ANNEX B

Overview of Modelling of the Relative Electricity Generating Costs of Different Technologies

Introduction

This paper sets out results of modelling undertaken as part of the Energy Review. The purpose of this modelling is to provide estimates of the relative cost of electricity generation technologies under different scenarios and assumptions to inform policy analysis. These estimates do not represent a government view on the relative costs of the technologies. To take account of uncertainties on the assumptions we have also undertaken sensitivities.

The modelling is based on levelised costs and is not intended to predict specific private sector investment decisions or to 'rank' different generation technologies. Energy investment decisions are taken in the UK by the private sector within a market-based energy policy framework and take into account a range of specific factors, including for example post construction financing costs and market conditions, which are not incorporated into this modelling.

The scenarios considered in the modelling include a base case; varying assumptions for gas and carbon prices; and a full range of sensitivities including discount rate, capital cost, operating and maintenance (O&M) costs, fuel prices, carbon prices, load factors and interest rate margin (for construction finance only).

Methodology

Overview

We have developed a model to assess the levelised cost of a number of technologies considered in the Energy Review. These technologies are gas- and coal-fired power plant (with and without Carbon Capture and Storage); nuclear; and onshore and offshore wind generation.

The levelised costs for the technologies are presented as a range in £/MWh. The levelised costs are calculated by summing capital (annuitised and including interest during construction), O&M and fuel costs over the life of the plant, and dividing this sum by the sum of electrical output, i.e. total lifetime costs divided by total lifetime electrical outputs.

The analysis is based on a range of assumptions and data. For each technology, assumptions have been compiled on the basis of recent studies which are referred to in the Appendix to this Annex. All of the assumptions and the resulting levelised costs are based on "first of a kind" costs (i.e. the costs incurred from building a standalone plant, ignoring cost reductions that may be achievable through economies of scale or technology learning). The model structure and assumptions used are set out in the Appendix to this Annex.

We have also modelled sensitivities on the key assumptions and data (up to 30 sensitivities, including ranges in the discount rate, capital cost, O&M costs, fuel prices[1], carbon prices, load factors and interest rate margin for construction finance). We do not estimate probabilities for the occurrence of the sensitivities. Providing probabilities would unfairly weight outcomes, and would add a spurious level of accuracy to the underlying probability distributions of the sensitivities.

Model review

As part of their financial advice to the Energy Review, Ernst & Young LLP performed a review of the structure and logical integrity of the model which was developed by the Department of Trade and Industry (DTI) to generate the relative costs set out in this Annex. This review included conducting a test programme of the model's arithmetic based on specific input scenarios to assess whether the model has been constructed in a manner consistent with its stated objectives of generating an estimated levelised cost of power and an estimated new entry price for each of the five energy technologies on the basis of the DTI's chosen assumptions and input data set out in the Appendix to this Annex.

Ernst & Young LLP reported to the DTI that in its opinion, based on the work performed on the specific instructions of and solely for the DTI, the model has been constructed appropriately, in so far as its logical integrity and arithmetic is concerned, so as to achieve materially the objectives described above under both the base case assumptions for each of the energy technologies and the specific designated sensitivities. The scope did not extend to considering the appropriateness of the assumptions and additionally Ernst & Young LLP may not have addressed issues of relevance to any other party. It accepts no responsibility or duty of care to any party other than the DTI. Any reliance placed upon the model review by any third party is entirely at such party's own risk.

Technologies modelled

The technologies that have been modelled are:

- Gas plant:
  - Combined Cycle Gas Turbine (CCGT). The analysis is based on H Frame technology which is now considered "state-of-the-art" in the UK context and is commercially available and deployed at Baglan Bay power station in Wales.
  - CCGT with Carbon Capture and Storage (CCS). CCS is an emerging technology and CCGT with CCS has not yet been deployed on a large scale. The key developmental elements of CCS relate to the CO_2 separation technologies (i.e. pre-combustion, post-combustion and oxyfuel) and the storage location and formation for storage (e.g. for enhanced oil or gas recovery, depleted gas fields and saline aquifers).

1 Fuel price assumptions and carbon costs are included as the basis for modelling a number of potential scenarios and do not represent predictions of future prices.

- Coal plant:
  - Pulverised Fuel (Advanced Super Critical, ASC) with Flue Gas Desulphurisation (FGD). This is considered the base case coal technology which is being deployed around the world.
  - Pulverised Fuel (ASC) with FGD and CCS.
  - Integrated Gasification Combined Cycle (IGCC). This technology is currently being commercialised.
  - IGCC with CCS.

- Retrofit coal plant based on Pulverised Fuel (ASC) with FGD with CCS.

- Nuclear:
  - The analysis focuses on the Light Water Reactor (LWR) design types, including Pressurised Water Reactors and Boiling Water Reactors which are based on evolutionary third generation nuclear technologies used worldwide.

- Wind:
  - Onshore wind. Modelling here is based on an 80MW wind farm.
  - Offshore wind. Modelling here is based on a 100MW wind farm.

Scenarios considered

There are a large number of potential factors that influence the generation costs of different technologies which are modelled here through sensitivity analysis of key data and assumptions. In this report we present four cases, demonstrated through seven charts. In each case we provide a short commentary to aid interpretation of the charts.

The four cases we consider are:

1. **Base Case** – central gas price (36.6p/therm[2]) and no carbon price included.

2. **Carbon Price Added**[3] – As the "Base Case" but with a carbon price of €25/t CO_2 (£17/t CO_2).

3. **Gas and Carbon Price Sensitivities** – As the "Base Case", but with low/high gas prices (low at 21p/therm and high at 53p/therm) and varying carbon prices €15/t CO_2 (£10/t CO_2) and €36/t CO2 (£25/t CO_2).

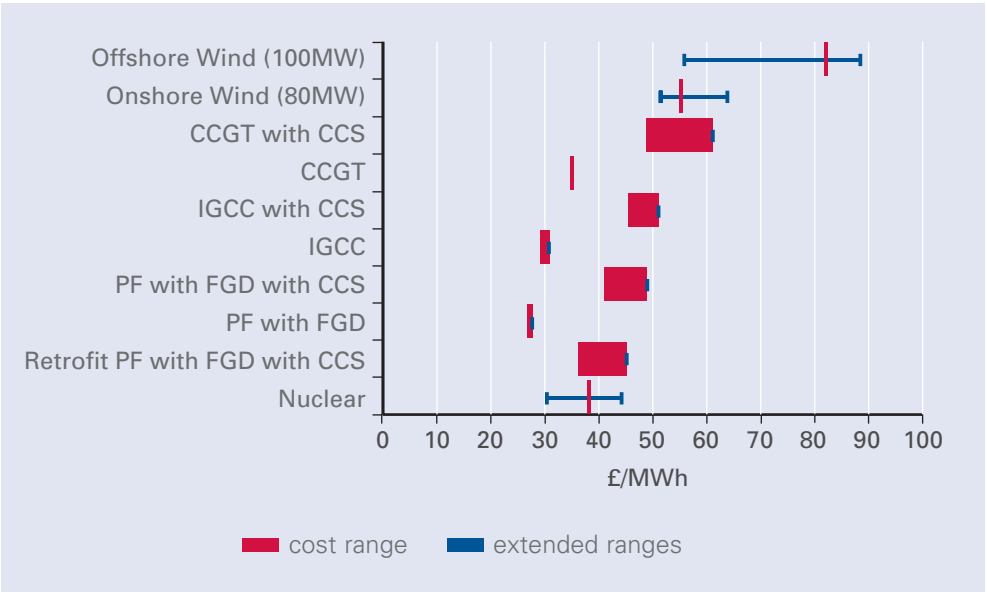
4. **Full Sensitivity Ranges** – As "Carbon Price Added" but with ranges for the discount rate, capital costs, O&M costs, fuel prices, carbon prices, load factors and interest rate margin (for construction finance).

2 Fuel price assumptions to 2020 are published in Annex C of this document.

3 Carbon costs are included as the basis for modelling a number of potential scenarios and do not represent predictions of future CO_2 prices. The range covered in the analysis models worlds where: there is some commitment to carbon reduction, but carbon reduction targets are such that abatement costs remain low (€15 (£10) / tonne of CO_2); there is ongoing commitment to carbon reduction, resulting in a carbon price in line with the first quarter 2006 UK market price (€25 (£17) / tonne of CO_2); there is ongoing commitment to carbon reduction, with tightening targets resulting in increased abatement costs (€36 (£25) / tonne of CO_2).

Results

CHART B1: BASE CASE (CENTRAL GAS PRICE AND NO CARBON PRICE INCLUDED)



Comments on Chart B1:

- In this case we plot base case costs for each technology. The red blocks represent the range of costs based on assumptions provided in Table B1 in the Appendix to this Annex and the blue lines represent extended assumptions on capital costs for wind and nuclear set out in Table B2.
- Given the sensitivity of the levelised cost to fuel prices, it is worth specifically noting that the CCGT cost is based on a 36.6p/therm gas price and the coal technologies are based on a £25/t coal price.
- The small red ranges associated with some technologies (e.g. CCGT) reflect a high degree of confidence in the cost estimates for technologies that are proven and where there is good data to draw on.
- In the case of technologies deploying CCS, the larger costs ranges in red reflect the lack of operational knowledge of these technologies, resulting in particular in large ranges in current estimates of operation and maintenance costs. The range of cost for IGCC technology without CCS is wider than PF coal technology, reflecting the uncertainty around integration and scale of the technology.
- For the wind and nuclear technologies, the range presented in blue reflects the influence of capital costs, which vary over time. In these cases, the levelised costs are particularly sensitive to these costs.

CHART B2: BASE CASE COSTS WITH CENTRAL GAS PRICE AND CARBON PRICE OF €25/tCO_2

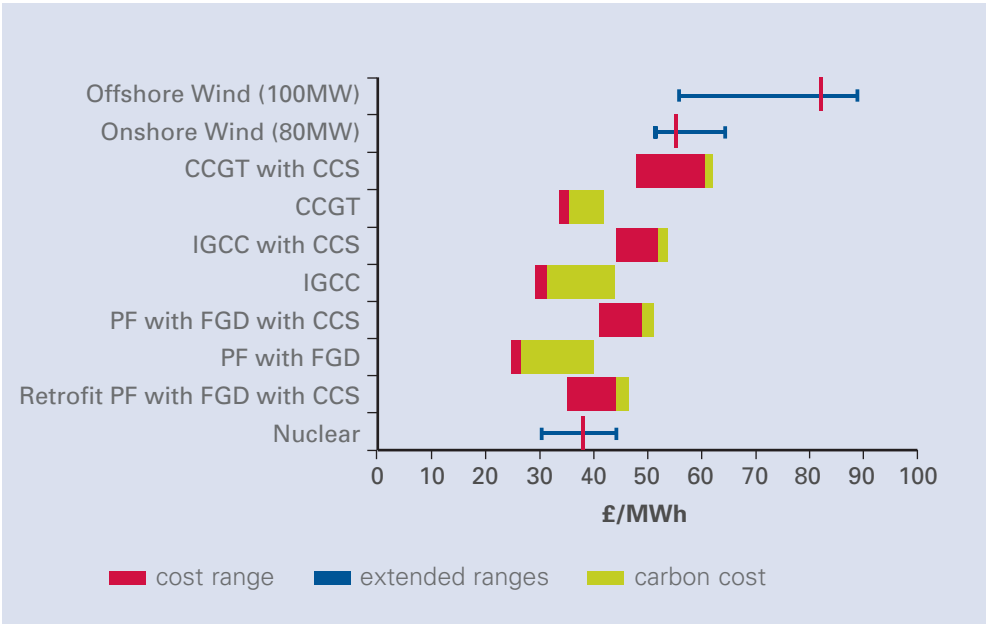


CHART B3: BASE CASE COSTS WITH CENTRAL GAS PRICE AND CARBON PRICE OF €15/tCO_2

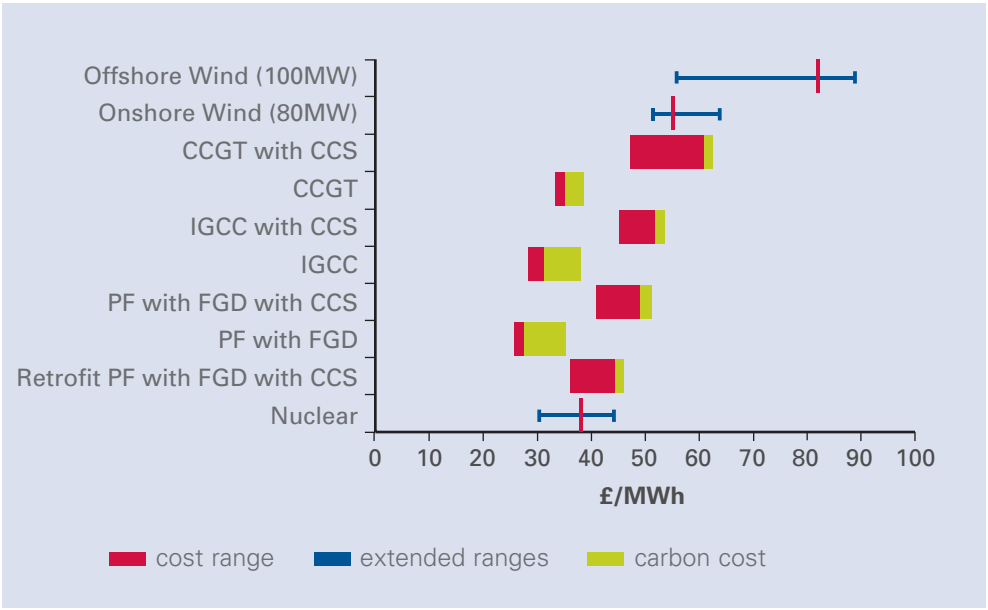
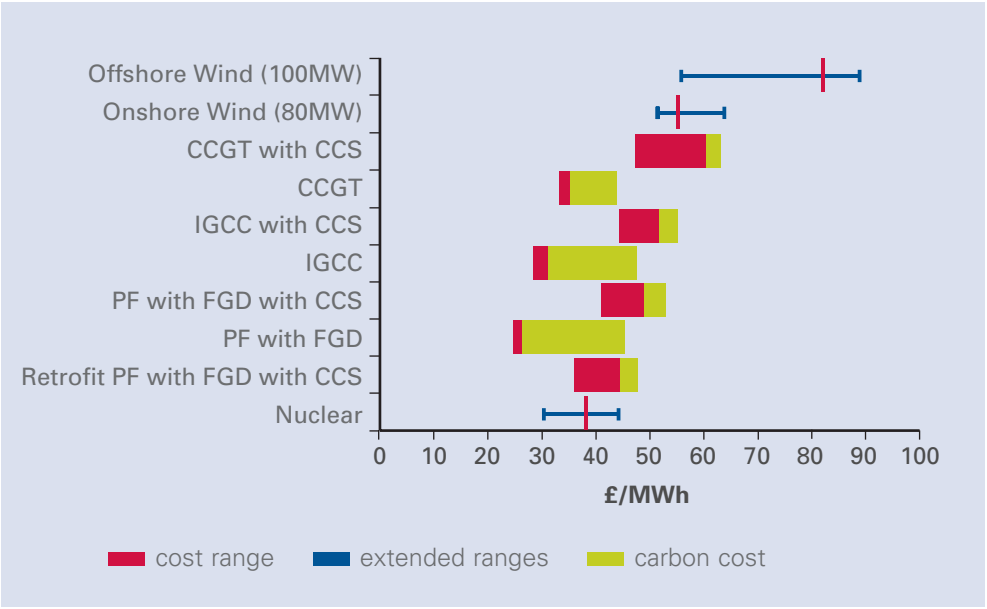


CHART B4: BASE CASE COSTS WITH CENTRAL GAS PRICE AND CARBON PRICE OF €36/tCO_2



Comments on charts B2 to B4:

- In these charts, the cost of carbon has been added to the base case costs from chart B1.
- Carbon costs are shown in green, and represent the additional cost of generation from each technology imposed by the carbon price. Thus the green bars are wider for more carbon intensive technologies.
- We take varying costs of carbon (€25/t CO_2 (£17/t CO_2); €15/t CO_2 (£10/t CO_2) and €36/t CO_2 (£25/t CO_2)). These costs are included as the basis for modelling a number of potential scenarios and do not represent predictions of future CO_2 prices.
- The carbon costs are based on the emission factor for the plant, multiplied by the market price for carbon (converted into a cost per MWh).
- The carbon emissions factors are based on DEFRA's National Atmospheric Emissions Inventory (NAEI) divided by the efficiency factor for the relevant technology.

CHART B5: BASE CASE COSTS WITH CARBON PRICE (€25/tCO_2) AND LOW GAS PRICE (21P/THERM)

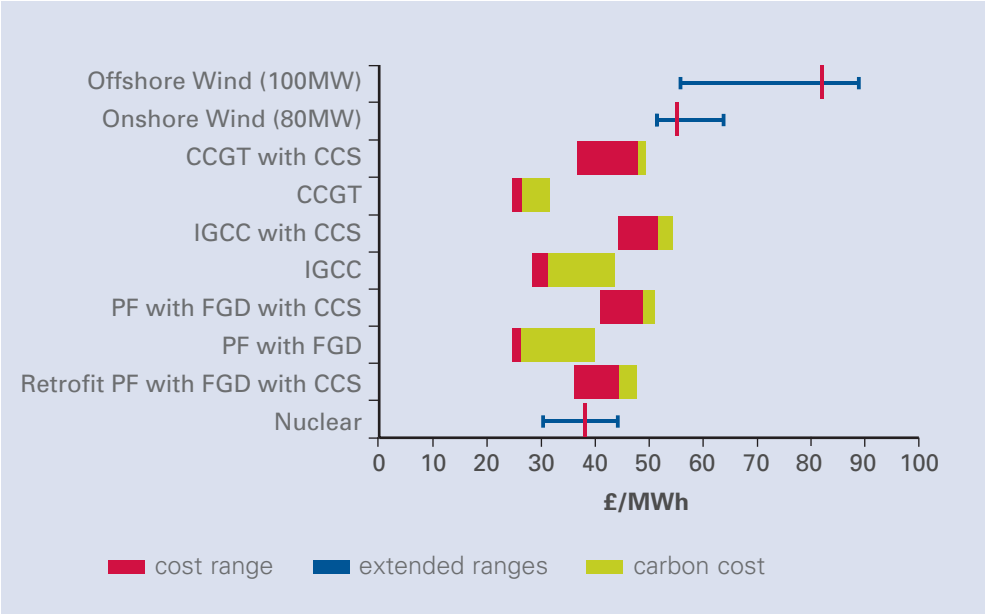
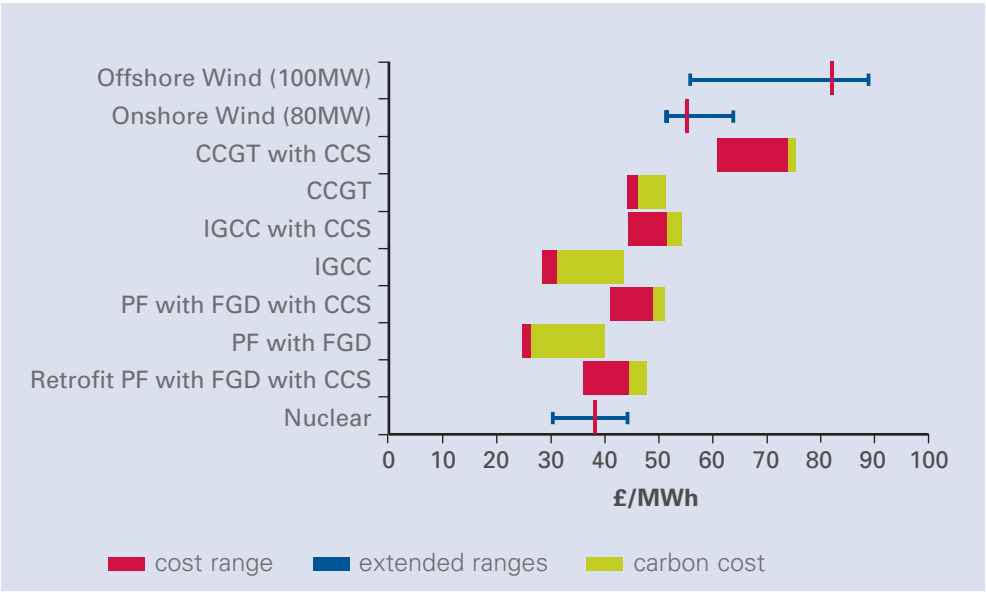


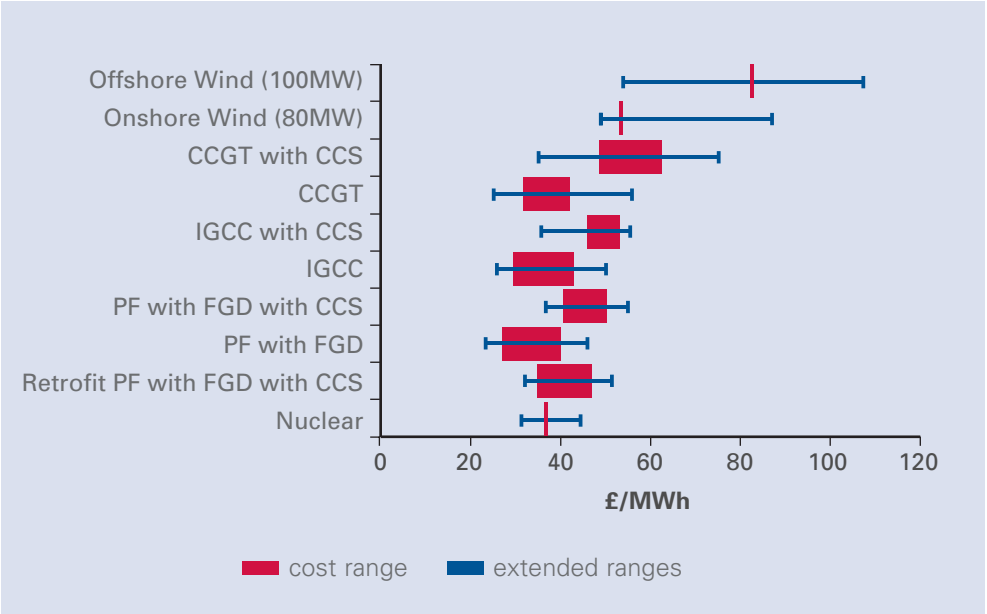
CHART B6: BASE CASE COSTS WITH CARBON PRICE (€25/tCO_2) AND HIGH GAS PRICE (53P/THERM)



Comments on charts B5 and B6:

- In these charts, the cost of gas is varied and a price of carbon of €25/t CO_2 (£17/t CO_2) is assumed. Varying the gas price results in changes to the cost of CCGT and CCGT with CCS, while the cost of all other generation technologies remain the same as in chart B2.
- Charts B5 and B6 take a low and high price for gas respectively (low is 21p/therm, and high is 53p/therm). These gas price assumptions are published in Annex C of this document.

CHART B7: FULL SENSITIVITIES (DISCOUNT RATE, CAPITAL COST, O&M COSTS, FUEL PRICES, CARBON PRICES, LOAD FACTOR AND INTEREST RATE MARGIN)



Comments on chart B7:

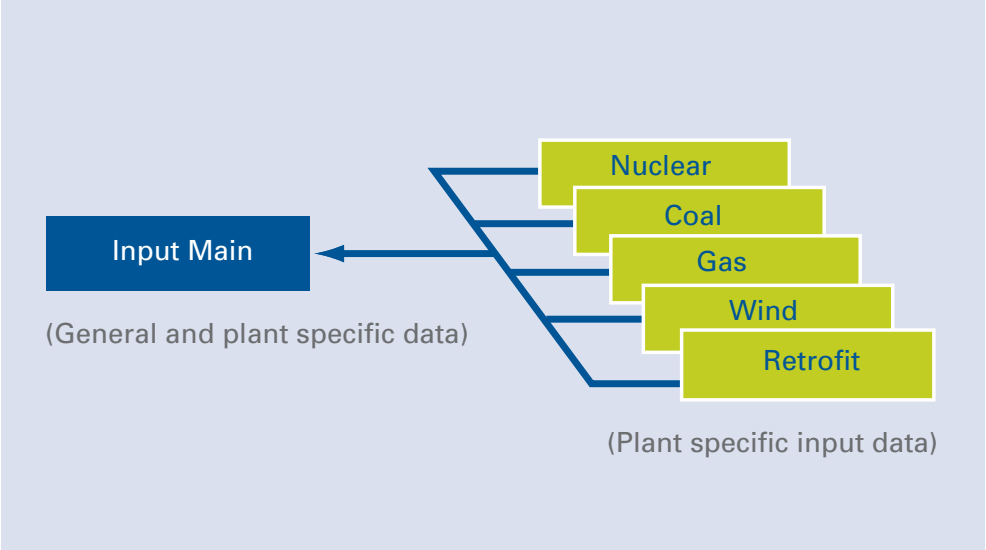
- The chart presents the full range of sensitivities that have been conducted for each technology represented by the blue lines. Section 3 of the Appendix to this Annex provides further detail on the sensitivities.
- The ranges in red include carbon costs based on a carbon price of €25/t CO_2 (£17/t CO_2). The red ranges are therefore different from the base cases presented in Chart 1.
- The blue lines around the red ranges are used to represent the outcomes from the range of sensitivities tested for each technology.
- The sensitivities examined are: discount rate, capital cost, O&M costs, fuel prices, carbon prices, load factors and interest rate margin for construction finance.
- The low end of the range reflects the low range of the sensitivities (low discount rate, low fuel prices) and the high end reflects high discount rate and high fuel prices.

APPENDIX: Overview of Modelling of the Relative Electricity Generating Costs of Different Technologies

1. Introduction

We have developed a financial model to assess the economic cost of the generating technologies (refer http://www.dti.gov.uk/energy/review). The generating technologies are gas-fired, coal-fired, nuclear, onshore wind and offshore wind generation.

INPUT DATA MODEL STRUCTURE



For each technology assumptions have been compiled on the basis of recent studies for the:

- predevelopment period;
- construction period; and
- costs associated with:
  - construction,
  - operation,
  - and the back-end costs as they apply to nuclear (specifically decommissioning and waste disposal).

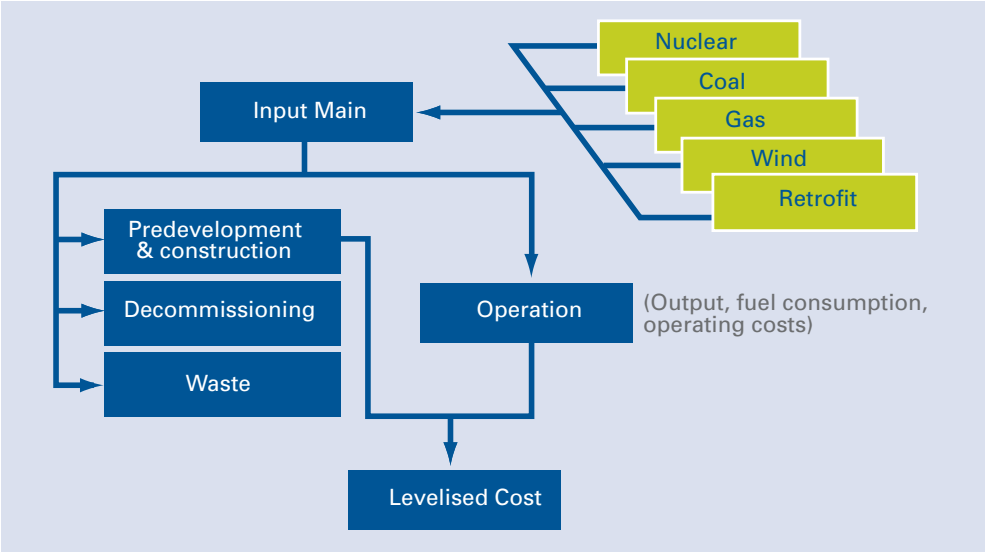
All of the assumptions are based on first of a kind costs, and therefore they do not take into account the effects of learning or the potential cost savings if more than one plant type is brought forward. The construction is assumed to be on a greenfield site aside from the retrofit coal option where the cost of the existing plant and associated infrastructure is fully depreciated, i.e. has a cost of zero. Furthermore we have modelled a range of cases for alternative values of key variables. Probabilities are not assigned to the various variables

as doing this would suggest a spurious degree of information about underlying probability distributions for the key variables.

1.1 Levelised costs

The cost of generating electricity has been calculated on a levelised cost basis expressed in £/MWh. The calculation takes the long-run average costs of a particular generating technology over its lifespan divided by the total output. Costs include the capital cost (in an annuitised form including interest during construction), the operating costs and the fuel cost. All numbers are real (in 2006 prices) and the capital cost is annuitised using a 10% discount rate.

LEVELISED COSTS



2. Modelling Assumptions

Table B1 details the assumptions used in the financial model and Section 4 details the sensitivities.

2.1 Capital, operating and plant performance assumptions

For the capital cost, operating cost and plant performance assumptions we have used Redpoint Energy[4] and industry sources for the gas and coal technologies, Oxera and Enviros[5] for the onshore wind, Climate Change Capital[6] for the offshore wind and various sources for nuclear technologies as noted in the Nuclear Cost Benefit Analysis on the Energy Review website.

These sources are a subset of the numerous market studies that have been published[7], some of which analyse all technologies whilst others have focused on specific technologies. Our aim has been to use the most representative data for a project being developed in the UK. We have not presumed to

4 Redpoint Energy (July 2006) *The Dynamics of UK Generation Investment.*
5 Enviros Consulting Limited (September 2005) *The Cost of Supplying Renewable Energy;* Oxera (January 2005) *What is the potential for commercially viable renewable generation technologies – Interim report prepared for the DTI.*
6 Climate Change Capital (February 2006) *Assessing the risks and implications of government contracts for offshore wind.*
7 A full list of studies referred to is included in Section 5 of this Appendix.

choose the best case but rather the most plausible and therefore our assumptions may appear to be conservative when compared to some studies.

2.2 Interest during construction

For all technologies, the interest during construction is added to the capital cost and annuitised for the levelised cost. Interest is assumed to be 6.26% (the London Inter Bank Offered Rate of 4.26% and a 2% margin). The amount leveraged is assumed to be 70%.

2.3 Fuel price assumptions

Fuel price assumptions for gas and coal to 2020 have been used, thereafter they have been assumed to be straight line. The fuel price assumptions are detailed in Annex C of this document.

2.4 Carbon Sequestration

Given the generic modelling of each project a simplified central assumption of £8/t CO_2 has been used for the transport and storage of CO_2. This equates to £3/MWh for a CCGT with CCS and £6/MWh for the coal-fired technologies with CCS.

2.5 Nuclear decommissioning and waste disposal

Details of the work programme and timetable to establish arrangements for dealing with the costs of decommissioning and waste from nuclear new build will be published by the time of the White Paper. The Government has not taken a position on how these arrangements should be designed. The nuclear section of chapter 5 sets out certain principles which will apply to the arrangements developed. That chapter also establishes that industry participants will need to meet the financial requirements established by the Government's decommissioning and waste frameworks even in challenging downside scenarios.

For the purposes of the cost benefit analysis, we have made some assumptions which in no way prejudice the outcome of work to determine the arrangements for dealing with the costs of decommissioning and waste from nuclear new build. The cost assumptions are detailed in Table B1 and in the Nuclear Cost Benefit Analysis[8].

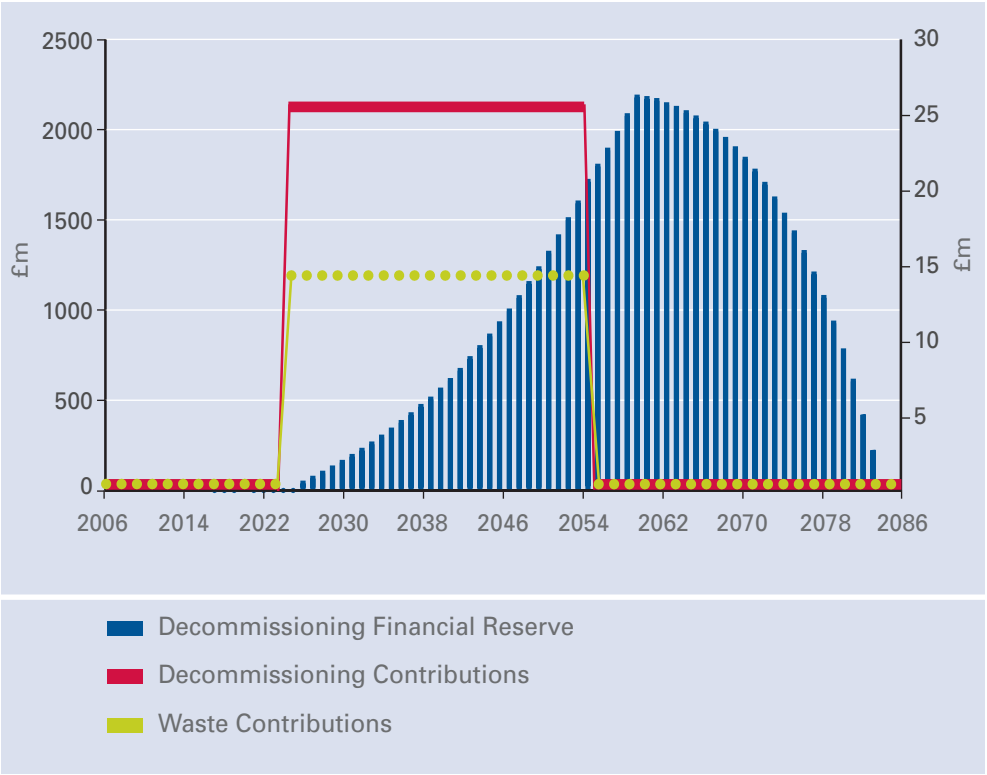
2.5.1 Decommissioning

As the entity operating the plant will be responsible for meeting the costs of decommissioning, it has been assumed that the entity operating the plant will make an annual contribution to build a financial reserve so that by the end of operation sufficient reserves are in place to meet the cost of decommissioning. The reserve is assumed to grow at 2.2%.

Decommissioning is assumed to take 25 years and begins at the end of the operating life of the plant and finishes 65 years after the start of plant life. Therefore whilst a portion of the reserve is being spent, the balance is continuing to grow at 2.2%. At the end of the 25 year decommissioning period the financial reserve has been drawndown to zero. This model is illustrative. The methodology described is illustrated in the chart below.

8 This is available at www.dti.gov.uk/energy/review

APPENDIX CHART 1: DECOMMISSIONING AND WASTE FUNDING



2.5.2 Waste management

Waste disposal assumes the same methodology as decommissioning as described in 2.5.1 above for the levelised cost calculation. For the purposes of the cost benefit analysis, we have made some assumptions which in no way prejudice the outcome of work to determine the arrangements for dealing with the costs of decommissioning and waste from nuclear new build. The financial reserve built by the operating entity to meet waste costs is assumed to be spent in the first year at the end of operations rather than over 25 years (as per decommissioning).

3. Data Assumptions

Table B1 details the key data assumptions used in the financial model.

Table B1: Assumptions underlying the levelised costs for the technologies

Technology	Capital Cost[1] £/kW	Operations & Maintenance Fixed £/kW	Operations & Maintenace Variable p/kWh	Efficiency[2] %
Gas-fired plant				
CCGT	440	7.0	0.20	58.0
CCGT with CCS – low	828	12.0	0.17	50.0
CCGT with CCS – high[3]	698	123.0	0.00	47.6
Coal-fired plant				
Retrofit PF with FGD and CCS – low	721	24.9	0.25	33.5
Retrofit PF with FGD and CCS – high[3]	721	77.9	0.46	33.5
PF with FGD – low	918	17.0	0.11	45.6
PF with FGD – high	882	31.3	0.20	44.1
PF with FGD with CCS – low	1,162	26.0	0.27	36.6
PF with FGD with CCS – high	1,625	81.3	0.50	34.8
IGCC – low	1,069	19.0	0.12	44.5
IGCC – high	1,030	50.0	0.20	48.3
IGCC with CCS – low	1,452	26.0	0.26	39.0
IGCC with CCS – high	1,715	100.0	0.40	39.9
Wind plant				
Onshore Wind (80MW)	819	44.4	0.00	100.0
Offshore Wind (100MW)	1,532	46.0	0.00	100.0
Nuclear plant				
Pressurised Water Reactor[4,5]	1,407	56.6	0.00	36.1

Real numbers in 2006 prices
1. Capital cost – includes owners costs but excludes interest during construction
2. Efficiency is noted on an LHV basis
3. O&M uplift based on Redpoint new build assumptions
4. The availability used for nuclear plant assumes 80% in the first five years
5. Decommissioning cost assumed to be £400/kW and waste cost assumed to be £173/kW

Plant Life years	Load Factor %	CO_2 Sequestration %	CO_2 Transport and Storage p/kWh	Basis for capital and O&M cost assumptions
35	85	N/A	N/A	Industry sources
35	85	90	0.3	Industry sources
35	85	90	0.3	Foster Wheeler
30	90	90	0.6	Industry sources
30	90	90	0.6	Industry sources
50	90	N/A	N/A	Industry sources
50	90	N/A	N/A	Redpoint Energy
50	90	90	0.6	Industry sources
50	90	90	0.6	Redpoint Energy
35	90	N/A	N/A	Industry sources
35	90	N/A	N/A	Redpoint Energy
35	90	90	0.6	Industry sources
35	90	90	0.6	Redpoint Energy
20	33	N/A	N/A	Oxera & Enviros
20	33	N/A	N/A	Climate Change Capital
40	85	N/A	N/A	Recent market data and current projects

4. Sensitivities

Table B2 details the key sensitivities used in the financial model.

Table B2: Sensitivity assumptions underlying the levelised costs for the technologies in Table B1

Technology	Sensitivity[1]	Low	High	Very High
Gas-fired plant				
CCGT	Fuel price	21p/therm	53p/therm	
Wind plant				
Onshore Wind (80MW)	Capital cost	£700/kW	£900/kW	£1000/kW
Offshore Wind (100MW)	Capital cost	£900/kW	£1550/kW	£1650/kW
Nuclear plant				
Pressurised Water Reactor	Capital cost	£850/kW	£1400/kW	£1600/kW

Real numbers in 2006 prices
1. Capital cost – excludes interest during construction and owners' costs

Additional sensitivities have been run for all of the technologies on the following variables:

- predevelopment period and cost;
- construction period and cost – including varying the interest margin and the leverage;
- operation period;
- operations and Maintenance cost;
- fuel cost;
- load factor in the first five years and thereafter;
- CO_2 price (only applies to the gas and coal technologies);
- CO_2 transport and storage cost (only applies to the technologies with CCS);
- decommissioning cost (only applies to nuclear);
- waste disposal cost (only applies to nuclear); and
- discount rate.

The sensitivity ranges and results for each technology are included in the financial model[9] and are summarised in Chart B7.

9 This is available at www.dti.gov.uk/energy/review

5. Market studies

Table B3 lists the market studies we have referred to during the building of the financial model other than internal and interdepartmental analysis.

Table B3: Source material	
Source material (in alphabetical order)	Web link (if available)
Climate Change Capital (February 2006) *Assessing the risks and implications of Government contracts for offshore wind*	
Consultation Submissions to the Energy Review (2006) British Energy, Centrica, EDF, E.ON, RWE, Scottish & Southern Energy and ScottishPower	http://www.dti.gov.uk/energy/review/consultation-submissions/page27883.html
Department for Environment, Food and Rural Affairs (April 2006) *UK Greenhouse Gas Inventory, 1990 – 2004 – Annual Report for submission under the Framework Convention on Climate Change*	http://www.airquality.co.uk/archive/reports/cat07/0605231047_ukghgi_90-04_v1.1.pdf
Department of Trade & Industry (July 2006) *DTI Energy and CO_2 Emissions Projections*	http://www.dti.gov.uk/energy/review
Department of Trade & Industry (July 2006) *Nuclear Cost Benefit Analysis*	http://www.dti.gov.uk/energy/review
Department of Trade & Industry (December 2005) *The Role of Fossil Fuel Carbon Abatement Technologies (CATs) in a Low Carbon Energy System – A Report on the Analysis Undertaken to Advise the DTI's CAT Strategy*	http://www.dti.gov.uk/energy/sources/sustainable/carbon-abatement-tech/techstrategy/page19434.html
Environmental Audit Committee (March 2006) *Keeping the Lights on: Nuclear, Renewables & Climate Change*	http://www.publications.parliament.uk/pa/cm200506/cmselect/cmenvaud/584/584i.pdf
Enviros Consulting Limited (September 2005) *The Cost of Supplying Renewable Energy*	http: www.dti.gov.uk/renewables
Oxera (January 2005) *What is the potential for commercially viable renewable generation technologies – Interim report prepared for the DTI*	http: www.dti.gov.uk/renewables
Foster Wheeler *Comparative Study of Pre and Post Combustion Decarbonisation for a Generic Combined Cycle Power Plant*	
HM Treasury (2005) *Appraisal and evaluation in Central Government, "The Green Book"*	http://www.hm-treasury.gov.uk./media/D5E/29/96.pdf

Table B3: Source material *continued*	
Source material (in alphabetical order)	Web link (if available)
Intergovernmental Panel on Climate Change (2005) *Carbon Dioxide Capture and Storage – Summary for Policymakers and Technical Summary*	http://www.ipcc.ch/activity/ccsspm.pdf
International Energy Agency (2005 Update) *Projected Costs of Generating Electricity*	http://www.iea.org/w/bookshop/add.aspx?id=196
PB Power (June 2006) *Powering the Nation – A review of the costs of generating electricity*	http://www.pbpower.net/inprint/pbpubs/powerthenation/powerthenation.htm
Public Services International Research Unit (July 2005) *The economics of nuclear power: analysis of recent studies by Steve Thomas*	http://www.psiru.org/reports/2005-09-E-Nuclear.pdf
Redpoint Energy (July 2006) *The Dynamics of UK Generation Investment*	http://www.dti.gov.uk/energy/review
Sustainable Development Commission (March 2006) *The role of nuclear power in a low carbon economy*	http://www.sd-commission.org.uk/publications/downloads/SDC-NuclearPosition-2006.pdf
Sustainable Development Commission (March 2006) *The role of nuclear power in a low carbon economy – Paper 4: The economics of nuclear power*	http://www.sd-commission.org.uk/publications/downloads/Nuclear-paper4-Economics.pdf
World Nuclear Association (December 2005) *WNA Report, The New Economics of Nuclear Power*	http://www.world-nuclear.org/economics.pdf