during construction) –variability only	£/kW	22.2	56.5	143.6	22.2	56.5	143.6
EPC cost (excluding interest during construction) – variability and uncertainty	£/kW	22.2	56.5	143.6	22.2	56.5	143.6
Infrastructure cost	£'000	0	0	0	0	0	0
Operating costs							
O&M fixed fee	£/MW/yr	120	240	360	120	240	360
O&M variable fee	£/MWh	0	0	0	0	0	0
Insurance	£/MW/yr	0	0	0	0	0	0
Connection and UoS charges	£/MW/yr	0	0	0	0	0	0
CO_2 transport and storage costs	£/MWh	0	0	0	0	0	0

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	1600	1600	1600	1600	1600	1600
Net Efficiency	%	29.9%	33.5%	35.5%	33.5%	35.0%	36.5%
Average Steam Output	MW (thermal)	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%	90.0%	90.0%	90.0%	90.0%
Capital costs							
Pre-licensing costs, Technical and design	£/kW	20.0	25.0	40.0	18.0	23.0	30.0
Regulatory + licensing + public enquiry	£/kW	0.2	0.2	1.7	0.2	0.2	1.7
EPC cost (excluding interest during construction) –variability only	£/kW	2723.3	3005.0	3380.6	2559.3	2824.0	3177.0
EPC cost (excluding interest during construction) – variability and uncertainty	£/kW	2404.0	3005.0	3606.0	2259.2	2824.0	3388.8
Infrastructure cost	£'000	0	7,500	15,000	0	7,500	15,000
Operating costs							
O&M fixed fee	£/MW/yr	45,990	76,211	106,432	36,291	63,509	90,727
O&M variable fee	£/MWh	2	3	3	2	2	2
Insurance	£/MW/yr	3,256	5,459	8,146	2,674	4,236	6,048
Connection and UoS charges	£/MW/yr	4,513	4,513	4,513	4,513	4,513	4,513
CO_2 transport and storage costs	£/MWh	8	12	17	8	12	17

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 Efficiency	%	29.9%	32.0%	34.2%	32.0%	33.5%	34.9%
Average Steam Output	MW (thermal)	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%	90.0%	90.0%	90.0%	90.0%
Capital costs							
Pre-licensing costs, Technical and design	£/kW	11.2	19.2	27.0	8.1	16.6	20.3
Regulatory + licensing + public enquiry	£/kW	0.0	0.0	0.2	0.0	0.0	0.2
EPC cost (excluding interest during construction) –variability only	£/kW	1654.8	1826.0	2054.3	1441.8	1591.0	1789.9
EPC cost (excluding interest during construction) – variability and uncertainty	£/kW	1460.8	1826.0	2191.2	1272.8	1591.0	1909.2
Infrastructure cost	£'000	0	0	0	0	0	0
Operating costs							
O&M fixed fee	£/MW/yr	45,990	76,211	106,432	36,291	63,509	90,727
O&M variable fee	£/MWh	2	3	3	2	2	2
Insurance	£/MW/yr	2,540	4,204	6,306	1,722	2,523	3,396
Connection and UoS charges	£/MW/yr	4,323	4,323	4,323	4,323	4,323	4,323
CO_2 transport and storage costs	£/MWh	8	12	17	8	12	17

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	6.0	7.0	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 Efficiency	%	30.9%	34.5%	36.5%	32.6%	36.0%	39.3%
Average Steam Output	MW (thermal)	0	0	0	0	0	0
Average Availability	%	89.9%	89.9%	89.9%	89.9%	89.9%	89.9%
Average Load Factor	%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
CO_2 Removal	%	90.0%	93.0%	95.0%	93.0%	95.0%	98.0%
Capital costs							
Pre-licensing costs, Technical and design	£/kW	21.0	26.9	44.0	18.0	23.0	30.0
Regulatory + licensing + public enquiry	£/kW	0.4	0.5	3.4	0.4	0.5	3.4
EPC cost (excluding interest during construction) –variability only	£/kW	2133.0	2399.0	2665.0	2031.0	2284.5	2538.00
EPC cost (excluding interest during construction) – variability and uncertainty	£/kW	1439.4	2399.0	3358.6	1370.7	2284.5	3198.3
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	2	2	3	2	2	3
Insurance	£/MW/yr	2,031	3,427	5,076	2,133	3,599	5,330
Connection and UoS charges	£/MW/yr	4,323	4,323	4,323	4,323	4,323	4,323
CO_2 transport and storage costs	£/MWh	8	12	17	8	12	17

Coal - IGCC

		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	4.0	5.0	6.0	4.0	5.0	6.0
Plant Operating Period	years	20.0	30.0	35.0	20.0	30.0	35.0
Technical data							
Net Power Output	MW	874	874	874	874	874	874
Net Efficiency	%	38.0%	40.1%	43.0%	38.0%	40.1%	43.0%
Average Steam Output	MW (thermal)	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%
CO_2 Removal	%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Capital costs							
Pre-licensing costs, Technical and design	£/kW	25.0	30.0	50.0	20.0	25.0	40.0
Regulatory + licensing + public enquiry	£/kW	0.4	0.4	2.9	0.4	0.4	2.9
EPC cost (excluding interest during construction) –variability only	£/kW	1500.0	1650.0	1800.0	1500.0	1650.0	1800.0
EPC cost (excluding interest during construction) – variability and uncertainty	£/kW	1500.0	1650.0	1800.0	1500.0	1650.0	1800.0
Infrastructure cost	£'000	0	7,500	15,000	0	7,500	15,000
Operating costs							
O&M fixed fee	£/MW/yr	39,000	51,750	68,000	39,000	51,750	68,000
O&M variable fee	£/MWh	1	1	1	1	1	1
Insurance	£/MW/yr	1,500	2,475	3,600	1,500	2,475	3,600
Connection and UoS charges	£/MW/yr	4,323	4,323	4,323	4,323	4,323	4,323
CO_2 transport and storage costs	£/MWh	0	0	0	0	0	0

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	5.0	6.0	7.0	4.5	5.5	6.5
Plant Operating Period	years	20.0	25.0	30.0	20.0	30.0	35.0
Technical data							
Net Power Output	MW	820	820	820	820	820	820
Net Efficiency	%	31.8%	33.6%	36.0%	33.3%	35.1%	37.6%
Average Steam Output	MW (thermal)	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%
CO_2 Removal	%	85.0%	88.6%	89.3%	88.6%	89.3%	90.0%
Capital costs							
Pre-licensing costs, Technical and design	£/kW	25.0	30.0	50.0	20.0	25.0	40.0
Regulatory + licensing + public enquiry	£/kW	0.4	0.5	3.4	0.4	0.5	3.4
EPC cost (excluding interest during construction) –variability only	£/kW	2078.4	2462.1	2877.8	2038.5	2374.2	2686.0
EPC cost (excluding interest during construction) – variability and uncertainty	£/kW	1477.3	2462.1	3446.9	1424.5	2374.2	3323.9
Infrastructure cost	£'000	0	7,500	15,000	0	7,500	15,000
Operating costs							
O&M fixed fee	£/MW/yr	45,733	60,684	79,740	41,398	54,932	72,181
O&M variable fee	£/MWh	2	2	3	2	2	2
Insurance	£/MW/yr	2,078	3,693	5,756	2,038	3,561	5,372
Connection and UoS charges	£/MW/yr	4,323	4,323	4,323	4,323	4,323	4,323
CO_2 transport and storage costs	£/MWh	8	12	17	8	12	17

Coal - IGCC with retro 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	757	757	757	757	757	757
Net Efficiency	%	29.9%	31.6%	33.8%	31.2%	33.0%	35.4%
Average Steam Output	MW (thermal)	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%
CO_2 Removal	%	84.3%	87.2%	88.6%	87.2%	88.6%	90.0%
Capital costs							
Pre-licensing costs, Technical and design	£/kW	14.0	23.0	33.8	9.0	18.0	27.0
Regulatory + licensing + public enquiry	£/kW	0.0	0.1	0.4	0.0	0.1	0.4
EPC cost (excluding interest during construction) –variability only	£/kW	1034.0	1189.5	1363.9	990.7	1094.2	1156.1
EPC cost (excluding interest during construction) – variability and uncertainty	£/kW	713.7	1189.5	1665.3	656.5	1094.2	1531.9
Infrastructure cost	£'000	0	0	0	0	0	0
Operating costs							
O&M fixed fee	£/MW/yr	45,733	60,684	79,740	41,398	54,932	72,181
O&M variable fee	£/MWh	2	2	3	2	2	2
Insurance	£/MW/yr	805	1,418	2,208	762	1,275	1,793
Connection and UoS charges	£/MW/yr	4,323	4,323	4,323	4,323	4,323	4,323
CO_2 transport and storage costs	£/MWh	8	12	17	8	12	17

Nuclear

		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 Efficiency	%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Average Steam Output	MW (thermal)	0	0	0	0	0	0
Average Availability	%	90.1%	91.1%	92.0%	90.1%	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-licensing costs, Technical and design	£/kW	103.6	188.3	408.0	87.8	159.6	346.2
Regulatory + licensing + public enquiry	£/kW	2.2	2.9	3.8	2.2	2.9	3.8
EPC cost (excluding interest during construction) –variability only	£/kW	3529.0	3823.5	4118.0	3000.0	3250.0	3500.0
EPC cost (excluding interest during construction) – variability and uncertainty	£/kW	3529.0	3823.5	4118.0	3000.0	3250.0	3500.0
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	3	3	3	3	3	3
Insurance	£/MW/yr	8,000	10,000	12,000	8,000	10,000	12,000
Connection and UoS charges	£/MW/yr	4,513	4,513	4,513	4,513	4,513	4,513
CO_2 transport and storage costs	£/MWh	0	0	0	0	0	0

Pumped storage

		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	3.5	4.5	5.0	3.5	4.5	5.0
Plant Operating Period	years	40.0	50.0	60.0	40.0	50.0	60.0
Technical data							
Net Power Output	MW	400	400	400	400	400	400
Net Efficiency	%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Average Steam Output	MW (thermal)	0	0	0	0	0	0
Average Availability	%	95.3%	95.8%	96.3%	95.3%	95.8%	96.3%
Average Load Factor	%	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%
CO_2 Removal	%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Capital costs							
Pre-licensing costs, Technical and design	£/kW	20.0	25.0	35.0	20.0	25.0	35.0
Regulatory + licensing + public enquiry	£/kW	0.8	0.9	6.2	0.8	0.9	6.2
EPC cost (excluding interest during construction) –variability only	£/kW	1030.0	1716.7	4721.0	1030.0	1716.7	4721.0
EPC cost (excluding interest during construction) – variability and uncertainty	£/kW	1030.0	1716.7	4721.0	1030.0	1716.7	4721.0
Infrastructure cost	£'000	8,200	12,300	16,400	8,200	12,300	16,400
Operating costs							
O&M fixed fee	£/MW/yr	10,200	12,000	14,400	10,200	12,000	14,400
O&M variable fee	£/MWh	0	0	0	0	0	0
Insurance	£/MW/yr	4,020	6,600	10,800	4,020	6,600	10,800
Connection and UoS charges	£/MW/yr	7,035	7,035	7,035	7,035	7,035	7,035
CO_2 transport and storage costs	£/MWh	0	0	0	0	0	0

Small GT based CHP

		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	2.0	2.0	3.0	2.0	2.0	3.0
Construction Period	years	1.0	1.2	1.5	1.0	1.2	1.5
Plant Operating Period	years	12.0	15.0	20.0	12.0	15.0	20.0
Technical data							
Net Power Output	MW	5	5	5	5	5	5
Net Efficiency	%	28.8%	29.3%	29.8%	28.8%	29.3%	29.8%
Average Steam Output	MW (thermal)	10	10	10	10	10	10
Average Availability	%	94.0%	94.9%	95.8%	94.0%	94.9%	95.8%
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-licensing costs, Technical and design	£/kW	66.0	76.4	99.3	66.0	76.4	99.3
Regulatory + licensing + public enquiry	£/kW	8.2	9.5	12.4	8.2	9.5	12.4
EPC cost (excluding interest during construction) –variability only	£/kW	1574.1	1839.8	2105.5	1574.1	1839.8	2105.5
EPC cost (excluding interest during construction) – variability and uncertainty	£/kW	1574.1	1839.8	2105.5	1574.1	1839.8	2105.5
Infrastructure cost	£'000	8,000	8,000	8,000	8,000	8,000	8,000
Operating costs							
O&M fixed fee	£/MW/yr	51,000	56,000	60,000	51,000	56,000	60,000
O&M variable fee	£/MWh	0	0	0	0	0	0
Insurance	£/MW/yr	4,932	7,639	10,877	4,932	7,639	10,877
Connection and UoS charges	£/MW/yr	0	0	0	0	0	0
CO_2 transport and storage costs	£/MWh	0	0	0	0	0	0

Medium GT with BP ST CHP

		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	2.0	2.0	3.0	2.0	2.0	3.0
Construction Period	years	1.0	1.5	1.8	1.0	1.5	1.8
Plant Operating Period	years	12.0	15.0	20.0	12.0	15.0	20.0
Technical data							
Net Power Output	MW	46	46	46	46	46	46
Net Efficiency	%	43.4%	44.1%	45.0%	43.4%	44.1%	45.0%
Average Steam Output	MW (thermal)	38	38	38	38	38	38
Average Availability	%	92.4%	93.3%	94.3%	92.4%	93.3%	94.3%
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-licensing costs, Technical and design	£/kW	30.3	35.0	45.5	30.3	35.0	45.5
Regulatory + licensing + public enquiry	£/kW	3.8	4.4	5.7	3.8	4.4	5.7
EPC cost (excluding interest during construction) –variability only	£/kW	716.7	838.5	960.3	716.7	838.5	960.3
EPC cost (excluding interest during construction) – variability and uncertainty	£/kW	716.7	838.5	960.3	716.7	838.5	960.3
Infrastructure cost	£'000	8,000	9,000	10,000	8,000	9,000	10,000
Operating costs							
O&M fixed fee	£/MW/yr	29,000	34,000	39,000	29,000	34,000	39,000
O&M variable fee	£/MWh	0	0	0	0	0	0
Insurance	£/MW/yr	2,262	3,503	4,988	2,262	3,503	4,988
Connection and UoS charges	£/MW/yr	3,223	3,223	3,223	3,223	3,223	3,223
CO_2 transport and storage costs	£/MWh	0	0	0	0	0	0

CCGT CHP

		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	2.0	2.3	5.0	2.0	2.3	5.0
Construction Period	years	2.0	2.5	3.0	2.0	2.5	3.0
Plant Operating Period	years	12.0	15.0	20.0	12.0	15.0	20.0
Technical data							
Net Power Output	MW	750	750	750	750	750	750
Net Efficiency	%	48.3%	49.1%	50.1%	48.3%	49.1%	50.1%
Average Steam Output	MW (thermal)	380	380	380	380	380	380
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	%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Capital costs							
Pre-licensing costs, Technical and design	£/kW	13.2	14.4	15.6	13.2	14.4	15.6
Regulatory + licensing + public enquiry	£/kW	0.4	0.5	3.5	0.4	0.5	3.5
EPC cost (excluding interest during construction) –variability only	£/kW	594.1	690.1	786.1	594.1	690.1	786.1
EPC cost (excluding interest during construction) – variability and uncertainty	£/kW	594.1	690.1	786.1	594.1	690.1	786.1
Infrastructure cost	£'000	7,000	14,500	22,000	7,000	14,500	22,000
Operating costs							
O&M fixed fee	£/MW/yr	21,631	22,661	23,691	21,631	22,661	23,691
O&M variable fee	£/MWh	0	0	0	0	0	0
Insurance	£/MW/yr	1,782	2,070	2,358	1,782	2,070	2,358
Connection and UoS charges	£/MW/yr	3,070	3,070	3,070	3,070	3,070	3,070
CO_2 transport and storage costs	£/MWh	0	0	0	0	0	0

7 APPENDIX B – MAJOR EQUIPMENT AND INTERFACES

Technology	Site interface points	Major components	Infrastructure
CCGT	Site foundations GIS substation metering on HV side of unit / station transformers Gas Receiving Facility gas intake and metering point Cooling fluid intake point and associated civil works Chemicals delivery and unloading point	Ground and civil works for a green field site GT(s), generator(s) and HRSG(s) Stack(s), ducting and pipework Steam turbine(s), generator(s) and condenser(s) Balance of plant and ancillaries Backup fuel storage tanks and delivery system Emergency generation and fuel storage GIS substation Electrical distribution system Control system	Gas pipeline, sized for plant demand, length varies with high, med low levels Tee-off substation, OHL sized for plant output, length varies with high, med low levels
OCGT	Site foundations GIS substation metering on HV side of unit / station transformers Gas Receiving Facility gas intake and metering point	Ground and civil works for a green field site GT(s), generator(s) and stack(s) Backup fuel storage tanks and delivery system GIS substation Electrical distribution system Control system	Gas pipeline, sized for plant demand, length varies with high, med low levels Tee-off substation, OHL sized for plant output, length varies with high, med low levels

Technology	Site interface points	Major components	Infrastructure
CCGT with pre-combustion CCS	Site foundations GIS substation metering on HV side of unit / station transformers Gas Receiving Facility gas intake and metering point Cooling fluid intake point and associated civil works Chemicals delivery and unloading point HP side of CO_2 compression unit	Ground and civil works for a green field site Desulphurisation unit Air separation unit Pre-reformer Reformer Shift reactor GT(s), generator(s) and HRSG(s) Stack(s), ducting and pipework Steam turbine(s), generator(s) and condenser(s) Balance of plant and ancillaries CO_2 compression unit Backup fuel storage tanks and delivery system Emergency generation and fuel storage GIS substation Electrical distribution system Control system	Gas pipeline, sized for plant demand, length varies with high, med low levels Tee-off substation, OHL sized for plant output, length varies with high, med low levels Pipeline and storage to be included as “CO_2 transport and storage cost”
CCGT with post-combustion CCS	Site foundations GIS substation metering on HV side of unit / station transformers Gas Receiving Facility gas intake and metering point Cooling fluid intake point and associated civil works Chemicals delivery and unloading point HP side of CO_2 compression unit	Ground and civil works for a green field site GT(s), generator(s) and HRSG(s) Stack(s), ducting and pipework Steam turbine(s), generator(s) and condenser(s) Balance of plant and ancillaries Capture plant CO_2 compression unit Backup fuel storage tanks and delivery system GIS substation Electrical distribution system Control system	Gas pipeline, sized for plant demand, length varies with high, med low levels Tee-off substation, OHL sized for plant output, length varies with high, med low levels Pipeline and storage to be included as “CO_2 transport and storage cost”

Technology	Site interface points	Major components	Infrastructure
CCGT with retrofit post-combustion CCS	Capture plant foundations Interface to flue gas from HRSG Interface to steam exit from the steam cycle Interface to feed water return to the steam cycle Extension to chemicals delivery and unloading point HP side of CO_2 compression unit Substation or auxiliaries board extension Interface to control system modifications	Ground and civil works for the capture plant for a green field site Stack(s), ducting and pipework for the capture plant and interfacing Balance of plant and ancillaries modifications Capture plant CO_2 compression unit Modifications to chemicals delivery and unloading area Electrical distribution system modifications including extension of substation or auxiliaries board Control system modifications Modifications or replacement of LP turbine	Pipeline and storage to be included as "CO_2 transport and storage cost"
CCGT with oxyfuel CCS	Site foundations GIS substation metering on HV side of unit / station transformers Gas Receiving Facility gas intake and metering point Cooling fluid intake point and associated civil works Chemicals delivery and unloading point HP side of CO_2 compression unit	Ground and civil works for a green field site Desulphurisation unit Air separation unit Oxyfuel GT(s) Generator(s) and HRSG(s) Stack(s), ducting and pipework Steam turbine(s), generator(s) and condenser(s) Balance of plant and ancillaries Flue gas treatment CO_2 processing/treatment unit CO_2 compression unit Backup fuel storage tanks and delivery system Emergency generation and fuel storage GIS substation Electrical distribution system Control system	Gas pipeline, sized for plant demand, length varies with high, med low levels Tee-off substation, OHL sized for plant output, length varies with high, med low levels Pipeline and storage to be included as "CO_2 transport and storage cost"

Technology	Site interface points	Major components	Infrastructure
ASC Coal with FGD	Site foundations GIS substation metering on HV side of unit / station transformers Rail on site spur and unloading facility Cooling fluid intake point and associated civil works Chemicals delivery and unloading point Ash removal from site	Ground and civil works for a green field site Fuel handling and processing equipment Boiler(s) FGD plant and Flue gas cleaning plant Stack(s), ducting and pipework Steam turbine(s), generator(s) and condenser(s) Balance of plant and ancillaries Ash handling system Emergency generation and fuel storage GIS substation Electrical distribution system Control system	Rail spur, length varies with high, med low levels Tee-off substation, OHL sized for plant output, length varies with high, med low levels
ASC Coal with FGD and post-combustion CCS	Site foundations GIS substation metering on HV side of unit / station transformers Rail on site spur and unloading facility Cooling fluid intake point and associated civil works Chemicals delivery and unloading point HP side of CO_2 compression unit Ash removal from site	Ground and civil works for a green field site Fuel handling and processing equipment Boiler(s) FGD plant and Flue gas cleaning plant Stack(s), ducting and pipework Steam turbine(s), generator(s) and condenser(s) Balance of plant and ancillaries Capture plant CO_2 compression unit Ash handling system Emergency generation and fuel storage GIS substation Electrical distribution system Control system	Rail spur, length varies with high, med low levels Tee-off substation, OHL sized for plant output, length varies with high, med low levels Pipeline and storage to be included as “CO_2 transport and storage cost”

Technology	Site interface points	Major components	Infrastructure
ASC Coal with FGD and oxy-fuel CCS	Site foundations GIS substation metering on HV side of unit / station transformers Rail on site spur and unloading facility Cooling fluid intake point and associated civil works Chemicals delivery and unloading point HP side of CO_2 compression unit Ash removal from site	Ground and civil works for a green field site Fuel handling and processing equipment Boiler(s) FGD plant and Flue gas cleaning plant Stack(s), ducting and pipework Steam turbine(s), generator(s) and condenser(s) Balance of plant and ancillaries Air separation unit Flue gas treatment CO_2 processing/treatment unit CO_2 compression unit Ash handling system Emergency generation and fuel storage GIS substation Electrical distribution system Control system	Rail spur, length varies with high, med low levels Tee-off substation, OHL sized for plant output, length varies with high, med low levels Pipeline and storage to be included as “CO_2 transport and storage cost”
ASC Coal with FGD and retrofit post-combustion CCS	Capture plant foundations Interface to flue gas from boiler(s) Interface to steam exit from the steam cycle Interface to feed water return to the steam cycle Extension to chemicals delivery and unloading point HP side of CO_2 compression unit Substation or auxiliaries board extension Interface to control system modifications	Ground and civil works for the capture plant for a green field site Stack, ducting and pipework for the capture plant and interfacing Balance of plant and ancillaries modifications Capture plant CO_2 compression unit Modifications to chemicals delivery and unloading area Electrical distribution system modifications including extension of substation or auxiliaries board Control system modifications Modifications or replacement of LP turbine	Pipeline and storage to be included as “CO_2 transport and storage cost”

Technology	Site interface points	Major components	Infrastructure
IGCC	Site foundations GIS substation metering on HV side of unit / station transformers Rail on site spur and unloading facility Cooling fluid intake point and associated civil works Chemicals delivery and unloading point Ash removal from site	Ground and civil works for a green field site Fuel handling and processing equipment Gasification boiler(s) [or separate gasifier(s) and boiler(s)] Gas cleaning plant GT(s), generator(s) and HRSG(s) Stack(s), ducting and pipework Steam turbine(s), generator(s) and condenser(s) Balance of plant and ancillaries Ash handling system Backup fuel storage tanks and delivery system Emergency generation and fuel storage GIS substation Electrical distribution system Control system	Rail spur, length varies with high, med low levels Tee-off substation, OHL sized for plant output, length varies with high, med low levels

Technology	Site interface points	Major components	Infrastructure
IGCC with CCS	Site foundations GIS substation metering on HV side of unit / station transformers Rail on site spur and unloading facility Cooling fluid intake point and associated civil works Chemicals delivery and unloading point HP side of CO_2 compression unit Ash removal from site	Ground and civil works for a green field site Fuel handling and processing equipment Gasification boiler(s) [or separate gasifier(s) and boiler(s)] Air separation unit Reformer Shift reactor Gas cleaning plant GT(s), generator(s) and HRSG(s) Stack(s), ducting and pipework Steam turbine(s), generator(s) and condenser(s) Balance of plant and ancillaries CO_2 compression unit Ash handling system Backup fuel storage tanks and delivery system Emergency generation and fuel storage GIS substation Electrical distribution system Control system	Rail spur, length varies with high, med low levels Tee-off substation, OHL sized for plant output, length varies with high, med low levels Pipeline and storage to be included as "CO_2 transport and storage cost"
IGCC with retrofit CCS [retrofit pre-comb capture to IGCC]	Capture plant foundations Extension to chemicals delivery and unloading point HP side of CO_2 compression unit Steam extraction to reformer Substation or auxiliaries board extension Interface to control system modifications Interface to gas cleaning plant modifications	Ground and civil works for the capture plant for a green field site Stack(s), ducting and pipework for the capture plant and interfacing Reformer Gas cleaning plant modifications Balance of plant and ancillaries modifications Capture plant CO_2 compression unit Electrical distribution system modifications including extension of substation or auxiliaries board Control system modifications Modifications to steam cycle or separate steam boiler	Pipeline and storage to be included as "CO_2 transport and storage cost"

Technology	Site interface points	Major components	Infrastructure
GT based CHP	Site foundations Gas Receiving Facility gas intake and metering point Generator circuit breaker Steam ducting to site boundary	Ground and civil works for a green field site GT, generator and HRSG with DB Stack, ducting and pipework Balance of plant and ancillaries Electrical distribution system Control system	Gas pipeline, sized for plant demand, length varies with high, med low levels
GT with back pressure steam turbine CHP	Site foundations GIS substation metering on HV side of unit / station transformers [to grid or private wire] Gas Receiving Facility gas intake and metering point Cooling fluid intake point and associated civil works Steam ducting to site boundary	Ground and civil works for a green field site GT, generator and HRSG Stack, ducting and pipework Balance of plant and ancillaries Emergency generation and fuel storage GIS substation Electrical distribution system Control system	Gas pipeline, sized for plant demand, length varies with high, med low levels
CCGT CHP	Site foundations GIS substation metering on HV side of unit / station transformers Gas Receiving Facility gas intake and metering point Cooling fluid intake point and associated civil works Chemicals delivery and unloading point Steam ducting to site boundary	Ground and civil works for a green field site GT(s), generator(s) and HRSG(s) Stack(s), ducting and pipework Steam turbine(s), generator(s) and condenser(s) Balance of plant and ancillaries Backup fuel storage tanks and delivery system Emergency generation and fuel storage GIS substation Electrical distribution system Control system	Gas pipeline, sized for plant demand, length varies with high, med low levels Tee-off substation, OHL sized for plant output, length varies with high, med low levels

Technology	Site interface points	Major components	Infrastructure
Pumped storage	Site foundations GIS substation metering on HV side of unit / station transformers	Ground and civil works for a green field site Reservoirs Turbines and generators Ducting and pipework GIS substation Electrical distribution system Control system	Tee-off substation, OHL sized for plant output, length varies with high, med low levels
Nuclear	Site foundations GIS substation metering on HV side of unit / station transformers Cooling fluid intake point and associated civil works Fuel unloading point from rail Chemicals delivery and unloading point Waste loading point onto rail	Ground and civil works for a green field site Fuel handling and processing equipment PWR reactors Reactor cooling system Ducting and pipework Steam turbines, generators and condensers Balance of plant and ancillaries Emergency generation and fuel storage GIS substation Electrical distribution system Control system	Tee-off substation, OHL sized for plant output, length varies with high, med low levels
SCR / SNCR retrofit	Extension of chemicals delivery and unloading point Interface to boiler modifications	Boiler modifications Catalyst system [for SCR only]	

8 APPENDIX C – ASSUMED DEVELOPMENT AND LICENSING ACTIVITIES

Technology	Pre-licensing, technical and design	Regulatory, licensing and public enquiry
CCGT	Site identification Feasibility study Programme development Technology review and selection Grid connection assessment Gas connection assessment Market analysis Development of contractual agreements Financial modelling and analysis Specification development Tender and procure	Planning or s36 consent preparation/submission EIA preparation Site surveys/assessments to support EIA (ecology, noise, air pollution, flood risk, visual impact etc.) Environmental permit application preparation/submission Environmental permit fees Stakeholder liaison Revision of proposals (if required by planning) Submissions to/attendance at public enquiry (if applicable)
OCGT	Site identification Feasibility study Programme development Technology review and selection Grid connection assessment Gas connection assessment Market analysis Development of contractual agreements Financial modelling and analysis Specification development Tender and procure	Planning or s36 consent preparation/submission EIA preparation Site surveys/assessments to support EIA (ecology, noise, air pollution, flood risk, visual impact etc.) Environmental permit application preparation/submission Environmental permit fees Stakeholder liaison Revision of proposals (if required by planning) Submissions to/attendance at public enquiry (if applicable)

Technology	Pre-licensing, technical and design	Regulatory, licensing and public enquiry
CCGT with pre-combustion CCS	Site identification Feasibility study Programme development Technology review and selection Grid connection assessment Gas connection assessment Market analysis Development of contractual agreements FEED study Financial modelling and analysis Specification development Tender and procure	Planning or s36 consent preparation/submission EIA preparation Site surveys/assessments to support EIA (ecology, noise, air pollution, flood risk, visual impact etc.) Environmental permit application preparation/submission Environmental permit fees Stakeholder liaison Revision of proposals (if required by planning) Submissions to/attendance at public enquiry (if applicable) CO_2 transport and storage application and permitting
CCGT with post-combustion CCS	Site identification Feasibility study Programme development Technology review and selection Grid connection assessment Gas connection assessment Market analysis Development of contractual agreements FEED study Financial modelling and analysis Specification development Tender and procure	Planning or s36 consent preparation/submission EIA preparation Site surveys/assessments to support EIA (ecology, noise, air pollution, flood risk, visual impact etc.) Environmental permit application preparation/submission Environmental permit fees Stakeholder liaison Revision of proposals (if required by planning) Submissions to/attendance at public enquiry (if applicable) CO_2 transport and storage application and permitting

Technology	Pre-licensing, technical and design	Regulatory, licensing and public enquiry
CCGT with retrofit post-combustion CCS	Feasibility study Programme development Technology review and selection Development of contractual agreements FEED study Financial modelling and analysis Specification development Tender and procure	Planning or s36 consent preparation/submission EIA preparation Site surveys/assessments to support EIA (ecology, noise, air pollution, flood risk, visual impact etc.) Environmental permit application preparation/submission Environmental permit fees Revision of proposals (if required by planning) Submissions to/attendance at public enquiry (if applicable) CO_2 transport and storage application and permitting
CCGT with oxyfuel CCS	Site identification Feasibility study Programme development Technology review and selection Grid connection assessment Gas connection assessment Market analysis Development of contractual agreements FEED study Financial modelling and analysis Specification development Tender and procure	Planning or s36 consent preparation/submission EIA preparation Site surveys/assessments to support EIA (ecology, noise, air pollution, flood risk, visual impact etc.) Environmental permit application preparation/submission Environmental permit fees Stakeholder liaison Revision of proposals (if required by planning) Submissions to/attendance at public enquiry (if applicable) CO_2 transport and storage application and permitting

Technology	Pre-licensing, technical and design	Regulatory, licensing and public enquiry
ASC Coal with FGD	Site identification Feasibility study Programme development Technology review and selection Grid connection assessment Fuel sourcing analysis Ash disposal study Limestone sourcing study Market analysis Development of contractual agreements Financial modelling and analysis Specification development Tender and procure	Planning or s36 consent preparation/submission EIA preparation Site surveys/assessments to support EIA (ecology, noise, air pollution, flood risk, visual impact etc.) Environmental permit application preparation/submission Environmental permit fees Stakeholder liaison Revision of proposals (if required by planning) Submissions to/attendance at public enquiry (if applicable)
ASC Coal with FGD and post-combustion CCS	Site identification Feasibility study Programme development Technology review and selection Grid connection assessment Fuel sourcing analysis Ash disposal study Limestone sourcing study Market analysis Development of contractual agreements FEED study Financial modelling and analysis Specification development Tender and procure	Planning or s36 consent preparation/submission EIA preparation Site surveys/assessments to support EIA (ecology, noise, air pollution, flood risk, visual impact etc.) Environmental permit application preparation/submission Environmental permit fees Stakeholder liaison Revision of proposals (if required by planning) Submissions to/attendance at public enquiry (if applicable) CO_2 transport and storage application and permitting

Technology	Pre-licensing, technical and design	Regulatory, licensing and public enquiry
ASC Coal with FGD and oxy-fuel CCS	Site identification Feasibility study Programme development Technology review and selection Grid connection assessment Fuel sourcing analysis Ash disposal study Limestone sourcing study Market analysis Development of contractual agreements FEED study Financial modelling and analysis Specification development Tender and procure	Planning or s36 consent preparation/submission EIA preparation Site surveys/assessments to support EIA (ecology, noise, air pollution, flood risk, visual impact etc.) Environmental permit application preparation/submission Environmental permit fees Stakeholder liaison Revision of proposals (if required by planning) Submissions to/attendance at public enquiry (if applicable) CO_2 transport and storage application and permitting
ASC Coal with FGD and retrofit post-combustion CCS	Feasibility study Programme development Technology review and selection Development of contractual agreements FEED study Financial modelling and analysis Specification development Tender and procure	Planning or s36 consent preparation/submission EIA preparation Site surveys/assessments to support EIA (ecology, noise, air pollution, flood risk, visual impact etc.) Environmental permit application preparation/submission Environmental permit fees Revision of proposals (if required by planning) Submissions to/attendance at public enquiry (if applicable) CO_2 transport and storage application and permitting

Technology	Pre-licensing, technical and design	Regulatory, licensing and public enquiry
IGCC	Site identification Feasibility study Programme development Technology review and selection Grid connection assessment Fuel Sourcing Analysis Market analysis Development of contractual agreements Ash handling assessment Financial modelling and analysis Specification development Tender and procure	Planning or s36 consent preparation/submission EIA preparation Site surveys/assessments to support EIA (ecology, noise, air pollution, flood risk, visual impact etc.) Environmental permit application preparation/submission Environmental permit fees Stakeholder liaison Technology licence agreement/preparation/negotiation Technology licence fees (if applicable at this stage) Revision of proposals (if required by planning) Submissions to/attendance at public enquiry (if applicable)
IGCC with CCS	Site identification Feasibility study Programme development Technology review and selection Grid connection assessment Fuel Sourcing Analysis Market analysis Development of contractual agreements Ash handling assessment FEED study Financial modelling and analysis Specification development Tender and procure	Planning or s36 consent preparation/submission EIA preparation Site surveys/assessments to support EIA (ecology, noise, air pollution, flood risk, visual impact etc.) Environmental permit application preparation/submission Environmental permit fees Stakeholder liaison Technology licence agreement/preparation/negotiation Technology licence fees (if applicable at this stage) Revision of proposals (if required by planning) Submissions to/attendance at public enquiry (if applicable) CO_2 transport and storage application and permitting

Technology	Pre-licensing, technical and design	Regulatory, licensing and public enquiry
IGCC with retrofit CCS [retrofit pre-comb capture to IGCC]	Feasibility study Programme development Technology review and selection Development of contractual agreements FEED study Financial modelling and analysis Specification development Tender and procure	Planning or s36 consent preparation/submission EIA preparation Site surveys/assessments to support EIA (ecology, noise, air pollution, flood risk, visual impact etc.) Environmental permit application preparation/submission Environmental permit fees Revision of proposals (if required by planning) Submissions to/attendance at public enquiry (if applicable) CO_2 transport and storage application
GT based CHP	Site identification Feasibility study Programme development Heat customer search and engagement Development of contractual agreements Financial modelling and analysis Specification development Tender and procure	Local planning process Site surveys/assessments (ecology, noise, air pollution, flood risk, visual impact etc.) Environmental permit application preparation/submission Environmental permit fees CHPQA qualification preparation/submission Stakeholder liaison Revision of proposals (if required by planning) Submissions to/attendance at public enquiry (if applicable)

Technology	Pre-licensing, technical and design	Regulatory, licensing and public enquiry
GT with back pressure steam turbine CHP	Site identification Feasibility study Programme development Heat customer search and engagement Grid connection assessment Gas connection assessment Market analysis Development of contractual agreements Financial modelling and analysis Specification development Tender and procure	Planning or s36 consent preparation/submission EIA preparation Site surveys/assessments to support EIA (ecology, noise, air pollution, flood risk, visual impact etc.) Environmental permit application preparation/submission Environmental permit fees CHPQA qualification preparation/submission Stakeholder liaison Revision of proposals (if required by planning) Submissions to/attendance at public enquiry (if applicable)
CCGT CHP	Site identification Feasibility study Programme development Heat customer search and engagement Technology review and selection Grid connection assessment Gas connection assessment Market analysis Development of contractual agreements Financial modelling and analysis Specification development Tender and procure	Planning or s36 consent preparation/submission EIA preparation Site surveys/assessments to support EIA (ecology, noise, air pollution, flood risk, visual impact etc.) Environmental permit application preparation/submission Environmental permit fees CHPQA qualification preparation/submission Stakeholder liaison Revision of proposals (if required by planning) Submissions to/attendance at public enquiry (if applicable)

Technology	Pre-licensing, technical and design	Regulatory, licensing and public enquiry
Pumped storage	Site identification Feasibility study Programme development Technology review and selection Grid connection assessment Market analysis Development of contractual agreements Financial modelling and analysis Specification development Tender and procure	Planning or s36 consent preparation/submission EIA preparation Site surveys/assessments to support EIA (ecology, noise, air pollution, flood risk, visual impact etc.) Environmental permit application preparation/submission Environmental permit fees Stakeholder liaison Revision of proposals (if required by planning) Submissions to/attendance at public enquiry (if applicable)
Nuclear	Site identification Feasibility study Programme development Technology review and selection Grid connection assessment Fuel sourcing analysis Market analysis Development of contractual agreements Financial modelling and analysis Specification development Tender and procure Safety systems design	Planning or s36 consent preparation/submission EIA preparation Site surveys/assessments to support EIA (ecology, noise, air pollution, flood risk, visual impact etc.) Environmental permit application preparation/submission Environmental permit fees Stakeholder liaison Revision of proposals (if required by planning) Submissions to/attendance at public enquiry (if applicable)
SCR / SNCR retrofit	Feasibility study Programme development Technology review and selection Outline design Tender and procure	

9 APPENDIX D – ASSUMED OPERATIONS AND MAINTENANCE ACTIVITIES

	not applicable
	Fixed
	Variable
	Part Fixed part variable

Item No.		CCGT	CCGT + pre comb. CCS	CCGT + post comb. CCS	CCGT + oxy-fuel CCS	OCGT	CCGT + retrofit CCS	ASC with FGD
1	Supplementary / start-up fuel							
2	Long term service agreement							
3	Boiler Chemicals							
4	Water - plant							
5	Water - staff							
6	Water cooling	Only if have to pay for cooling water	Only if have to pay for cooling water	Only if have to pay for cooling water	Only if have to pay for cooling water		Only if have to pay for cooling water	Only if have to pay for cooling water
7	spare parts							
8	Staff and admin							
9	Hydrogen	If hydrogen cooled generators	If hydrogen cooled generators	If hydrogen cooled generators	If hydrogen cooled generators		If hydrogen cooled generators	
10	Input electricity	Proportional to non running hours	Proportional to non running hours	Proportional to non running hours	Proportional to non running hours	Proportional to non running hours	Proportional to non running hours	Proportional to non running hours
11	Pre combustion CCS chemicals							
12	Post combustion chemicals							
13	FGD chemicals							
14	Transport of CO_2							
15	Ash disposal							Net sum of processing costs and re-sale value assumed zero
16	Fuel handling	Dependant on if back up oil fired	Dependant on if back up oil fired	Dependant on if back up oil fired	Dependant on if back up oil fired	Dependant on if back up oil fired	Dependant on if back up oil fired	
17	Consumables							
18	Limestone							Dependant on FGD type
19	COB bed							
20	Nuclear waste storage							
21	Nuclear waste disposal							
22	IG chemicals							
23	Chemicals disposal / recycle							
24	Slurry/solids disposal							
25	Steam treatment chemicals							
26	Effluent treatment / sewerage charges	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible
27	Business Rates							
28	Insurance							
29	Transport Costs							
30	SCADA							
31	Asset replacement costs							
32	Community Benefits							

Item No.		ASC with FGD + post comb. CCS	ASC with FGD + oxy-fuel CCS	ASC + retrofit CCS	Retrofit of SCR / SNCR	IGCC	IGCC + CCS	IGCC + retrofit CCS
1	Supplementary / start-up fuel							
2	Long term service agreement				Incremental cost of SCR / NSCR			
3	Boiler Chemicals				catalyst only			
4	Water - plant							
5	Water - staff							
6	Water cooling	Only if have to pay for cooling water	Only if have to pay for cooling water	Only if have to pay for cooling water		Only if have to pay for cooling water	Only if have to pay for cooling water	Only if have to pay for cooling water
7	spare parts							
8	Staff and admin							
9	Hydrogen					If hydrogen cooled generators	If hydrogen cooled generators	If hydrogen cooled generators
10	Input electricity	Proportional to non running hours	Proportional to non running hours	Proportional to non running hours		Proportional to non running hours	Proportional to non running hours	Proportional to non running hours
11	Pre combustion CCS chemicals							
12	Post combustion chemicals							
13	FGD chemicals							
14	Transport of CO_2							
15	Ash disposal	Net sum of processing costs and re-sale value assumed zero	Net sum of processing costs and re-sale value assumed zero	Net sum of processing costs and re-sale value assumed zero		Net sum of processing costs and re-sale value assumed zero	Net sum of processing costs and re-sale value assumed zero	Net sum of processing costs and re-sale value assumed zero
16	Fuel handling							
17	Consumables							
18	Limestone	Dependant on FGD type	Dependant on FGD type	Dependant on FGD type				
19	COB bed							
20	Nuclear waste storage							
21	Nuclear waste disposal							
22	IG chemicals							
23	Chemicals disposal / recycle							
24	Slurry/solids disposal							
25	Steam treatment chemicals							
26	Effluent treatment / sewerage charges	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible
27	Business Rates							
28	Insurance							
29	Transport Costs							
30	SCADA							
31	Asset replacement costs							
32	Community Benefits							

Item No.		Nuclear	GT based CHP	GT and back pressure steam turbine CHP	CCGT CHP	Pumped storage
1	Supplementary / start-up fuel					
2	Long term service agreement					
3	Boiler Chemicals					
4	Water - plant					
5	Water - staff					
6	Water cooling	Only if have to pay for cooling water	Only if have to pay for cooling water	Only if have to pay for cooling water	Only if have to pay for cooling water	
7	spare parts					
8	Staff and admin					
9	Hydrogen				If hydrogen cooled generators	
10	Input electricity	Proportional to non running hours	Proportional to non running hours	Proportional to non running hours	Proportional to non running hours	Proportional to non running hours
11	Pre combustion CCS chemicals					
12	Post combustion chemicals					
13	FGD chemicals					
14	Transport of CO_2					
15	Ash disposal					
16	Fuel handling		Dependant on if back up oil fired	Dependant on if back up oil fired	Dependant on if back up oil fired	
17	Consumables					
18	Limestone					
19	COB bed					
20	Nuclear waste storage					
21	Nuclear waste disposal					
22	IG chemicals					
23	Chemicals disposal / recycle					
24	Slurry/solids disposal					
25	Steam treatment chemicals					
26	Effluent treatment / sewerage charges	Negligible	Negligible	Negligible	Negligible	Negligible
27	Business Rates					
28	Insurance					
29	Transport Costs					
30	SCADA					
31	Asset replacement costs					
32	Community Benefits					

10 APPENDIX E – FLOW DIAGRAM FOR THE FORWARD PRICING MODEL

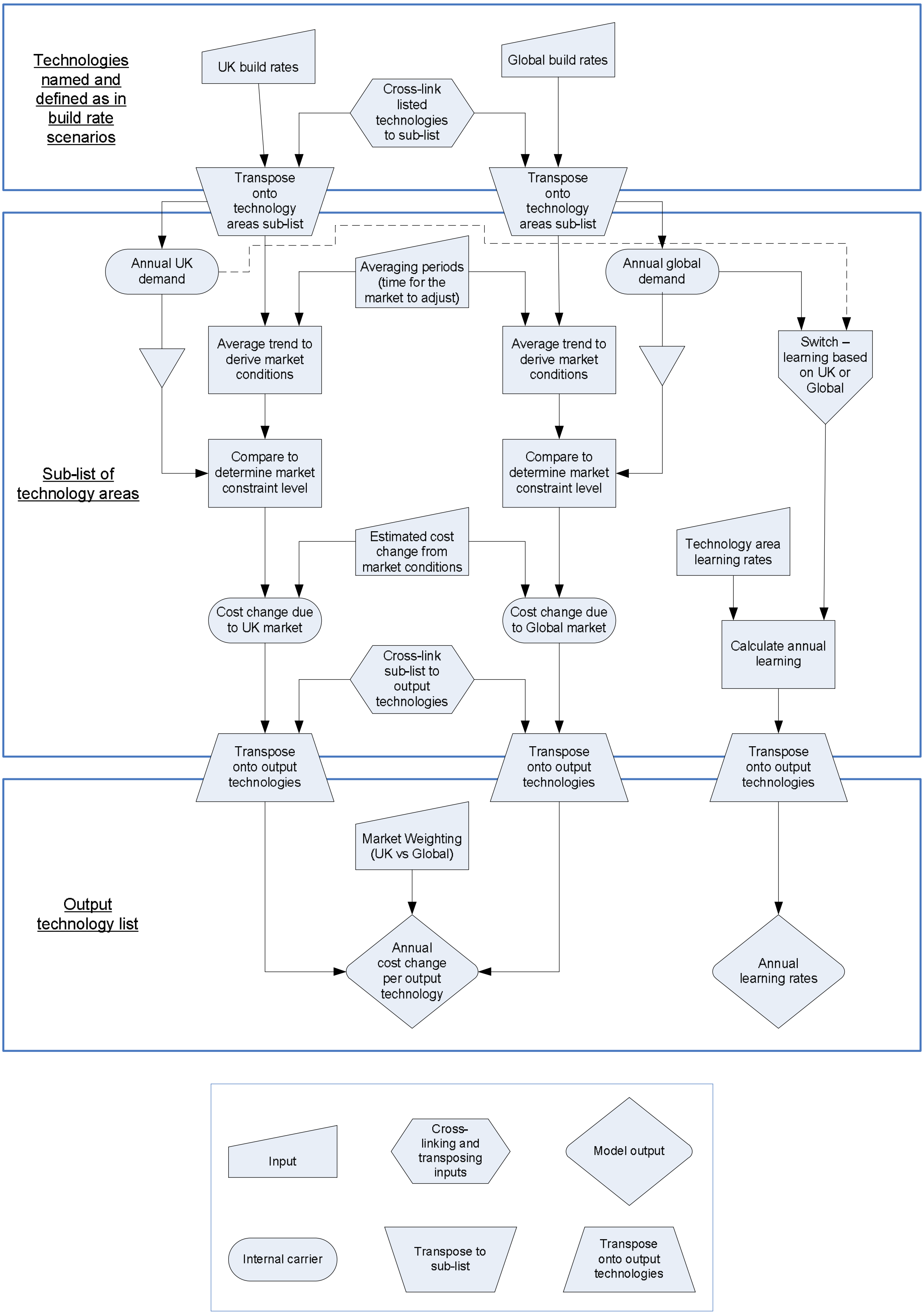

Figure 4 – Flow diagram for the Forward Pricing Model

11 APPENDIX F – INTERPRETATION NOTES AND MODEL LIMITATIONS

11.1 Model Limitations

11.1.1 Cost of Risks and Liabilities

The model does not take account of the risks or liabilities created or mitigated by specific design options. The associated cost impact cannot therefore be included in the analysis as this would skew the overall result.

11.1.2 Linked Parameters and Parameter Definition

The values for each level of each parameter were required to appear in arithmetical order. This meant that if a direct relationship existed between two parameters, a high parameter would have to be modelled with a corresponding high parameter. If an inverse relationship existed between two parameters; a high parameter would have to be modelled with a low parameter. These inter-connections between parameters which often reflect trade-offs that are optimised during the development phase of a project were not an inherent function of the model. Inputs were therefore chosen such that any combination of input levels would be valid by basing values on the expected variation of a single plant configuration. This however resulted in the exclusion of more unusual, but potentially viable plant configurations.

> An example of this was CCGT with post combustion capture. The information gathered related to the technology in its current conception. However there is evidence that performance could be improved through the recirculation of flue gases within the system. This would give a higher efficiency at a lower cost than the current central estimates, however the analysis would only be valid if each parameter was aligned (i.e. medium efficiency with low cost and high power output). Any other combination would lead to an invalid result. This configuration was therefore not represented within the model inputs.

Further limitations were introduced by the format of parameters required for certain inputs, which could not be altered without significant intrusions into the mathematics and workings of the model. Category names and unit choices also lead to some difficulties when manipulating raw data to fit within the model.

11.2 Retro-Fitted Plant

The retro-fit of a plant at some point prior to the end of the original economic life generally affects performance in a detrimental manner. In the case of retro-fitting post combustion capture, steam flows are altered and additional auxiliaries are required. No value was attributed within the modelling methodology to the lost revenues caused by this reduction in output. Additional fuel was however accounted for by a change in efficiency.

Further more, no value was attributed to the base plant. This may affect the validity of comparisons to other technologies.

11.3 Effects of Heat Load Characteristics

Heat loads are bespoke to each plant and a function of the customer's demand, and so could not be rationalised using any internal plant parameters expressed as input parameters from the Levelised Cost of Electricity Model. The model inputs presented for each CHP technology were therefore only valid for the plant configuration and heat load characteristics assumed.

In order to evaluate the intrinsic cost, performance and variability of parameters for each CHP technology, variability in parameters from reference projects resulting solely from differing heat loads would have to be identified and removed; however without detailed models of each plant this was not possible.

The assumed plant configuration for each CHP technology was designed to a certain physical size, absolute cost and fuel demand. The actual heat to power ratio could be varied by the extraction of varying quantities of steam (resulting in different power outputs) without significant impact on the physical size and therefore cost of the plant. The levelised costs were therefore highly sensitive to the choice of heat to power ratio.

The following figures illustrate the effect of the choice of heat to power ratio on the levelised costs. The solid line(s) on each graph represent potential design points for the plant. The dashed lines show the boundary of "good quality CHP" and the dotted lines indicate constant heat to power ratios.

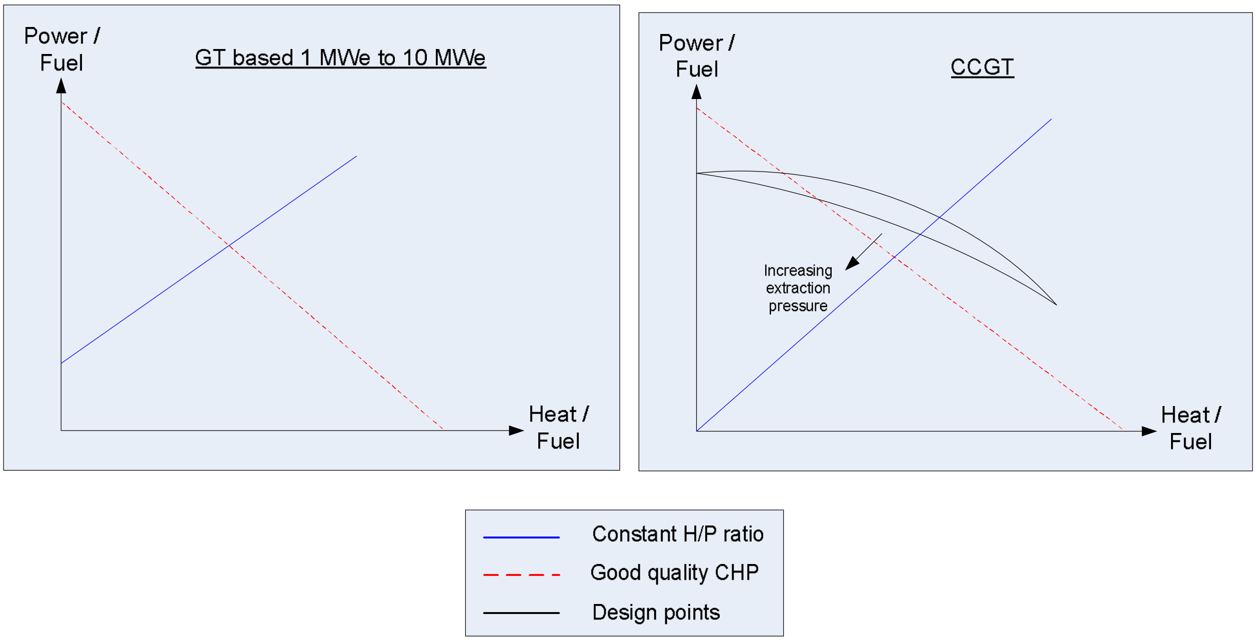

Figure 5 – Choice of heat and power

In the above cases, the levelised cost would vary approximately linearly and positively with increasing heat to power ratio.

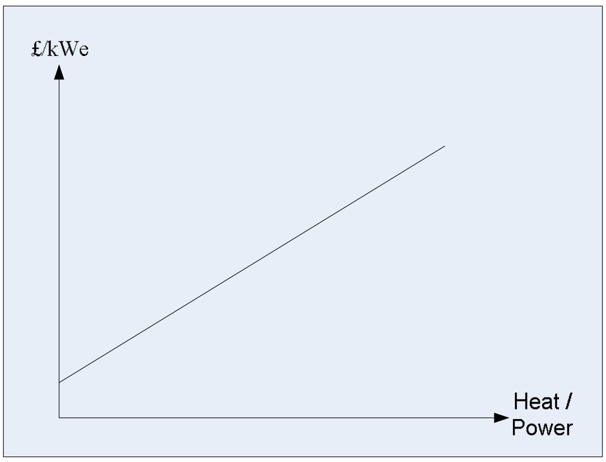

Figure 6 – Effect of heat to power ratio of levelised cost

The problem could also be viewed from the point of comparing two plants with the same electrical output. One may have a small heat load and one may have a large heat load. The plant with the larger heat load would have a significantly higher capital cost for the same electrical output, and therefore a higher levelised cost. The avoided gas boiler cost methodology would not fully cancel out additional costs of the higher heat load because the avoided boiler cost would be less than the additional cost of supplying the heat.

The heat load of a CHP plant varies with time. For specified loads, it is sometimes appropriate to model seasonal conditions, day and night conditions, or some other time split depending on the customer. The Levelised Cost Model only deals with annual average data. The design point of the plant was therefore assumed to represent the average steady state operation of the plant.

The avoided gas boiler cost methodology assumed that revenues from heat were available for the first ten years of the operational life (i.e. the owner can secure a contract for off-take of hear for ten years). This was appropriate up until the end of this ten year period, after which it was implied that the heat load would no longer be available. If this were the expected case in reality, the plant would continue operation at a higher electrical output and higher electrical efficiency with no heat extraction. The model does not account for this change of operating regime.