PARSONS BRINCKERHOFF

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ELECTRICITY GENERATION COSTS MODEL – 2013 UPDATE OF RENEWABLE TECHNOLOGIES

Department of Energy and Climate Change

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Final

Electricity Generation Costs Model – 2013 Update of Renewable Technologies

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CONTENTS

LIST OF ABBREVIATIONS

ACT	Advanced Conversion Technologies (Pyrolysis and Gasification)
AD	Anaerobic Digestion
CAPEX	Capital Expenditure
CCS	Carbon Capture and Storage
CFB	Circulating Fluidised Bed
CHP	Combined Heat and Power
DECC	Department of Energy and Climate Change
DNO	Distribution Network Operator
EfW	Energy from Waste
FOAK	First Of A Kind
HHV	Higher Heating Value
HP	High Pressure
kV	Kilo Volt
kW	Kilo Watt
LHV	Lower Heating Value
LP	Low Pressure
MW	Mega Watt
MWh	Mega Watt Hour
NOAK	Nth Of A Kind
O&M	Operation and Maintenance
OEM	Original Equipment Manufacturer
RO	Renewables Obligation

EXECUTIVE SUMMARY

This report provides the supporting information behind the 2013 update of the cost and technical evidence used by the Department of Energy and Climate Change for renewable technologies. New evidence was gathered and compared to the Baseline Dataset.

The first two sections provide general information about the background of the study and the scope of the work undertaken by Parsons Brinckerhoff. Following these, the detailed methodology is presented which provides information about the limitations experienced and the assumptions made. The main focus of the report is an analysis of the methods and assumptions used to update the cost and technical inputs. The main parameters of technical data, capital costs and operation and maintenance (O&M) costs are discussed in full.

The report concludes by giving an overview of each technology, in terms of the notable updates and key reasons behind these updates. The current state of the technology and any expected future changes are also discussed.

In summary, the new evidence gathered supported the Baseline Dataset and no updates were recommended.

A summary of the cost assumptions and technical inputs assessed has been included in the appendices of the report.

1 INTRODUCTION

1.1.1 Parsons Brinckerhoff was contracted by the Department of Energy and Climate Change (DECC) in December 2012 to undertake an update of the evidence underpinning the Renewables Obligation Banding Review Dataset. The Dataset (available in Appendix A) was used by DECC for the Renewables Obligation Banding Review carried out in 2012. For the purposes of this study, this dataset was considered as a baseline against which new evidence was compared and is therefore referred to in this report as the Baseline Dataset. The Baseline Dataset consists of pre-development, construction and fixed and variable O&M costs for numerous renewable technologies. The dataset also contains efficiency values for fuelled technologies and is assumed to be representative of plants that are likely to reach commissioning between 2016 and 2020; i.e. under the first round of Electricity Market Reform.

1.1.2 The aim of this study was to collect any new evidence that has come to light since the last data gathering exercise (completed in January 2012) which was used to develop the Baseline Dataset. The current view of generation costs and performance was assessed for projects that are currently in development and/or are expected to be commissioned in the period 2016 to 2020. This new evidence either corroborated the underpinning evidence used to develop the Baseline Dataset or represented a change in market conditions. It was intended that the Baseline Dataset would be updated for any changes identified, thus ensuring that the Baseline Dataset was accurate and forward-looking and therefore remained a suitable basis on which to base energy policy and planning decisions.

1.1.3 Evidence gathering was mainly focused on pre-development and construction costs because the capital cost is the largest cost driver for non-fuelled technologies and because data for these parameters was readily comparable to the Baseline Dataset. Evidence on efficiencies and O&M costs was also gathered and compared to the Baseline Dataset where available. New evidence for additional parameters such as project key timings, insurance costs, use of system costs and infrastructure costs where available (and stratified from the main parameters) was reviewed and provided to DECC as stand-alone data sets.

2 SCOPE

2.1 Technologies

2.1.1 The technologies covered within this study were:

- Onshore wind >5MW
- Onshore wind re-powering*
- Offshore wind Round 2
- Offshore wind Round 3
- Biomass conversion
- Enhanced co-firing
- Dedicated biomass <50MW
- Dedicated biomass >50MW
- Dedicated biomass with CCS*
- Dedicated biomass CHP
- Standard co-firing
- Co-firing with CHP
- Hydro >5MW without storage
- Geothermal
- AD
- Advanced ACT
- Standard ACT
- Energy from Waste
- Energy from Waste CHP

2.2 Parameters

2.2.1 A range of cost and performance parameters were investigated by Parsons Brinckerhoff and were classified under the following areas:

- Timings – the development, construction and operational periods

* Technologies not included in previous analyses.

- Technical data – plant heat and power output, efficiency
- 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 CO2 disposal and decommissioning where appropriate.

2.2.2 Comparisons were drawn between new evidence and the Baseline Dataset for the following parameters:

- Pre-development cost (£/kW)
- Construction cost (£/kW)
- Fixed O&M cost (£/MW/year)
- Variable O&M cost (£/MWh)
- Net efficiency (%)

2.2.3 It should be noted that cost of capital (i.e. financing and interest during construction) assumptions were not reviewed as part of this study.

3 METHODOLOGY

3.1 General Methodology

3.1.1 Parsons Brinckerhoff approached the update of the evidence base supporting the Baseline Dataset for projects commissioning in 2016/17 onwards from an analytical perspective, relying on real project data (when available) and modelling to augment data into a form suitable for comparison with the Baseline Dataset. Where there was no new evidence, or where new evidence did not constitute a significant change from the Baseline Dataset, the Baseline Dataset was considered current and no update was recommended.

3.1.2 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. Additionally, the net heat and power outputs were assumed to be those indicated as reference values from the Baseline Dataset. This facilitated a cross-reference with the underlying assumptions for the Baseline Dataset to ensure consistency of approach and therefore the validity of comparisons.

3.1.3 The scope of the study required that the focus was on new evidence relating to cost and technical inputs that has come to light since January 2012 and is also applicable to projects that may reach commissioning between 2016 and 2020. The study intended to capture data from new projects that may not have been included in the evidence incorporated in the 'Government response to the consultation on proposals for the levels of banded support under the Renewables Obligation for the period 2013-17 and the Renewables Obligation Order 2012'[1]. The potential size of the data pool was therefore highly limited.

3.1.4 In terms of project specific variation, the Baseline Dataset appears to include a large cost range. This is because the Baseline Dataset looks at a range which incorporates the full technical potential of each technology, indicating that some more difficult projects have been considered. Therefore, the aim of the data collection was to encapsulate a wide range of projects at the development stage so that this data range can be investigated.

3.2 Treatment of Input Levels

3.2.1 The Baseline Dataset includes a high, medium and low level for capital cost data. The difference in high, medium and low capital costs therefore represented the variability in costs caused by variation in design, planning and regulatory difficulties, risk mitigation, physical site characteristics and choice of contractor or manufacturer.

3.3 Treatment of FOAK and NOAK

3.3.1 Previous cost studies undertaken by Parsons Brinckerhoff and others have included data presented for FOAK and for NOAK projects. In order to preserve a consistent approach to the presentation of data between the Baseline Dataset and the 2013 update, no FOAK / NOAK distinction was made for renewable technologies. However, an exception to this rule was made for Biomass CCS so that the presented

[1] Department of Energy and Climate Change. *Government response to the consultation on proposals for the levels of banded support under the Renewables Obligation for the period 2013-17 and the Renewables Obligation Order 2012*, July 2012

data is consistent with the Electricity Generation Cost Model – 2013 Update of Non-renewable Technologies[2].

3.4 Parameters

Key Timings

3.4.1 The period (in years) required for pre-development, construction and operation for each technology was generally based on projects that are currently being commissioned and industry expectations of how these timings may vary for projects reaching completion between 2016 and 2020.

Power, Heat and Efficiency

3.4.2 As in the Baseline Dataset, the capacity of each technology was presented as net output values. The power output given was assumed to be representative of the costed projects. However, in general, experience shows that the costs per MW of capacity over the ranges presented may also be applicable to plant sizes between 50% and 200% of the stated power output. A single net output for each technology was presented across the high, medium and low input levels to avoid the potential for miscalculation.

3.4.3 Heat outputs were also presented on a net output basis.

3.4.4 Efficiency values were presented as net values based on the lower heating value of the input fuel.

Capital and O&M Costs

3.4.5 Capital and O&M cost data for well understood technologies with reasonable data availability represented observed market costs relating to each technology. Modelled costs based on industry estimates were utilised for immature technologies those with limited data availability. Whether evidence was based on observed data or modelled costs is identified in Section 4 for each technology.

3.5 Technical and Cost Modelling

3.5.1 Where possible, cost and performance data was based on new evidence gathered from developers.

3.5.2 Technical and cost modelling was also undertaken where necessary using the Thermoflow software suite. 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.

3.6 Assessment Criteria

3.6.1 As part of the scope of work, the data collected was assessed to see whether it could be incorporated into the Baseline Dataset. The data collected, if any, was discussed under the following headings:

[2] Parsons Brinckerhoff. *Electricity Generation Cost Model – 2013 Update of Non-Renewable Technologies*, April 2013

- Technology Description
- Sources of New Data
- Presentation of New Data
- Comparison to Baseline Dataset
- Suggestions for Incorporation of New Data

3.6.2 In order to determine if the Baseline Dataset should be updated, new evidence that represented a significant change to the ranges expressed in the Baseline Dataset was identified. For construction costs, a significant change was defined by Parsons Brinckerhoff as a difference of more than 30% between any capital cost level suggested by new evidence and the corresponding level in the Baseline Dataset. A variation of less than 30% could not be attributed to a market change with any level of confidence due to the uncertainly in data. Once such variances were identified, an update was only recommended if the difference could not be explained by any potential difference in approach or underlying assumptions.

3.6.3 For other parameters, a higher threshold of 60% was utilised due to the inherent uncertainty in the factors covered by such parameters.

4 RESULTS

4.1 Onshore Wind >5MW

Technology Description

4.1.1 Wind power generation uses the kinetic energy in moving atmospheric air to rotate turbine blades, thereby driving a generator in the nacelle. In addition to the on-site construction activities, grid extension and re-enforcement works can be included in the costs of the technology.

4.1.2 The technology is relatively mature and exists across a range of scales. The system design and rated capacity are selected based on the site size and wind resource.

Sources of New Data

4.1.3 Three respondents provided information for this study, and out of those, only two provided new data on pre-development, construction and O&M costs.

4.1.4 The main reason behind developers not participating in the study was that developers and industry stakeholders stated that they have recently provided the same or similar information to DECC in response to its Call for Evidence on onshore wind costs in the UK and to National Grid to support the development of strike prices under EMR.

Presentation of New Data

4.1.5 New evidence indicated a pre-development cost range of 22 £/kW to 72 £/kW and a construction cost range of 1,160 £/kW to 1,600 £/kW. The medium fixed O&M cost quoted was 16,000 £/MW/year and the medium variable O&M cost quoted was 4 £/MWh.

Comparison to Baseline Dataset

4.1.6 The limited data provided for the analysis is insufficient to form robust comparisons with the Baseline Dataset; however the pre-development cost range closely matches the Baseline Dataset and the construction cost varies from the Baseline Dataset by up to an 11% reduction. Fixed and variable O&M costs varied from the Baseline Dataset by +7% and +33% from respectively.

Suggestions for Incorporation of New Data

4.1.7 The limited amount of new evidence collected corroborates the Baseline Dataset as any statistical differences between the new evidence and the Baseline Dataset for capital cost elements are not significant. The difference in variable O&M costs of 33% cannot be assumed to be indicative of a market change due to the uncertainty in how O&M costs are calculated.

4.1.8 There is also an insufficient total amount of data to support a change to the Baseline Dataset. It is recommended therefore that the new evidence is incorporated into the evidence base supporting the dataset.

4.2 Onshore Re-powering

Technology Description

4.2.1 After the operational lifetime of a wind farm, developers may choose to 'repower' the site. This usually involves replacing the older wind turbines with higher capacity machines that are considerably larger. This would likely require new layouts, foundations and ground works, higher rated electrical components and potentially a new grid connection and regulatory agreements such as planning permission.

Sources of New Data

4.2.2 Due to the issues outlined in paragraph 4.1.4 with regards to the collection of wind data, there was very little written quantitative or qualitative information to base analysis on, with only one unqualified and unsupported quantitative response and one qualitative response.

Presentation of New Data

4.2.3 The quantitative response suggested that the capital cost of re-powering could be up to 28.5% lower than that of a new build site and that operational costs would be the same as for a new build site. This information however was based on a 5 MW project and therefore unlikely to be representative of the majority of projects in the >5 MW category.

4.2.4 The qualitative source however stated that a re-powering project would have the same costs as a new build. The rationale behind this statement was that re-powering an onshore wind farm requires a new planning application, including the supporting Environmental Statement.

4.2.5 If a re-powering project were to utilise larger turbines, existing infrastructure may not be suitably rated and consequently may require replacement. If there would be an increase in the overall wind farm capacity, a new grid connection would be required, as well as new foundations, access tracks and potentially a completely new layout due to the larger, higher capacity turbines.

4.2.6 The existing turbines may have value on the second hand turbine market, or could be sold as scrap. Some parts of the turbines may also be salvageable. However, if these options are not available to the developer, decommissioning costs would be incurred. It was stated that the potential costs and revenues from these processes are likely to cancel each other out.

Comparison to Baseline Dataset

4.2.7 Not applicable as onshore re-powering was not presented in the Baseline Dataset.

Suggestions for Incorporation of New Data

4.2.8 We recommend that until evidence of onshore wind re-powering improves, the cost of re-powering is assumed to be similar to the cost of new build. This assumption however should be re-investigated frequently in order to adequately track progress within this technology.

4.3 Offshore Round 2 and Round 3

Technology Description

4.3.1 Offshore wind generation in deep water environments consists of several major components including tower, nacelle, three blades, foundations, inter-array cabling, electrical equipment, control systems and ancillary equipment. An electrical connection to the onshore grid via sub-sea cable and onshore substation is also required.

Sources of New Data

4.3.2 After consultation with industry, no sources of new data were provided.

4.3.3 However, two developers stated that any offshore wind data supplied to support the recent banding review would also be representative of projects that could reach commissioning between 2016 and 2020.

Suggestions for Incorporation of New Data

4.3.4 We received no new information or data to challenge the Baseline Dataset.

4.4 Biomass Conversion

Technology Description

4.4.1 Coal can be replaced by biomass to fuel large conventional thermal power plant. If the plant is converted to run on 100% biomass then the plant is termed a “biomass conversion”. Some modifications to the boiler and fuel handling system may be required.

Sources of New Data

4.4.2 Parsons Brinckerhoff contacted all fossil fuel generators in the UK to investigate potential biomass conversion costs and performance.

4.4.3 Although there are two 100% conversion projects underway there was not sufficient supporting evidence to analyse how these projects would affect the Baseline Dataset. Due to the commercial sensitivity of the projects however, Parsons Brinkerhoff was unable to obtain the real cost data for either project at this stage. It is the author’s belief that data for one of the projects will be made available in the future once the project has been fully executed.

4.4.4 A published estimate of the capital cost range for one UK project was therefore utilised and supported by a confidential estimate that was found to be in line.

Presentation of New Data

4.4.5 The capital costs for biomass conversion were found to be in the range of 300 £/kW, to 360 £/kW. A breakdown or evidence of the basis or constituents of the estimates was not provided by the sources. Therefore, whilst it is likely that the estimates cover construction and development costs, the development activities included and the plant configuration were unknown.

Comparison to Baseline Dataset

4.4.6 The capital cost range (pre-development plus construction) stated in the Baseline Dataset was 328 £/kW to 808 £/kW. The Baseline Dataset however combined data for Biomass conversion and Biomass enhanced co-firing (levelised on the basis of the renewable component only).

4.4.7 The capital cost range derived for this study was in line with the lower end of the Baseline Dataset and therefore corroborates the Baseline Dataset.

Suggestions for Incorporation of New Data

4.4.8 As there was a significantly limited amount of real project data gathered and the evidence provided supported the lower end of the Baseline Dataset (likely to represent full conversion projects), there was no basis on which to update the Baseline Dataset.

4.5 Enhanced Co-Firing

Technology Description

4.5.1 Coal and biomass are burned together in the same boiler. The extent to which this occurs is measured by the ratio of the energy content of the biomass fuel to the total energy content of the biomass fuel and the coal fuel. If the energy content of the biomass is greater than 50% of the total energy of the fuel, then the plant is termed "enhanced co-firing". When converting to enhanced co-firing, significant additional fuel handling and processing equipment is required so that the biomass remains segregated from the coal until the boiler feeders for measurement purposes. Some modifications to the boiler, ash handling system and flue gas treatment system may also be required for optimisation purposes and to control emissions.

Sources of New Data

4.5.2 Following consultation with the main UK generators, only one project is looking to take advantage of the RO banding for enhanced co-firing. The project at Eon Ironbridge will seek to co-fire 90% wood pellets with 10% coal. Parsons Brinkerhoff requested information for the project but did not receive a response.

Suggestions for Incorporation of New Data

4.5.3 There is no new information or data to challenge the Baseline Data set.

4.6 Dedicated Biomass <50 MW

Technology Description

4.6.1 Biomass is a mature technology that involves burning biomass in a boiler to produce steam. The steam then passes through a steam turbine which drives a generator to generate electricity. For this study, dedicated biomass plants were separated in size. This section deals with the smaller plants, with a capacity below 50 MW.

Sources of New Data

4.6.2 It was discovered that one dedicated biomass project has progressed within the development stage and aims to begin commissioning in 2017/2018. Despite a request for data, the developer declined to share information with Parsons Brinckerhoff at this time.

4.6.3 From discussions with OEMs and from Parsons Brinckerhoff's experience of working with biomass developers, a continuous trend of falling boiler costs and enhanced boiler performance leading to significant efficiency savings was identified.

4.6.4 Parsons Brinckerhoff therefore developed a thermal model using parameters that were considered to be representative of projects likely to reach commissioning in 2016 and beyond in order to verify the efficiency value in the Baseline Dataset. The following design parameters were used:

- High pressure steam of 130 bara and 540 ºC
- Circulating fluidised bed boiler
- Net power = 34 MW

<u>Presentation of New Data</u>

4.6.5 From the thermal modelling described above, the updated efficiency was calculated as 33.4%.

<u>Comparison to Baseline Dataset</u>

4.6.6 It is expected that new projects will have improvements in efficiency and reductions in capital costs compared to the Baseline Dataset due to changes in boiler and fuel handling costs and boiler performance. Such improvements would apply to both dedicated biomass and biomass with CHP.

4.6.7 The calculated net efficiency of 33.4% is higher than the 31% stated within the Baseline Dataset. This is potentially because the efficiency value stated within the Baseline Dataset is based on a plant with high pressure steam conditions that are lower than those detailed above and / or due to a difference in the assumed fuel composition and moisture content.

<u>Suggestions for Incorporation of New Data</u>

4.6.8 Using thermal modelling and expected boiler performance for projects currently under development, the technical parameters can be updated, although under current cost assumptions the change in levelised costs is expected to be less than £5 per MWh. As mentioned above however, there is no new cost evidence to challenge the Baseline Dataset.

4.7 Dedicated Biomass >50 MW

<u>Technology Description</u>

4.7.1 As previously mentioned in paragraph 4.6.1, dedicated biomass plants were separated into two categories by their capacity. This section investigates plant sizes that are above 50 MW.

Sources of New Data

4.7.2 There was no new information relating to projects that could reach commissioning in 2016 to 2020 for biomass projects larger than 50 MW due to the limited deployment of the technology at this scale.

Suggestions for Incorporation of New Data

4.7.3 There is no new information or data to challenge the Baseline Data set.

4.8 Dedicated Biomass Combined Heat and Power (CHP)

Technology Description

4.8.1 Biomass CHP is a mature technology that involves burning biomass in a boiler to produce steam. The steam then passes through a steam turbine which drives a generator to generate electricity. To provide heat, some steam is extracted from the turbine at an intermediate stage at the pressure suitable for the heat load.

Sources of New Data

4.8.2 There was no new information relating to projects that could reach commissioning in 2016 to 2020. However, in order to ensure consistency across similar technologies within the Baseline Dataset, a comparison case was derived using the cost parameters for Dedicated Biomass >50 MW and thermal modelling based on plant heat and power outputs that matched those used for the development of the Baseline Dataset.

4.8.3 A thermal model for a biomass CHP plant with the design parameters described below was initially developed. This was then utilised to calculate the electrical output of an equivalent sized (and therefore equivalent cost) power only plant. This electrical output was then multiplied by each cost parameter from the dedicated biomass >50 MW case to give absolute costs. Each absolute cost was then re-levelised on the basis of the electrical output of the modelled CHP plant.

4.8.4 As mentioned previously in paragraph 4.6.4, there is a trend in increasing boiler efficiencies, which was also accounted for by the thermal modelling.

4.8.5 A Thermoflow model of a Dedicated Biomass CHP plant was conducted with the following parameters:

- High pressure steam of 130 bara and 540ºC
- Circulating fluidised bed boiler
- Net power = 62 MW
- Net heat = 2.3 (Heat to power ratio) x 62 = 142.6 MW
- Extraction pressure = 11.4 bara (superheated)

Presentation of New Data

4.8.6 From the thermal modelling carried out by Parsons Brinckerhoff, the updated net LHV electrical efficiency was calculated as 21.3%.

4.8.7 The low, medium and high pre-development costs were calculated as 27 £/kW, 52 £/kW and 63 £/kW respectively.

4.8.8 The capital cost values for low, medium and high were 3,323 £/kW, 4,153 £/kW and 7,642 £/kW respectively.

4.8.9 Fixed O&M cost was to 159,484 £/MW/year, and variable cost was 7.31 £/MWh.

Comparison to Baseline Dataset

4.8.10 The calculated net efficiency of 21.3% is higher than the 20% stated within the Baseline Dataset.

4.8.11 As there is no data provided within the Baseline Dataset for pre development costs, no stratified comparison can be made. The pre-development and construction costs presented above were therefore summed in order to compare capital costs on a like for like basis.

4.8.12 The calculated low and medium capital cost data for Biomass CHP were 24% and 8% higher than the Baseline Dataset values of 2,700 £/kW and 3,900 £/kW.

4.8.13 The calculated high capital cost was 54% higher than the Baseline Dataset value of 5,000 £/kW.

4.8.14 The Baseline Dataset quotes values for fixed and variable O&M as 150,000 £/MW/year and 9.7 £/MWh. The fixed O&M cost from the remodelling of the Dedicated Biomass >50MW was 6% higher than the Baseline Data and the variable fee was 38.6% lower.

Suggestions for Incorporation of New Data

4.8.15 The close correlation of the modelled efficiency and that used in the Baseline Dataset supports the notion that the heat, power and efficiency values as a set are coherent. Additionally, a variance in efficiency of 1.3 percentage points would have limited impact on levelised cost calculations.

4.8.16 With the exception of the high capital cost, the variation between the Baseline Dataset and parameters calculated above by modelling were considered to be small. The central capital cost values are similar and therefore the central capital cost value was supported by Parsons Brinckerhoff's modelling.

4.8.17 The variation between the high capital cost and that in the Baseline Dataset could be due to widely varying heat to power ratios across supporting evidence for the Baseline Dataset. Because of the uncertainty in the heat to power ratios used in the Baseline Dataset supporting evidence, a direct comparison could not be undertaken and a change was not justifiable.

4.9 Standard Co-Firing

Technology Description

4.9.1 Coal can be supplemented by biomass to fuel large conventional power plant. If the energy from biomass constitutes less than 20% of the total energy in the fuel then the plant is termed "standard co-firing".

Sources of New Data

4.9.2 Following consultation with most UK fossil fuel generating stations, there are no stations with current plans to undertake standard co-firing that haven't already done so. There is however potential for this to change in the future.

Suggestions for Incorporation of New Data

4.9.3 There is no new information or data to challenge the Baseline Data set.

4.10 Co-Firing with CHP

Technology Description

4.10.1 This technology includes a number of potential plant configurations that could technically be developed (under agreeable economic and commercial circumstances). Such configuration involve either co-firing of biomass with other fossil fuels in a single boiler that supplies steam or the addition of a small biomass boiler that would deliver low grade heat used either as feed water heating or delivered directly to the heat customer.

Sources of New Data

4.10.2 After consulting industry, no new evidence was forthcoming with regards to co-firing plants with CHP due to the highly limited uptake of the plant configurations described in paragraph 4.10.1.

Suggestions for Incorporation of New Data

4.10.3 There is no new information or data to challenge the Baseline Data set.

4.11 Dedicated Biomass with CCS

Technology Description

4.11.1 Early biomass plants with CCS are most likely to incorporate post combustion capture as this is the simplest and most commercialised type of carbon capture technology and is likely to be the easiest to adapt from coal to biomass. For post combustion, the flue gases from a biomass plant are directed into an absorber vessel in which they react with a liquid base solvent, usually amine, which absorbs typically around 90% of the carbon dioxide (CO_2) in the flue gases. The CO_2 is removed from the solvent in a stripping column, then dehydrated, 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 heat required for the stripping column. This incurs an energy penalty (efficiency loss) in the steam cycle.

4.11.2 Results and discussion for Biomass with CCS have been included within this report as well as the Parsons Brinckerhoff's Electricity Generation Costs Model – 2013 Update of Non-renewable Technologies[2]. The motivation for inclusion of Biomass CCS within this report was to enable comparison with other Biomass technologies.

Sources of New Data

4.11.3 After contacting industry stakeholders in the attempt to collect data, no information on biomass with CCS was forthcoming. The evidence base for Biomass plants with CCS is highly limited due to the technology being relatively new. Therefore the CCS portion from coal plants with post combustion CCS was remodelled with large scale biomass data to provide indicative cost evidence and performance parameters.

4.11.4 To give an approximation of the costs of a biomass CCS project, the incremental increase in capital costs and fixed and variable O&M costs attributable to a post combustion capture plant were derived from coal with post combustion capture projects[2]. These values were then scaled based on the relative CO_2 flow rates from a biomass plant with post combustion capture and a coal plant with post combustion capture and re-levelised on the output of the biomass with post combustion capture. The re-levelised costs attributed to the capture plant was then added to the accepted Baseline Dataset values for >50 MW Dedicated Biomass.

4.11.5 Through this method, the costs for Biomass with CCS have been calculated as commercial projects, and not demonstration projects. However, as Biomass with CCS is an immature technology, and as data was difficult to obtain, there is increased uncertainty with the estimated costs.

Presentation of New Data

4.11.6 Costs associated with the capture plant were derived on a "first of a kind" (FOAK) and "n^{th} of a kind" (NOAK) basis.

4.11.7 The FOAK low, medium and high construction costs were calculated as 3,512 £/kW, 4,055 £/kW and 6,357 £/kW respectively.

4.11.8 The FOAK fixed O&M costs were calculated as 96,031 £/MW/year, 96,052 £/MW/year and 96,071 £/MW/year for the low, medium and high respectively. Due to the addition of the medium Baseline Dataset value for dedicated biomass to the high, medium and low O&M values for the capture plant, the range reflects potential variation in O&M fixed costs for the capture plant only. At the time of this study, only the medium O&M values were available to Parsons Brinckerhoff.

4.11.9 The FOAK variable O&M cost was estimated at 4 £/MWh.

4.11.10 The NOAK low, medium and high capital costs were calculated as 3,054 £/kW, 3,663 £/kW and 5,909 £/kW respectively.

4.11.11 The NOAK fixed O&M costs were calculated as 96,021 £/MW/year, 96,037 £/MW/year and 96,061 £/MW/year for the low, medium and high respectively. As described in paragraph 4.11.8 in relation to the FOAK values, the range of NOAK values should also be viewed as representative of the variation in the fixed O&M costs associated with the capture plant only.

4.11.12 The NOAK variable O&M cost was estimated at 4 £/MWh.

Comparison to Baseline Dataset

4.11.13 A comparison is not applicable as Dedicated Biomass with CCS was not assessed in Baseline Dataset.

Suggestions for Incorporation of New Data

4.11.14 Due to the limited evidence available and the basic nature of the analysis undertaken, a significant margin of uncertainty should be placed on all parameters. Therefore, both FOAK and NOAK values should be considered as indicative only.

4.12 Hydro >5 MW without storage

Technology Description

4.12.1 Hydroelectric generation uses the pressure head available from water changing height to drive a turbine and generate electricity. Cost and technical parameters are very site specific, with the capacity and system design depending on the flow and difference in height available at a specific site. A range of different turbine types are used depending on the characteristics of different sites.

Sources of New Data

4.12.2 There are currently no new hydro projects above 5 MW under development, or expected to be commissioned by 2016/17. Only pumped storage projects are being considered currently.

Suggestions for Incorporation of New Data

4.12.3 Due to the lack of development within the UK, there is no evidence to suggest that the current Baseline Dataset figures for projects commissioning in 2016/17 onwards need to be altered.

4.13 Geothermal

Technology Description

4.13.1 Electricity generation from geothermal sources is an established technology in other parts of the world and uses drilling to access underground steam resources which can be used to drive a steam turbine. This technology however is restricted to more geologically active areas of the world and is not suitable for the UK. Making use of geothermal heat to generate electricity where no such steam resources exist requires a different approach, for example by engineering a deep underground heat exchanger. This technology has been in the demonstration phase for a number of years on projects in Europe and elsewhere and, although now beginning to be deployed more widely, is still a relatively immature technology.

4.13.2 The well depths required in the UK to get the necessary temperatures for power generating geothermal (above 120ºC) are at depths greater than 3000 m. Drilling at these depths presents significant challenges to the commercial viability of geothermal projects in the current market.

Sources of New Data

4.13.3 There are a small number of projects with planning permission but which are not underway. It is unlikely that one or more of these plants will be commissioned by 2016/17. There is therefore no new evidence; however DECC are commissioning a feasibility study on the potential of deep geothermal power in the UK which is likely to conclude by summer 2013.

Suggestions for Incorporation of New Data

4.13.4 There is no new information or data to challenge the Baseline Data set.

4.14 Anaerobic Digestion

Technology Description

4.14.1 Anaerobic Digestion (AD) is a biological process whereby naturally occurring microbes break down waste material in the absence of oxygen to produce biogas. Biogas is a mixture of primarily methane and carbon dioxide and is suitable for combustion to produce heat and electricity.

4.14.2 Feed stocks for AD are materials that are putrescible including animal slurries and litter, waste from the food and fodder industries, residuals from beverage production, abattoir waste, green material (e.g. grass cuttings, leaves), purpose grown energy crops, vegetable waste and wastes from households. Inert impurities (such as wood, metal, plastic, glass and aggregates) and chemicals that may harm the process (such as biocides, antibiotics and fossil fuels) are not suitable for AD.

4.14.3 The basic unit operations include feedstock preparation where high liquid content slurry is produced; this is then pumped to the digestion tank. Here the substrate is stirred and heated in a controlled environment, material is typically added and removed continually with a residence time of several weeks. During this period biogas is produced and removed from the top of the digester. The product is biogas which is either burnt to produce heat for the process only or sent to a Combined Heat and Power (CHP) engine to produce heat and electricity. The processed material (digestate) is sent to a storage tank from which it can be collected and spread to land as a fertiliser.

Sources of New Data

4.14.4 Following consultation with industry, Parsons Brinckerhoff was unable to obtain any new sources of data for anaerobic digestion plants above 2 MW.

Suggestions for Incorporation of New Data

4.14.5 There is no new information or data to challenge the Baseline Data set.

4.15 Standard ACT

Technology Description

4.15.1 ACT is the use of gasification or pyrolysis to convert biomass or waste feed stocks into a fuel gas that can then be used to produce electricity. Standard ACT is defined by the use of combustion within a boiler to raise steam that is passed to a steam turbine.

Sources of New Data

4.15.2 Data collected by Parsons Brinckerhoff in mid-2012 from one developer was utilised and covered numerous projects currently under development. The data provided was based on gross power output and was therefore rebased to be on a net power output basis for comparison to the Baseline Dataset. The output of the base case plant was also increased from 8 MW to 15 MW so that the data was consistent with the Baseline Dataset.

Presentation of New Data

4.15.3 The net LHV efficiencies of investigated projects ranged from 16.4% to 19.1%.

4.15.4 The pre-development costs ranged from 302 £/kW to 417 £/kW.

4.15.5 The construction costs including related infrastructure ranged from 7,318 £/kW to 8,374 £/kW.

4.15.6 The average fixed and variable O&M costs were 446,428 £/MW/year and 22.1 £/MWh.

Comparison to Baseline Dataset

4.15.7 The average net efficiency was calculated as 17.4% which is lower than the 22% noted in the Baseline Dataset. There is potential that the efficiency value within the Baseline Dataset does not account for all auxiliary loads associated with fuel processing. The calculated result of 17.4% accounts for fuel processing and is in line with current performance data. This figure may improve in the future.

4.15.8 The predevelopment costs came to an average of 358 £/kW. This value is -0.6% below the mid-value of the Baseline Dataset.

4.15.9 The average capital cost data came to 7,919 £/kW. All data points are in between the medium and high values of the Baseline Dataset.

4.15.10 The average fixed O&M cost was 3.7% higher than the 430,000 £/MW/year stated in the Baseline Dataset. The average variable O&M cost was 9.1% lower than the 24 £/MWh quoted in the Baseline Dataset.

Suggestions for Incorporation of New Data

4.15.11 New evidence was only available from a single developer and may therefore only cover a narrow range of possible technology options or configurations. However, comfort can be drawn from the close correlation between the cost data and the banding dataset.

4.15.12 It is recommended that the new cost evidence is incorporated into the supporting evidence base for the Baseline Dataset due to the close correlation of the new evidence and the Baseline Dataset.

4.15.13 Further work is required to ascertain the extent to which fuel processing is accounted for in the Baseline Dataset efficiency value.

4.16 Advanced ACT

Technology Description

4.16.1 ACT is the use of gasification or pyrolysis to convert biomass or waste feed stocks into a fuel gas that can then be used to produce electricity. Advanced ACT is defined by the use of internal combustion, such as a gas engine or gas turbine, to generate electricity.

Sources of New Data

4.16.2 Data collected by Parsons Brinckerhoff in mid-2012 from three developers was utilised, although a complete data set was not provided. As with Standard ACT, data supplied was based on gross power output and was therefore rebased to be on a net power output basis for comparison to the Baseline Dataset.

4.16.3 An additional confidential data source was also considered. The cost data provided by this source is consistent with Baseline Dataset.

4.16.4 It was expected that there would be insufficient information on fuel cells, and therefore these were excluded from the analysis.

Presentation of New Data

4.16.5 The average efficiency for the remodelled existing PB data was calculated as 25.5%.

4.16.6 One capital cost data point was available at 9,353 £/kW.

Comparison to Baseline Dataset

4.16.7 The efficiency of 25.5% is in line with the efficiency of 26% quoted in the Baseline Dataset.

4.16.8 The capital cost was 26.2% higher than the high value of 6,900 £/kW presented in the Baseline Dataset.

Suggestions for Incorporation of New Data

4.16.9 The efficiency is consistent with the Baseline Dataset, providing evidence that no change is required.

4.16.10 Since the capital cost is based on one data point from one source, there is a lack of confidence with this value, and suggests a change in the Baseline Dataset is not required.

4.17 Energy from Waste and Energy from Waste CHP

Technology Description

4.17.1 Energy from waste is a mature technology that involves burning mixed waste in a boiler to produce steam. The steam then passes through a steam turbine which drives a generator to generate electricity. When utilised as CHP, the low grade heat that is emitted from the steam turbine or higher grade heat that is extracted at an intermediary pressure is delivered directly to a heat customer.

Sources of New Data

4.17.2 No new information relating to projects that could reach commissioning in 2016 to 2020 for energy from waste and energy from waste CHP was discovered. The small number of projects that are currently under development are likely to have been included within the Baseline Dataset.

4.17.3 Due to the maturity of the technology, costs and technical parameters are likely to vary little.

Suggestions for Incorporation of New Data

4.17.4 There is no new information or data to challenge the Baseline Data set. The Baseline Data set is therefore considered valid and up to date.

5 APPENDIX A – SUMMARY OF TECHNOLOGY INPUT ASSUMPTIONS

Cost/parameter	**Pre-development costs**			**Construction costs**						**Fixed O&M**		**Variable O&M**		**Efficiency**
Units	**£/kW**			**£/kW**						**£/MW/year**		**£/MWh**		**%**
Commissioning year	**All years**			**2016/17**			**2017/18**			**2016/17**	**2017/18**	**2016/17**	**2017/18**	**All years**
	L	**M**	**H**	**L**	**M**	**H**	**L**	**M**	**H**	**M**	**M**	**M**	**M**	**M**
Onshore wind >5MW [1]	21	32	110	1,200	1,500	1,800	1,200	1,500	1,800	15,000	15,000	3.00	3.00	NA
Offshore wind R2 [2]	46	70	120	2,000	2,300	2,700	2,000	2,300	2,700	63,000	61,000	1.50	1.50	NA
Offshore wind R3	49	100	150	2,500	2,900	3,500	2,500	2,900	3,500	71,000	67,000	*Included in fixed*		NA
Biomass conversion and enhanced co-firing	58	58	58	270	440	750	260	430	740	41,000	41,000	1.40	1.40	36%
Dedicated biomass <50MW	38	96	110	2,500	3,600	5,100	2,500	3,500	5,000	110,000	110,000	5.30	5.30	31%
Dedicated biomass >50MW	16	31	38	2,000	2,500	4,600	2,000	2,400	4,500	96,000	96,000	4.40	4.40	36%
Dedicated biomass CHP [3]	*Included in construction*			2,700	3,900	5,000	2,700	3,800	5,000	150,000	150,000	9.70	9.60	20% [4]
Standard co-firing	2	5	7	40	120	170	40	120	160	10,000	10,000	1.30	1.30	37%
Co-firing with CHP [3]	*Included in construction*				4,300			4,300		260,000	260,000	2.20	2.20	20% [4]
Hydro >5MW without storage		53			3,100			3,100		44,000	44,000	*Included in fixed*		NA
Geothermal	46	140	300	2,300	4,600	6,700	2,200	4,400	6,300	36,000	36,000	10.90	10.90	NA
AD	54	180	580	1,700	4,000	7,200	1,700	3,900	7,200	300,000	300,000	31.10	31.10	37%
Advanced ACT	165	410	1,010	5,100	6,800	6,900	5,000	6,700	6,800	410,000	410,000	12.90	12.80	26%
Standard ACT	170	360	1,010	930	5,600	10,100	920	5,500	10,000	430,000	420,000	24.00	24.00	22%
Energy from Waste	*Included in construction*			5,200	5,900	6,600	5,200	5,900	6,600	220,000	220,000	24.00	24.00	24%
Energy from Waste CHP [3]	*Included in construction*			5,500	6,200	6,900	5,500	6,200	6,900	270,000	270,000	29.00	30.00	20% [4]

All data rounded to 2 significant figures
[1] Fixed O&M is for years 1 to 5. Assumed to increase for years 6 to 24 up to 33,500 £/MW/year
[2] Early Round 3 with Round 2 type site conditions included in Round 2
[3] With CHP QA heat off-take for separate demand (on or offsite)
[4] Electrical efficiency

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