Policy Studies Institute

COMPARATIVE COST INFORMATION: SUPPORTING THE DEVELOPMENT OF THE MARKAL MACRO MODEL OF THE UK ENERGY RESEARCH CENTRE (UKERC)

by

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This Paper

This paper summarises research by PSI Visiting Research Fellow Derek Smith, carried out in support of the MARKAL-MACRO energy modelling team, funded by the UK Energy Research Centre (UKERC) and the Departments of Trade & Industry (DTI) and Environment & Rural Affairs (DEFRA) to develop energy systems modelling, and to give support to the 2006 UK Energy Review and White Paper processes. The modelling work, involving the development of the UK MARKAL-MACRO model, is being led by a partnership comprising the Policy Studies Institute (PSI) and Future Energy Solutions (FES).

The MARKAL-MACRO model

MARKAL (acronym for MARKet ALlocation) is a widely applied bottom-up, dynamic, linear programming optimisation model. MARKAL was developed in the late 1970s and has been continually supported by the International Energy Agency via the Energy Technology and Systems Analysis Program (ETSAP). The MARKAL model has contributed to numerous and wide-ranging energy policy studies including the UK Department of Trade and Industry "Options for a Low Carbon Future – Phase 2" analysis, which underpinned the 2003 Energy White Paper (FES, 2003).

The standard version of MARKAL is a data-driven, technology-rich energy systems economic optimisation model. The user inputs the structure of the energy system to be modelled, including resource supplies, energy conversion technologies, end-use demands, and the technologies used to satisfy these demands. The user must also provide data to characterize each of the technologies and resources used, including fixed and variable costs, technology availability and performance, and pollutant emissions. MARKAL then calculates, using dynamic linear programming techniques, the least cost way to satisfy the specified demands, subject to a range of constraints. Thus the optimised quantity is the total system cost, with the decision variables the investment and operation costs of all the interconnected system elements

A range of extensions to the MARKAL paradigm have been developed including linkage to a simple MACRO economic component. Figure 1 provides an overview of the MARKAL and MACRO components.

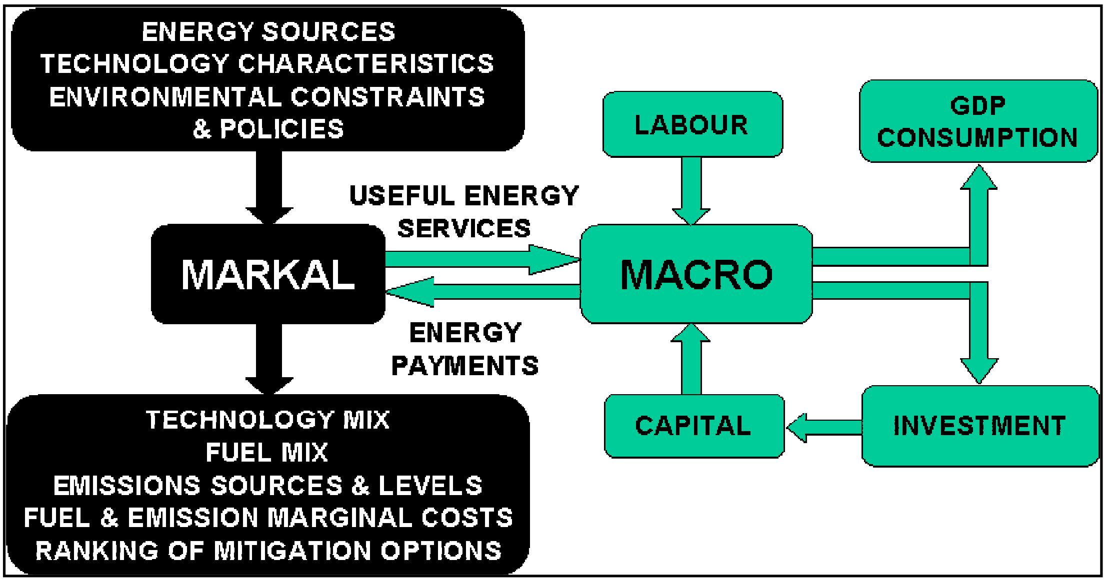

Figure 1: MARKAL- MACRO overview schematic

MARKAL results are obviously very dependent on the cost data and other assumptions that are fed into the model. As a guiding principle supporting the model's development, costs and performance data were set to be representative of commercially deployed technologies enjoying the benefits of volume production and of good installation and operating practices. Technologies were also assumed to be developed globally and to benefit from advances in design, engineering, and production.

As part of the model's development, a review was undertaken to gather and update data. Data on coal and natural gas technologies included in the electricity and heat generation technology module were sourced from DTI studies in 2003 and 2005. Information on renewable electricity technologies was derived from major data sources such as Enviros (2005) for hydro and biogas/biomass, IEA/DTI (2005) for solar PV, OXERA (2004) for wind, and ETSU (reviewed and revised from 1997) for CHP. Key references for data on nuclear generation were work for the Sustainable Development Commission (2006), Kolb and Martinsen (2003), and a study into the future of nuclear power by MIT (2005).

Data were subject to a number of checking and validation processes with expert stakeholders. This included a stakeholder workshop specifically on electricity generation technologies to gain feedback on the key model parameters, notably costs and efficiencies, and to explore alternate assumptions and supporting data sources. Feedback from the workshop was fed into the model.

Research scope and approach

The research reported in this paper was carried out from 1 May to 9 June 2006. It was commissioned by PSI to put the costs (and other key assumptions where possible) used in the MARKAL-MACRO model, which are important for generating its results, in the context of those cited in the literature, illustrating the range which these assumptions could plausibly have covered, drawing on a number of analyses of the electricity generating sector.

Sources containing cost information were identified by the MARKAL team for review. These included economic and market analyses of a range of electricity generation technologies including reviews of nuclear economics provided by independent analysts as well as the nuclear industry itself, and several studies of different types of renewable technologies. A total of fourteen key sources were reviewed, of which eight provided relevant cost data in a form that could be readily used for comparison within the existing structure of the MARKAL model. One source, the WADE report (World Alliance for Decentralized Energy), carried out on behalf of Greenpeace in the context of the 2006 UK Energy Review, differs significantly from the others in that it seeks to quantify the benefits for the UK of adopting a decentralized energy system.[1] The report presents conclusions from the application of the WADE model and compares traditional centralized energy systems to decentralized systems using local generation and renewable sources, under the same conditions for growth, and fuel costs.

A further eight sources, which were referred to in the key sources mentioned above, contained cost information of potential relevance to the model. All of these sources focused on nuclear power. They were produced by organisations outside the UK and present international nuclear industry experience, primarily North American and northern European. All but three of the 22 total sources were published in 2003 or later.

Figure 2 below shows sources reviewed. The 'Data used' column indicates whether data from this source is used in the detailed comparisons later in this paper. Where a 'no' is shown in this column it is because the data provided was not in a form readily comparable to that within MARKAL – pertaining to different years, for example.

Source	*Reviewed*	*Data used*	*Summarized*	*Document title*	*Author*	*Pub'n date*
RAE	Yes	Yes	Yes	The Costs of Generating Electricity: A study carried out for the Royal Academy of Engineering	P B Power (for RAE)	2004
WNA	Yes	Yes	Yes	The New Economics of Nuclear Power	World Nuclear Association	2005
OXERA	Yes	Yes	Yes	Results of Renewables Market Modelling	OXERA	2004
ECN	Yes	Yes	No	Characterization of Power Generation Options for the 21st century	ECN Policy Studies (P. Lako and A.J.Seebregts)	1998
ICEPT	Yes	No	No	Alternative fuels for transport and low carbon electricity generation: A technical note	Robert Gross and Ausilio Bauer	2005
SDC	Yes	Yes	Yes	Economics of Nuclear Power: A report to the Sustainable Development Commission	University of Sussex and NERA	2005
WADE	Yes	Yes	Yes	Decentralizing UK Energy: Cleaner, cheaper, more secure energy for the 21st century: application of the WADE economic model to the UK economy	World Alliance for Decentralized Energy (for Greenpeace)	2006
Carbon Trust	Yes	Yes	Yes	Future Marine Energy: Results of the Marine Energy challenge: cost competitiveness and growth of wave and tidal energy stream	Carbon Trust	2006
RCEP	Yes	No	No	Biomass as a renewable energy source	Royal Commission on Environmental Pollution	2004
Enviros	Yes	No	Yes	The costs of supplying nuclear energy	Enviros Consulting	2005

[1] 'Decentralising UK energy: Cleaner, cheaper, more secure energy for the 21st century: application of the WADE economic model to the UK economy' (2006). WADE, for Greenpeace.

					(for DTI)	
IEA	Yes	No	No	National survey report of PV power applications in the United Kingdom	International Energy Agency	2004
UKERC	Yes	No	No	The costs and impacts of intermittency	UK Energy Research Centre	2006
AEA	Yes	Yes	No	Options for a low carbon future: Appendix D (Technology Data and Comparisons), and Appendix E (Revised Technology Data and Assumptions)	AEA Technology	2002 and 2003
PSIRU	Yes	No	Yes	The Economics of Nuclear Power: analysis of recent studies	Steve Thomas (PSIRU)	2005
Chicago	No	No	Yes	The Economic Future of Nuclear Power	University of Chicago	2004
MIT	No	No	No	The Future of Nuclear Power: an interdisciplinary MIT study	Massachusetts Institute of Technology	2003
DGEMP	No	No	No	Energy Baseline Scenario for France to 2030	General Directorate for Energy & Raw Materials	2004
T&R	No	No	No	Nuclear Power: Least-cost option for baseload electricity in Finland	Tarjanne and Rissanen	2000
T&L	No	No	No	Research report: Competitiveness comparisons of electricity production alternatives	Tarjanne and Luostarinen (in Finnish)	2003
CERI	No	No	No		Canadian Energy Research Institute	2004
Scully	No	No	No	Business case for new nuclear power plants: bringing public and private resources together for nuclear power	Scully Capital (for US Dept of Energy)	2004
AREVA	No	No	No	EPR background and its role in Continental Europe	AREVA	2005

Figure 2: List of sources

Cost information and other relevant data were initially gathered from the sources in their original format, using the currencies and units provided in each source. Costs were subsequently converted into sterling and units converted to match those used within MARKAL to facilitate comparison. The collected information was provided to the MARKAL modelling team for comparison with MARKAL data. In addition, a number of the sources which contained useful cost information were summarised in order to capture information on the assumptions which underpin their data. These summaries were provided to the project team and are included here as an appendix.

The key categories of cost information sought in the review of sources were capital costs and fixed and variable operation and maintenance costs (O&M costs). In addition to these however, as suggested by the MARKAL team, information was collected on the following parameters:

- the first year the relevant technology becomes available. This is important given the significance of construction costs within overall costs, and because of the importance of the cost of capital. Information on construction and first year of availability also enables observations to be made about the trends in cost profiles over a long period, typically over 20-30 years.
- the efficiency of individual technologies
- ‘availability factors’, that is the ratio of the actual energy produced by a power plant in a given period to the hypothetical maximum possible, i.e. running full time at rated power.
- the life expectancy of the technology or plant, in years.

Cost commentary

The key area of analysis is capital costs. It has been estimated that they typically represent 60-75% of nuclear costs and 85-90% of wind renewables.[2] O&M costs are estimated to represent up to 15% of total costs for nuclear and renewables. From the sources reviewed, information on O&M costs is less comprehensive and data which distinguishes fixed from variable O&M costs is rare.

There are several important limitations to the analysis that can be done of the comparative data. First, and most importantly, the analysis of sources has confirmed the difficulty of determining the true costs of generating electrical power from different technologies. The definitions of capital and O&M costs are frequently obscure, rarely consistent and often blurred by commercial sensitivities or competing claims. The allocation of costs is particularly difficult in the nuclear sector (discussed below), where figures for capital costs are affected by assumptions about construction cost and the rate at which future costs and benefits are discounted. For other technologies as well, uncertainties are introduced by differing assumptions about learning and build rates.

Second, in many cases the sources reviewed do not include the same specific generation technologies as within the MARKAL model. The cost and performance characteristics of different types of technology often vary significantly within a cluster or category of generating technology. Third, the information in these sources often pertains to years which are different to those within MARKAL, making straightforward comparison difficult.

The commentary below provides extracts from the information gathered. In each technology cluster, tables are presented which show information where the basic assumptions – about the type of technology and the year the costs relate to – are similar to those within MARKAL. The tables therefore show only a subset of the information gathered during the research. In each case, comment is provided on the positioning of the MARKAL cost data relative to the other cost information shown.

Government energy cost assumptions

A very wide range of analysis has contributed to the preparation of UK energy policy as presented in energy white papers and other policy documents since 2003. It has not been within the scope of this work to review the many submissions made which have contributed to these policy papers. From the sources reviewed in the scope of this work, however, observations can be made about the cost assumptions for nuclear and other sources of generation which were one input to the policy process.

It is important to note, of course, that these sources represent an extremely small proportion of the inputs provided to government which have influenced the development of energy policy, and that the assumptions underpinning the cost information may not be consistent from one analysis to the

[2] See Table 3.1 ('Representative proportions of Electricity Generating Costs' within 'Economics of Nuclear Power' (NERA/University of Sussex) (2005). Wind power was included as a reference because it is becoming the predominant renewable technology.

next. For example, the nuclear cost estimates are very dependent on the financing structure and interest rates that have been assumed, which are not always transparent and are rarely consistent. Observations, therefore, about change or trends in the data need, therefore, to be treated cautiously. Cost data provided has also fed into models which have many other assumptions, which in turn will influence outcomes.

From the sources reviewed in this assessment, the capital cost estimates for nuclear are relatively stable from 2003-2006. The NERA report cites DTI capital costs figures[3] from 2003 (the year of the Energy White Paper, 'Our Energy Future'[4]) which fall in a range of £1,070-1,400/kW. Analysis and modelling done by AEA Technology[5] in support of the 2003 Energy White Paper cites estimated capital costs for new nuclear at £1,300/kW (in 2010) and £1,100 (in 2020). The data assumptions supporting modelling carried out in the support of the 2006 Energy Review[6] show nuclear capital costs of £1,407/kW. In other words, the capital cost estimates for nuclear, although marginally higher in 2006, fall within a stable band over this period.

The capital cost estimates for other forms of generation, however, change more markedly from 2003-2006. Figure 3 below sets out capital cost estimates for comparable technologies (including nuclear) included within the 2006 Energy Review set against the AEA modelling work in 'Options for a Low Carbon Future' which supported the 2003 Energy White Paper. Where a row is blank, it is because there is no comparable data relating to these technology options.

The comparison suggests that while the economics of nuclear power have not changed significantly in the source information from 2003-2006, the economics of other forms of generation have deteriorated between 2003 and 2006, making their position less attractive relative to nuclear.

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[3] See Table 5.2 and accompanying footnotes within the NERA report ('Different cost estimates: Capital Costs'), page 19.

[4] 'Our Energy Future: Creating a low carbon economy' (DTI, February 2003, Cm 5761).

[5] 'Options for a low carbon future' phase 2. (AEA Technology) Appendix D (Technology Data and Comparisons) shows capital cost estimates of £1100-1300 £/kW). Appendix E (Revised Technology Data and Assumptions) shows the same figures for both the 'World Markets' scenario and the 'Global Sustainability' scenario. The World Markets scenario is 'based on individual consumerist values, a high degree of globalization and scant regard for the global environment (GDP growth 3% per year)'. The Global Sustainability scenario is 'based on the predominance of social and ecological values, strong collective environmental action and globalization of governance systems (GDP growth 2.25% per year).'

[6] See Table B1 ('Data Assumptions') within 'Overview of Modelling of the Relative Electricity Generating Costs of Different Technologies': Appendix to Annex B of 'The Energy Challenge: Energy Review Report 2006' (DTI, July 2006; Cm 6887). Table B1 details the key data assumptions used in the financial model developed by DTI to assess the economic cost of different generating technologies. The technologies modelled covered gas-fired, coal-fired, nuclear, onshore and offshore wind. For each technology assumptions have been compiled on the basis of market studies for the pre-development period; the construction period; and costs associated with construction, operation, and the back-end costs as they apply to nuclear (specifically decommissioning and waste disposal). The appendix points out that market studies reviewed form a subset of the numerous market studies that have been published, some of which analyse all technologies whilst others have focused on specific technologies. DTI's aim was to use the most representative data for a project being developed in the UK. Internal and interdepartmental analysis also contributed to the development of the financial model. Nineteen sources are listed. Several of these have been reviewed in the course of this work.

Source: appendix to annex B of 2006 Energy Challenge		*Source: Annex D of 'Options for a Low Carbon Future' ('Technology Data and Comparisons') 2003*	
Technology description	*Capital Cost £/kW*	*Technology description*	*Capital Cost: £/kW*
Gas-fired CCGT	440	New CCGT, from 2000-2040	250-270
CCGT with CCS – low *	828	New GTCC/CO_2 from 2000-2040	514-450
CCGT with CCS – high *	698		
Retrofit PF with FGD and CCS – low	721		
Retrofit PF with FGD and CCS - high	721		
PF with FGD – low	918		
PF with FGD – high	882		
PF with FGD with CCS - low	1,162		
PF with FGD with CCS - high	1,625		
IGCC – low	1,069	New IGCC, from 2000-2040	1,232-700
IGCC – high	1,625		
IGCC with CCS – low	1,452	New IGCC/CO_2 from 2000-2040	1,685-988.3
IGCC with CCS – high	1,715		
Onshore wind (80MW)	819	Wind - offshore(2020-2040)	812-480
Offshore wind (100MW)	1,532	Wind - onshore (2000-2040)	570-330
Nuclear – PWR	1,407	New nuclear 2010	1,300
		New nuclear 2020	1,100
* Author's note: The 'low' and 'high' in the 2006 technology descriptions do not refer to the capital costs but to sensitivity ranges within the modelling, in which 'low' reflects factors such as low discount rates and low fuel prices, and 'high' reflects high discount rates and high fuel prices.			

Figure 3: 2003/2006 Capital Cost Estimates

Nuclear

Commentary by the Sustainable Development Commission,[7] based on the analysis of NERA and the University of Sussex[8], has argued that the full costs of nuclear power are as hard to calculate today as they ever have been.

In summary, the SDC argue that accurate cost assessment is hampered by many factors including difficulties in estimating costs of decommissioning and waste disposal, the way in which the industry is financed (with or without government support), and the variation in fuel cycle costs because of their dependence on the technology being used. The importance of capital costs makes accurate estimation of cost/kWh difficult given the sensitivity of this to overruns and the cost of capital. It argues that cost estimates provided by the nuclear industry suffer from 'appraisal optimism' and must be treated with caution. The fact that the available studies often derive from

[7] 'Is nuclear the answer?' A commentary by Jonathon Porritt, Chairman of the Sustainable Development Commission. (March 2006).

[8] 'Economics of Nuclear Power: A Report to the Sustainable Development Commission' (2005) University of Sussex and NERA.

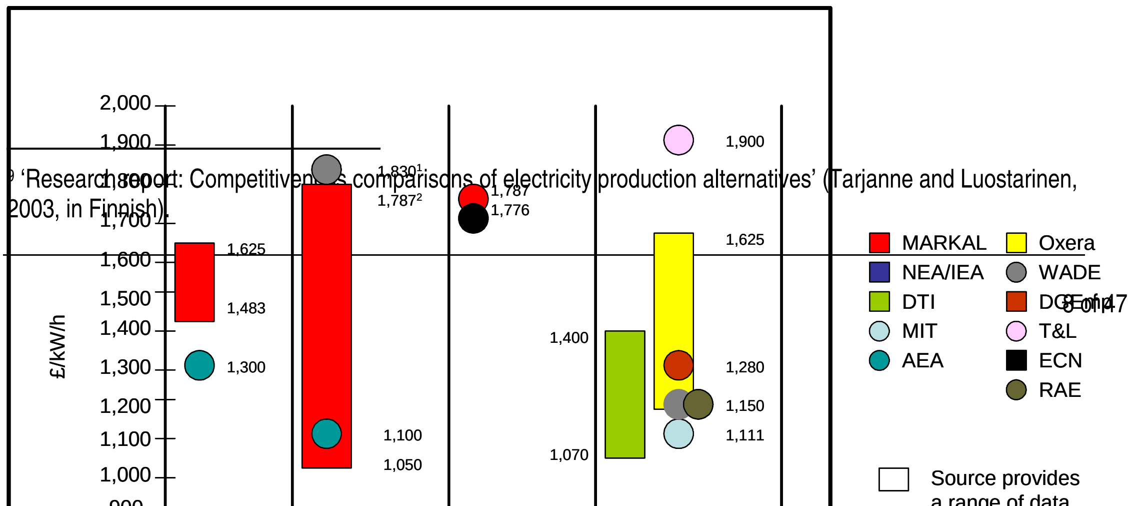
international experience makes them unlikely to be readily applicable to the UK market given the differing regulatory contexts and the importance of local factors (such as the cost of labour) in determining O&M costs.

Review of the NERA / University of Sussex study (which provides a thorough review of the limitations and uncertainties inherent in nuclear generation cost information) and the others on nuclear power confirms the complexities of comparing information about nuclear capital costs, which are affected by a number of important assumptions. These include assumptions about the treatment of ‘overnight costs’ (typically equipment, engineering and labour costs during construction) and ‘FOAKE’ (first of a kind engineering) costs. The inclusion (or not) of ‘back end’ costs for waste and decommissioning within capital costs is also inconsistent. In some studies, the funding for this is included in construction costs. In others, a segregated fund is shown which grows over the lifetime of the plant – typically 30-40 years.

Despite these uncertainties, the key area where comparative cost information is available is in the area of capital costs, which as we have noted typically represent approximately two thirds to three-quarters of total nuclear generating costs. As noted, MARKAL’s cost data derives from work done by NERA/University of Sussex (which itself gathers information from different sources), MIT, and Kolb and Martinesen. Excluding fusion technology, the capital costs per kW within MARKAL range from £1,050 for reactors first available in 2020 to £1,787 for a GTMH (a French design) reactor and pebble bed reactors, potentially available from 2025 and 2030 respectively. Three of the alternative sources cite ranges of possible costs. Two of these (Oxera and work for the DTI) are very close to the MARKAL data at the bottom end of the scale (within 10%) and slightly less at the top end of the cost estimates (within 10-20%). The third (NEA/IEA) shows cost estimates notably lower than all of the others, showing a range of £611-889/kW. Individual studies cite estimated capital costs/kW which fall within the range within MARKAL. The exceptions to this are studies by Tarjanne and Luostarinen[9] (£1,900) and the WADE study estimates of future nuclear power from 2023 (£1,830).

In relation to parameters other than capital costs, MARKAL assumes an efficiency rating for existing nuclear technologies (AGR, Magnox, and PWR) of 31.6%. Efficiency rates are expected to improve for new reactors to reach up to 35% for technologies available from 2010 onwards. This excludes GTMH reactors (from 2025) which have an estimated efficiency rating of 46% and fusion plant (from 2050) which are assumed 100% efficient.

The MARKAL estimates for the availability factor range from 76-95%. All of the estimates within the alternative sources show availability factors that fall within this range. Diagram 1 below plots the capital cost data from the various sources, showing ranges where appropriate. Table 1 then provides the detailed information.



[9] ‘Research report: Competitiveness comparisons of electricity production alternatives’ (Tarjanne and Luostarinen, 2003, in Finnish).

Diagram 1: Comparative capital costs: nuclear

Nuclear						
Source	*Technology*	*First year available*	*Construction period (years)*	*Efficiency %*	*Availability factor %*	*Capital cost £/kW*
Markal	**Advanced Gas-cooled reactor (AGR)**	**Existing**	**-**	**31.6**	**76**	**-**
	Magnox reactor	**Existing**	**-**	**31.6**	**76**	**-**
	PWR	**Existing**	**-**	**31.6**	**76**	**-**
	AP1000 (URN)	**2010**	**-**	**35**	**85**	**1,625**
	Block of AP1000 (URN)	**2020**	**-**	**35**	**85**	**1,050**
	EPWR (URN)	**2010**	**-**	**31.6**	**85**	**1,483**
	Block of EPWR (URN)	**2020**	**-**	**31.6**	**90**	**1,050**
	APRW (URN-MOX)	**2010**	**-**	**35**	**85**	**1,625**
	EPWR (URN-MOX)	**2010**	**-**	**32**	**85**	**1,483**
	Pebble bed reactor	**2030**	**-**	**35**	**95**	**1,787**
	GMTH reactor	**2025**	**-**	**48**	**90**	**1,787**
	Fusion plant	**2050**	**-**	**100**	**76**	**5,333**
SDC	-	-	6	-	85	-
DTI	-	-	-	-	85	1,070-1,400
Oxera	-	-	-	-	95	1,150-1,625
RAE	Nuclear fission plant	-	5	-	85	1,150
	Nuclear fission plant	-	-	-	-	-
WADE	Nuclear installed	-	-	-	-	1,500
	Nuclear	2023	-	-	-	1,830
ECN	Light water reactor	-	6	33.5	-	1,172.41
	Fusion power	2030	6.25	46.3	-	1,776.55
	Existing Nuclear	Existing	-	-	75	-
AEA	New nuclear	2010	-	-	85	1,300
	New nuclear	2020	-	-	85	1,100
MIT	-	-	5	-	75-85	1,111.11
DG EMP	-	-	5	-	-	1,280
T&R	-	-	-	-	-	-
T&L	-	-	5	-	-	1,900
Chicago	-	-	5.3-9.3	-	85	-
CERI	-	-	5	-	-	-
NEA/IEA	-	-	5-10	-	85	611-889
Areva	-	-	5.5	-	90	-
Scully	-	-	5	-	-	-

Table 1: Comparative data: nuclear

Onshore wind

For onshore wind, the MARKAL cost data, which are derived principally from work done for DTI in 2005 by Enviros (see the appendix for a summary) lies in the middle of the range of cost data available in other sources. This is shown in diagram 2.

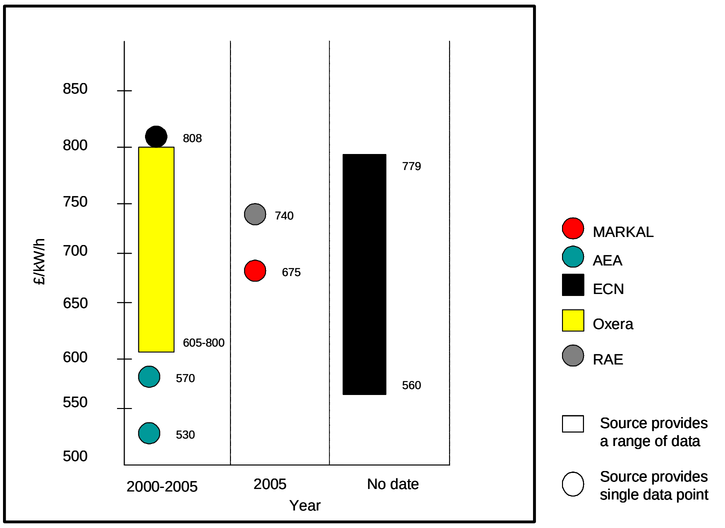


Diagram 2: Comparative capital costs: onshore wind

Available comparable information is shown in table 2 below.

Onshore wind					
Source	*Technology*	*First year available*	*Construction period (years)*	*Availability factor %*	*Capital cost £/kW*
ECN	Inland location	-	0.25	24	580-793
	Shore location	-	0.25	27.4	563-779
	Near shore	2000	1	33.8	808
MARKAL	**Various**	**2005**	**-**	**17-47**	**675**
RAE	Onshore wind	Current	2	35	740
OXERA	Existing onshore	2004	-	30	605-800
AEA (Appendix. D and E)	Wind on-shore 1	2000	-	50	570
	Wind on-shore 2	2000	-	47	530
	Wind on-shore 3	2000	-	45	530
	Wind on-shore 4	2000	-	43	530
	Wind on-shore 5	2000	-	40	530
	Wind on-shore 6	2000	-	37.25	530
	Wind on-shore 7	2000	-	35	530
	Wind on-shore 8	2000	-	31	530

Table 2: Comparative data: onshore wind

Offshore wind

For offshore wind, the MARKAL capital cost estimates (principally from Enviros, plus stakeholder feedback) are at the top end of the range of data for current and future capacity – shown in table 3 below.

Offshore wind

Source	*Technology*	*First year available*	*Construction period (years)*	*Availability Factor %*	*Capital cost £/kW*	*O&M fixed (£/kW)*
RAE	Offshore wind - current	-		35	920	57
OXERA	Offshore wind – existing	2004		35	1,100	-
MARKAL	**Offshore – existing**	**2000**		**39**	**-**	**70**
	Two step resource curve	**2010**	**-**	**30**	**1,141**	**34.74**
ECN	Offshore wind	2010	4	36.5	947	-
RAE	Offshore wind	Future (but no date specified)	2	-	780	-
OXERA	Offshore wind – new plant	2010	-	-	863-1,122	-
AEA (Appendix D and E	Wind Off-shore 1	2020-2040	-	43	765-490	-
	Wind Off-shore 2	2020-2040	-	36	718-450	-
	Wind Off-shore 3	2020-2040	-	36	765-480	-
	Wind Off-shore 4	2020-2040	-	36	812-510	-
	Wind Off-shore 5	2020-2040	-	29	756-480	-

Table 3: Comparative data: offshore wind

Diagram 3 below plots comparative capital costs for future offshore wind. The most directly comparable information relates to 2010 but other information for comparable technologies is also shown for 2020-2040.

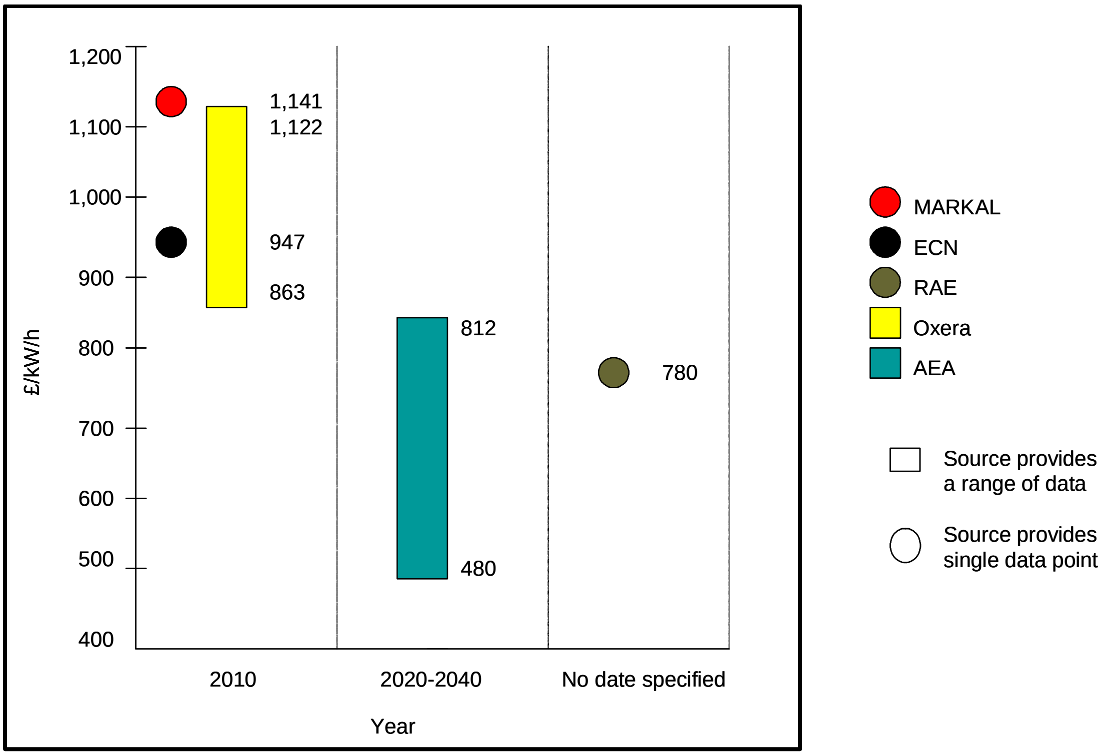


Diagram 3: Comparative capital costs: offshore wind

Solar

Few sources provide comparable information on solar generation. MARKAL data on capital costs for photovoltaics (derived from an IEA survey report[10]) are higher than the ranges set out in AEA

[10] 'National survey report of PV power application in the UK 2004, International Energy Agency, Department of Trade and Industry'.

and markedly higher - approximately 45-50% than the higher estimates provided in the ECN study. However, the wide-ranging cost estimates in the ECN report suggests the uncertainty inherent in these figures and the potential for future cost reductions from learning by doing and market growth.

Diagram 4 plots comparative capital cost data for solar photovoltaic generation.

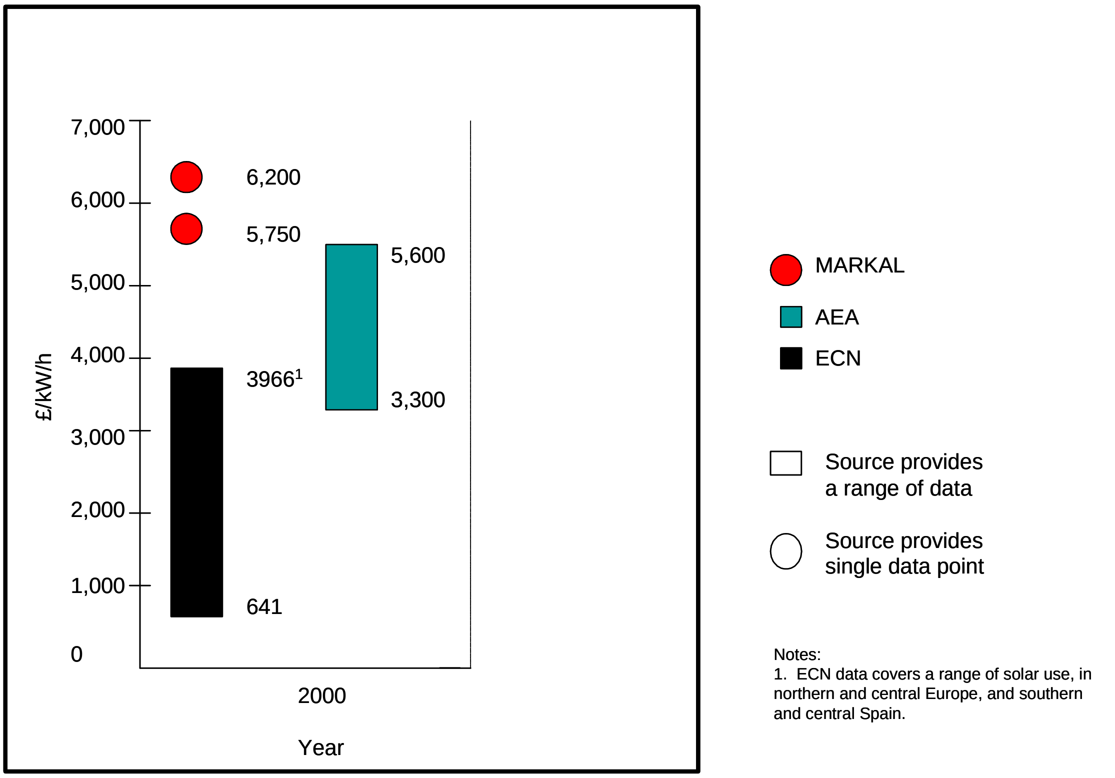


Diagram 4: Comparative capital costs: solar photovoltaic

Solar photovoltaic				
Source	*Technology*	*First year available*	*Availability factor %*	*Capital cost £/kW*
ECN	Northern Europe	2000	10.64	641-3448
	Central Europe	2000	15	641-3449
	Southern Spain	2000	19.4	641-3450
	Central Spain	2000	18.26	663-3966
MARKAL	**Commercial**	**2000**	**9**	**5,750**
	Residential	**2000**	**9**	**6,200**
AEA (Appendix D and E)	PV retro domestic	2000	-	5,600
	PV new build domestic	2000	-	4,300
	PV retro non-domestic (1)	2000	-	3,500
	PV new non-domestic (1)	2000	-	3,300
	PV retro non- domestic (2)	2000	-	5,500
	PV new non domestic (2)	2000	-	3,400
	PV new non-domestic roofs	2000	-	5,300
	PV retro non- domestic roofs	2000	-	4,000

Table 4: Comparative data: solar photovoltaic.

Tidal stream and wave

Comparisons for tidal stream and wave power data are constrained by the immaturity of the technology and the lack of information about the first years of availability. Uncertainties therefore are large. The Carbon Trust report[11] into the cost competitiveness and growth of wave and tidal stream, which contains the most detailed analysis of this area of the market, does not include reference to the date of first availability. It shows steep reductions in cost from first prototypes to first production in both wave and tidal stream farms and suggests learning rates could be around 10-15%. The MARKAL data (from Enviros) lie within the range of the Carbon Trust estimates for first production. Diagram 5 plots the comparative capital cost information.

[11] 'Future Marine Energy: Results of the Marine Energy Challenge: cost competitiveness and growth of wave and tidal stream energy' (2006). The report contains discussion of the difficulty of presenting cost information given the embryonic nature of the industry. For example, it highlights that analysis of prototype costs will not give a robust indication of the commercial costs of energy from marine sources given that prototypes are built as one-offs (thereby not incorporating economies of scale) and that prototype costs will not factor in cost reductions from learning and design improvement.

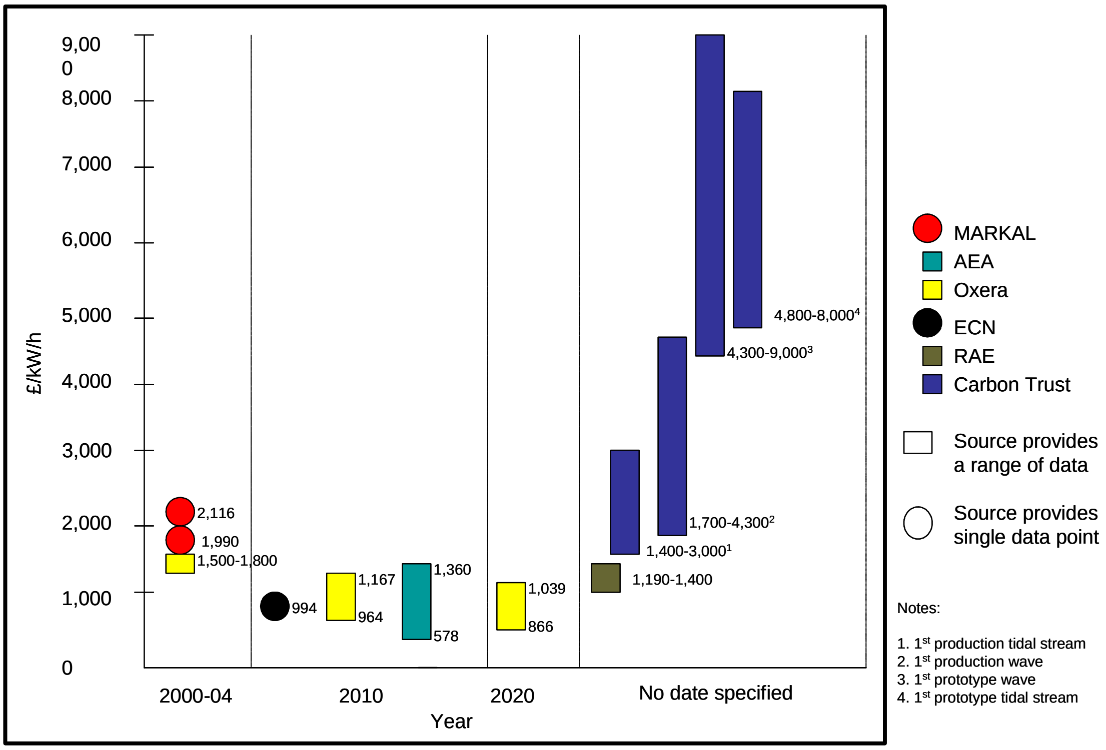


Diagram 5: Comparative capital costs: tidal stream and wave.

Marine				
Source	*Technology*	*First year available*	*Availability factor %*	*Capital cost £/kW*
ECN	Tidal energy	2010	23	994
Oxera	Existing	2004	30	1,500
	New plant	2004	-	1,500-1,800
	New plant	2010	-	964-1,167
	New plant	2020	-	866-1,039
RAE	Wave and marine - current	Not specified	-	1,400
	Wave and marine – future	Not specified	-	1,190
MARKAL	**Tidal stream**	**2000**	**39**	**2,116**
	Offshore wave	**2000**	**39**	**1,990**
Carbon Trust	First prototype wave energy convertor	Not specified	-	4,300-9,000
	First production wave farms	Not specified	-	1,700-4,300
	First prototype tidal stream	Not specified	-	4,800-8,000
	First production tidal stream farms	Not specified	-	1,400-3,000
AEA (Appendix D and E)	Wave off-shore single	2010	-	578-1,145
	Wave off-shore large scale	2010	-	950-1,236
	Tidal stream	2010	-	1,052-1,360
	Wave – shoreline	2010	-	674-1,011

Table 5: Comparative data: wave and tidal stream.

Landfill gas

Just one of the sources (Oxera[12]) contains cost information on landfill gas technologies. The MARKAL capital costs (from Enviros, for DTI, 2005) are considerably lower – roughly 50% - than those shown in Oxera for both large and small scale operations. Diagram 6 plots the capital cost data, with table 6 showing the detailed data.

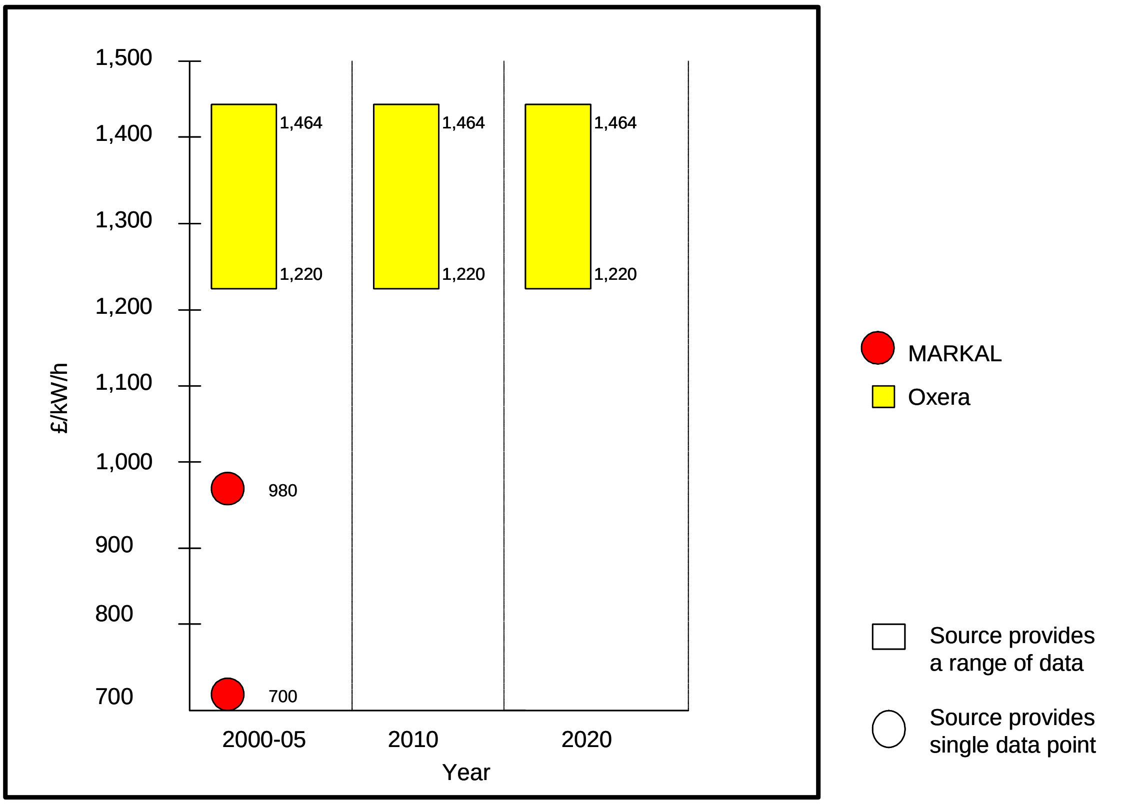


Diagram 6: Comparative capital costs: landfill gas.

Landfill gas				
Source	*Technology*	*First year available*	*Availability factor %*	*Capital cost £/kW*
Oxera	Existing	2004	63	1,464
	New plant	2004	-	1,220-1,464
	New plant	2010	-	1,220-1,464
	New plant	2020	-	1,220-1,464
MARKAL	**Landfill gas driven IC engines – small (<1MW)**	**2000**	**70**	**980**
	Landfill gas driven IC engines – large (>1MW)	**2005**	**70**	**700**

Table 6: comparative data: landfill gas.

Coal-fired plants (including CO_2 capture)

[12] 'Results of Renewables Market Modelling' (OXERA, 2004).

The range of technologies within MARKAL and the alternative sources covers existing technologies and new approaches introduced from 2010 to 2040. The new technologies are typically integrated gasification combined cycle (IGCC). The construction period for new plant is commonly assumed to be 3-5 years.

Within MARKAL, the average efficiency rating for current and future technologies is estimated at 41%, with a maximum efficiency rating of 55% (for new pulverised fuel plant). In the alternative sources, the assumed efficiencies for existing plant are lower, between 31-38%. For future plant, the maximum efficiency is 65% (for new IGCC in 2040), but most projections show a progressive increase in efficiency from the mid-40s to mid-50s, to mid-60s in 2000, 2020 and 2040. The availability factor is assumed to be 90% in most cases within MARKAL but typically lower in the other sources, in the range of 75-90%.

MARKAL's cost data for coal fired plants is drawn principally from work done for DTI in 2005, supplemented by stakeholder feedback. In MARKAL, capital costs range from £320-601/kW for existing coal plant with flue-gas desulphurisation (FGD), and from £765-968/kW for new pulverised fuel plant. Costs decrease over the period 2010-2030 to an estimated £698/kW (for pulverised fuel) in 2030 or £802/kW (for pulverised fuel with CO_2 capture). Costs for coal-pulverised steam plant from the RAE report[13] are estimated at £820/kW currently and £860/kW in future.

For IGCC technologies, the range of costs in 2010 in MARKAL is £891-1210/kW, with the more costly technologies incorporating CO_2 capture plus 10% hydrogen. By 2030, it is estimated that these costs will have fallen to £835-994/kW. In the alternative studies, future IGCC costs with CO_2 capture are broadly within this range – at £1000/kW in the RAE work (although the date is unspecified), and decline from £1,450 to 989 in the AEA study.[14] The ECN[15] work includes an estimate for IG SOFC (integrated gasification solid oxide fuel cells, in which the coal is gasified and the gas provides the input for the fuel cell) with CO_2 separation and sequestration in 2030 of £1093/kW, which is slightly higher than the MARKAL technologies at a comparable date.

O&M fixed cost estimates for future IGCC are slightly higher in the ECN study than in MARKAL, but two to three times higher in the RAE and AEA estimates. These costs reach roughly two or three times those within MARKAL reflecting the steady increase in O&M estimates in AEA as sequestration is added, set against the flat cost estimates within MARKAL from 2010-2040.

Diagram 7 plots the capital cost data for pulverised fuel and table 7 the detailed data.

[13] 'The costs of generating electricity – a study carried out for the Royal Academy of Engineering' (PB Power, 2004).
[14] 'Options for a Low Carbon Future: appendix E' (Energy White Paper modelling).
[15] 'Characterisation of Power Generation Options for the 21st. century' (December 1998); a report by ECN Policy Studies which gives an overview of power generation options in the MARKAL model for Western Europe.

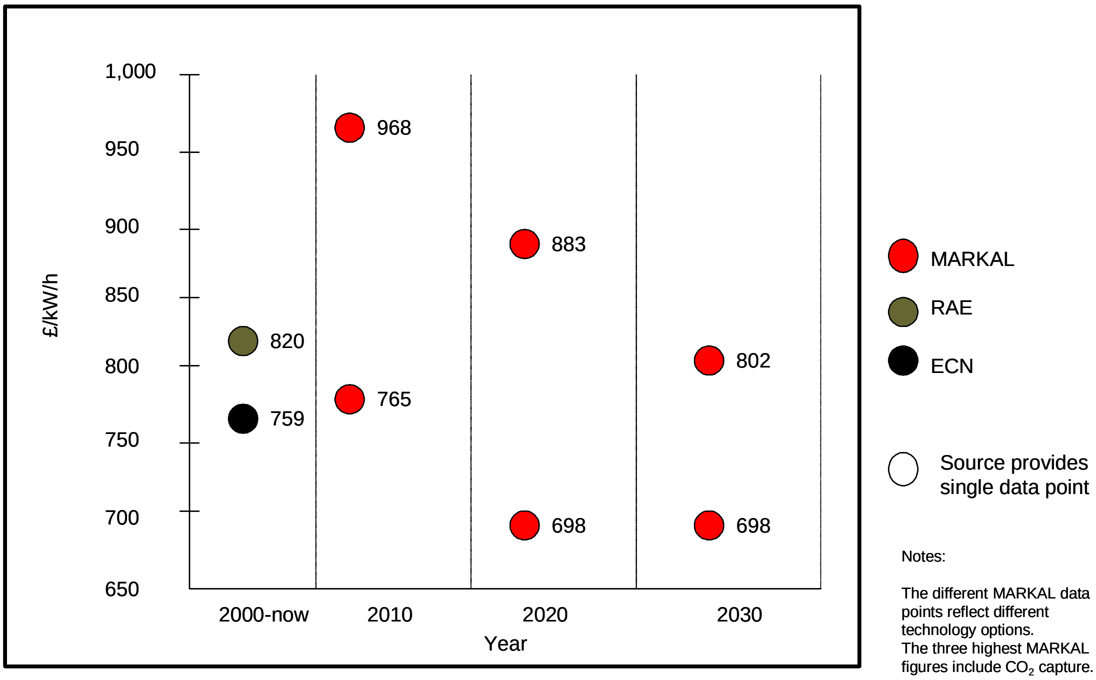


Diagram 7: Comparative capital costs: coal fired (pulverised fuel).

Coal-fired plants: Pulverised fuel						
Source	*Technology*	*First year available*	*Efficiency %*	*Availability factor %*	*Capital cost £/kW*	*O&M fixed (£/kW)*
RAE	Pulverised fuel steam plant	Now	38	-	820	24
	Pulverised fuel steam plant	Future	40	-	860	-
MARKAL	**New PF**	**2010**	**45.6**	**90**	**765**	**17**
	New PF	**2020**	**50**	**90**	**698**	**17**
	New PF	**2030**	**55**	**90**	**698**	**17**
	New PF with CO_2 capture	**2010**	**36.6**	**90**	**968**	**26**
	New PF with CO_2 capture	**2020**	**43**	**90**	**883**	**26**
	New PF with CO_2 capture	**2030**	**48**	**90**	**802**	**26**
ECN	Advanced Pulverised Fuel	2000	-	75	759	26

Table 7: comparative data: coal fired (pulverized fuel)

Diagram 8 plots the capital cost data for IGCC plant, and table 8 the detailed data.

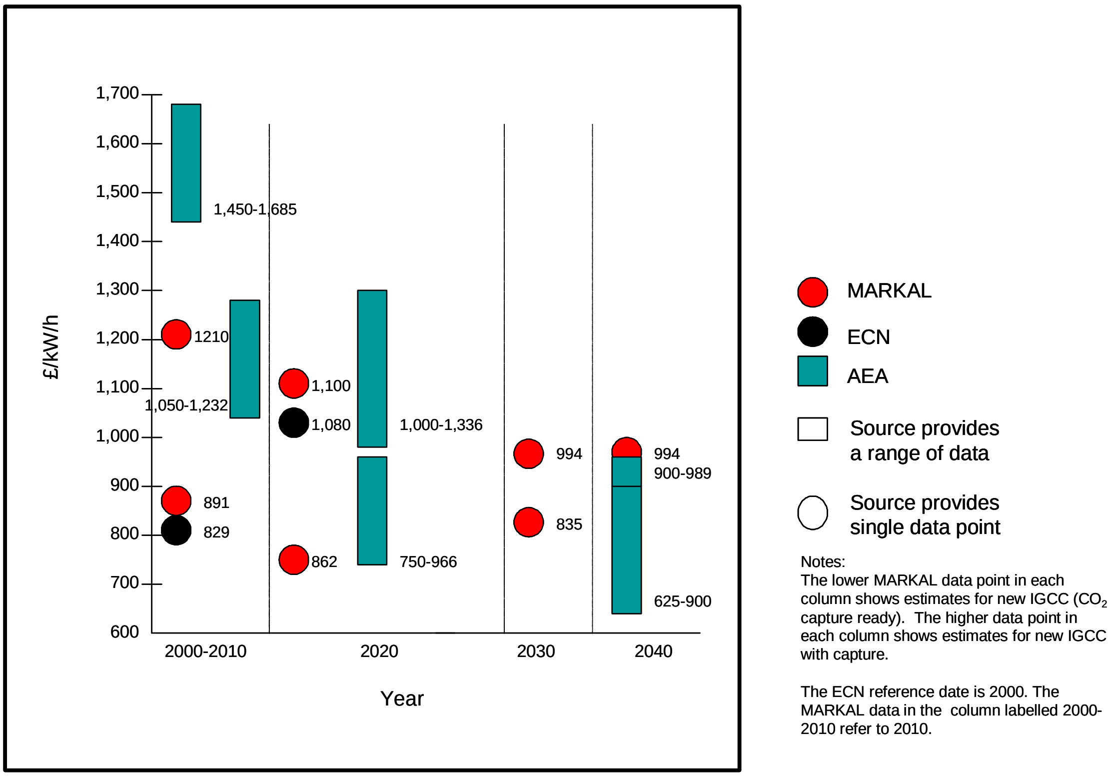


Diagram 8: Comparative capital costs: IGCC

Coal-fired plant: IGCC					
Source	*Technology*	*First year available*	*Availability factor %*	*Capital cost*	*O&M cost (£/kW)*
MARKAL	**New IGCC (CO_2 capture ready)**	**2010**	**90**	**891**	**19**
	New IGCC (capture ready)	**2020**	**90**	**862**	**19**
	New IGCC (capture ready)	**2030**	**90**	**835**	**19**
	New IGCC (with capture)	**2010**	**90**	**1210**	**26**
	New IGCC (with capture)	**2020**	**90**	**1100**	**26**
	New IGCC (with capture)	**2030**	**90**	**994**	**26**
	New IGCC (with capture) + 10% hydrogen	**2010**	**90**	**1210**	**26**
	New IGCC (with capture) + 10% hydrogen	**2020**	**90**	**1100**	**26**
	New IGCC (with capture) + 10% hydrogen	**2030**	**90**	**994**	**26**
	New IGCC (with capture) + 10% hydrogen	**2040**	**90**	**994**	**26**
ECN	IGCC	2000	75	829	21
	IGCC with water gas shift conversion and sequestration	2010	75	1080	30
	IG SOFC with CO_2 separation and sequestration	2030	75	1093	37

AEA (Appendix D and E)	New IGCC	2000	85	1,050-1,232	52
	New IGCC	2020	87.5	750-966	52
	New IGCC	2040	90	625-900	52
	New IGCC/CO_2	2000	85	1,450-1,685	72.9
	New IGCC/CO_2	2020	87.5	1,000-1,336	72.9
	New IGCC/CO_2	2040	90	900-989	72.9

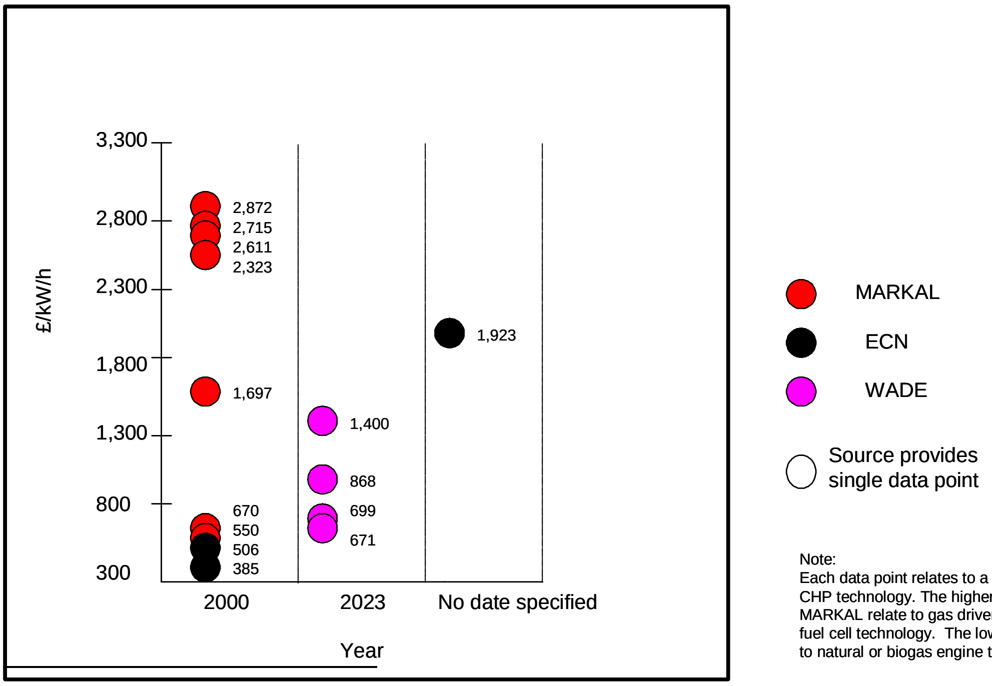
Table 8: comparative data: IGCC

Combined Heat and Power (CHP)

Two sources contain capital cost information on CHP. The WADE model assumes that gas, coal or renewable CHP in a decentralised system would first become available in 2023. The 2023 capital costs are £671/kW for gas CHP, £699/kW for gas micro-CHP, £1,400/kW for coal CHP and £868/kW for renewable CHP.[16]

The second source with information about CHP, the ECN report, dates from 1998. It contains an even broader range of capital costs, from £385/kW (combined cycle CHP) to £1,923/kW for fluidised bed combustion CHP technology.

These wide ranges are reflected in the MARKAL capital costs data which are drawn principally from work done for DTI for the 2003 Energy White Paper and from the work of Hawkins et al.[17] CHP costs range from a figure of £550/kW for natural gas fired combined cycle CHP plant to £2,872/kW for Hydrogen PEMFC–CHP (proton exchange membrane fuel cell) over 200kW. Diagram and table 9 show comparative capital cost data. In this table, figures from the WADE analysis have been included even though they pertain to a different year to the figures within MARKAL. This is to provide the alternative perspective which the WADE analysis offers.



Note:
Each data point relates to a different type of CHP technology. The higher values within MARKAL relate to gas driven or hydrogen fuel cell technology. The lower values relate to natural or biogas engine technology.

[16] These figures are taken from Annex 1 to the WADE report, which contains a number of tables of input data and information about assumptions used in the model.
[17] Hawkins et al: 'Hydrogen fuel cells for stationary power' (2005)

Diagram 9: Comparative capital costs: CHP

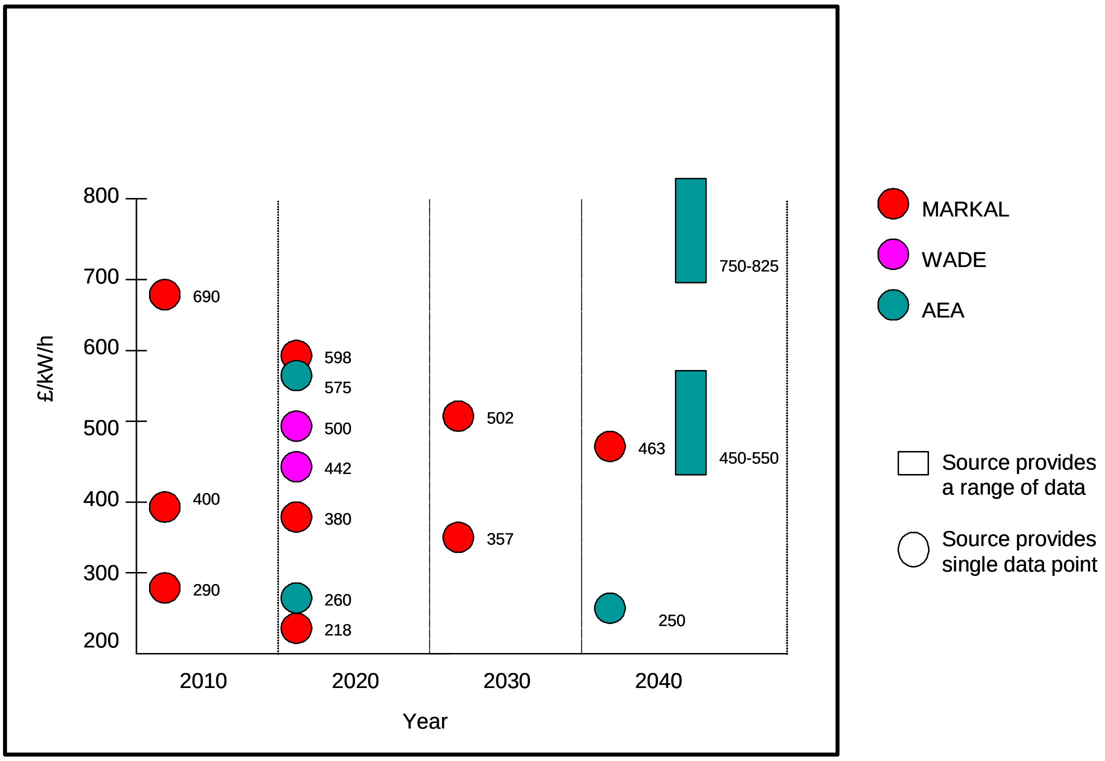
CHP			
Source	*Technology*	*First year available*	*Capital cost £/kW*
ECN	Gas turbine– thermal / electric	2000	506
	Combined cycle – thermal / electric	2000	385
	Fluidised bed combustion	Not specified	1,923
MARKAL	**Natural gas engine**	**2000**	**670**
	Natural gas fired gas turbine	**2000**	**550**
	Biogas engine	**2000**	**670**
	Gas driven MCFC	**2000**	**2,611**
	Gas driven MCFC	**2020**	**862**
	Gas driven MCFC – 2MW	**2000**	**1,697**
	Gas driven MCFC – 2MW	**2020**	**731**
	Gas driven SOFC	**2000**	**2,323**
	Gas driven SOFC	**2020**	**940**
	Hydrogen PAFC	**2000**	**2,715**
	Hydrogen PEMFC	**2000**	**2,872**
	Hydrogen PEMFC	**2020**	**1,148**
	Hydrogen PEMFC >200kW	**2000**	**2,872**
	Hydrogen PEMFC >200kW	**2020**	**887**
WADE	Gas CHP	2023	671
	Gas micro-CHP	2023	699
	Coal CHP	2023	1,400
	Renewable CHP	2023	868

Table 9 comparative data: CHP.

Gas-fired plant

For gas-fired plant, that is new GTCC technology (gas turbine combined cycle), MARKAL costs are higher than those in AEA. For new GTCC with CO_2 capture (by 2040), MARKAL costs are initially slightly higher than those in AEA but are lower by 2040. This reflects the steady decline in estimated costs in MARKAL for this technology from 2010-2040. There is less data in AEA but what there is also shows declining costs, but less pronounced. MARKAL also shows estimated costs for retrofitting CO_2 capture on existing GTCC (in 2020) to have lower capital costs than new GTCC without CO_2 capture in AEA.

For 2040, MARKAL's single cost (£463/kW – for new GTCC with CO_2 capture) lies in the mid-range of the AEA data (£250-550/kW) for GTCC technologies with and without CO_2 capture. The outlying higher cost in AEA (in 2040) relates to gas fuel cell technology with sequestration.



800
700
600
500
400
300
200
£/kW/h
690
400
290
598
575
500
442
380
260
218
502
357
463
250
750-825
450-550
2010
2020
2030
2040
Year
MARKAL
WADE
AEA
Source provides a range of data
Source provides single data point

Diagram 10: Comparative capital costs: gas-fired

Gas-fired plant			
Source	*Technology*	*First year available*	*Capital cost £/kW*
AEA (Appendix D and E)	New GTCC	2020	260
	New GTCC /CO_2	2020	575
	New GTCC	2040	250
	New GTCC / CO_2	2040	450-550
	Gas/FC/CO_2	2040	750-825
MARKAL	**Existing GTCC (CO_2 capture retrofit)**	**2010**	**290**
	Existing GTCC (CO_2 capture retrofit)	**2020**	**218**
	New GTCC	**2010**	**400**
	New GTCC	**2020**	**380**
	New GTCC	**2030**	**357**
	New GTCC with CO_2 capture	**2010**	**690**
	New GTCC with CO_2 capture	**2020**	**598**
	New GTCC with CO_2 capture	**2030**	**502**
	New GTCC with CO_2 capture	**2040**	**463**
WADE	Gas T and oil engines	2023	500
	Gas CCGT	2023	442

Table 10: comparative data: gas-fired plant

Conclusions

This paper has reviewed has energy technology cost information from a number of studies undertaken at different times and with different assumptions about cost allocations, within and across a range of technologies. Inevitably therefore the comparison of such data has many difficulties, limitations and uncertainties, and caution must be exercised in pushing it, and any resulting conclusions, too far. Nevertheless, it is important to attempt such a comparison, especially in order to give insights into the results from a model such a MARKAL, which are totally dependent on the input cost data.

For the cost estimates for one of the most contentious energy technologies (in some countries at least), nuclear power, the capital cost data (which is the most important single element of overall costs) used in MARKAL falls mainly within the range of cost estimates in other studies. Where ranges of costs are provided in the other studies, these lie within the range of the data used in MARKAL for the different nuclear technologies (see diagram 1). The exception is the NEA/IEA data, which is significantly lower than other estimates.

In other technology areas, the correlation between the data used in MARKAL and the data in other studies is less consistent. Within the area of renewables, MARKAL data lies squarely in the mid-range of estimates for onshore wind (diagram 2) and for future first production of wave and tidal stream (diagram 5). The range of potential future costs for wave and tidal sources, however, is very wide, reflecting the lack of practical experience to date. For offshore wind, MARKAL's estimated costs for future capacity lie just above the top of the ranges provided by other estimates (diagram 3). MARKAL costs are markedly higher for solar photovoltaics (diagram 4) but there is very little comparable data to consider and very wide ranging cost estimates exist. For landfill gas technologies (diagram 6), MARKAL data are markedly lower than other estimates, but the resource is limited and is already largely exploited, so this makes little difference to model results.

For coal fired plant, MARKAL costs are within 10-20% of the estimated costs in other sources for future pulverised fuel plant (diagram 7). MARKAL costs diverge furthest from the other estimate in 2020 and 2030, because MARKAL capital costs fall by just under 10% compared with 2010. For IGCC plant with CO_2 capture, MARKAL capital costs are lower than those in AEA up to 2020 but AEA's estimated O&M costs are considerably higher (about three times as high) (diagram 8). MARKAL and AEA capital costs show a similar rate of decline over this period, while O&M costs remain constant in both sources. By 2040, the estimated capital costs are almost the same.

For CHP, comparable data is very limited. Future cost projections show very broad ranges in MARKAL and in other sources (diagram 9).

For gas-fired plant, MARKAL covers a range of possibilities including existing, new and CO_2 retrofitted GTCC technologies. The estimated capital costs in MARKAL are slightly higher than in comparable data initially but fall to being slightly lower by 2040 (diagram 10). The costs of retrofitting CO_2 capture technology are also shown as being lower than new construction without CO_2 capture.

It should also be noted that different conclusions from those derived from the MARKAL model may result from other analyses even when there is basic agreement on the range of costs/kWh. This is because MARKAL's results, and those from other analyses, will be influenced by other assumptions, such as constraints on the role to be played by different sources of power, as well as by the modelling methodology employed.

Appendix: Summary of key individual sources

This appendix provides summaries of sources which contain information on the costs of electricity generation. In each case, basic information about the source is provided followed by a description of the key assumptions that have been used when defining costs or other features which shape the analysis such as fuel prices or costs of capital. A brief summary of the source's conclusions is provided.

Tables and charts from the source documents have been reproduced where they provide cost information which is likely to be of interest but not readily comparable to the data sets within the MARKAL model.

The following sources are summarized:

<table>
<tr><td>'Economics of Nuclear Power: A report to the Sustainable Development Commission' (NERA, University of Sussex).</td><td rowspan="4">Reviews of the available evidence which present comparative information from different studies or industry information.</td></tr>
<tr><td>The economics of nuclear power: analysis of recent studies' by Steve Thomas (PSIRU).</td></tr>
<tr><td>'Alternative fuels for transport and low carbon electricity generation: A Technical note' by Robert Gross and Ausilio Bauen (ICEPT).</td></tr>
<tr><td>'The New Economics of Nuclear Power' by the World Nuclear Association.</td></tr>
<tr><td>'The Economic Future of Nuclear Power' (University of Chicago).</td><td rowspan="4">Studies which include their own cost information on different electricity generating technologies, or that arising from alternative market structures.</td></tr>
<tr><td>'The Costs of Generating Electricity': A study carried out for the Royal Academy of Engineering.</td></tr>
<tr><td>'Future Marine Energy: Results of the Marine Energy Challenge: Cost competitiveness and growth of wave and tidal stream energy' (Carbon Trust)</td></tr>
<tr><td>Decentralizing UK energy: cleaner, cheaper, more secure energy for the 21st century: Application of the WADE economic model to the UK. (A report for Greenpeace).</td></tr>
</table>

1	**Source Title**	**'Economics of Nuclear Power: A report to the Sustainable Development Commission'**
	Author	University of Sussex and NERA Economic Consulting
	Date of publication	November 2005
2	**Abstract**	None provided
3	**Purpose of the research / analysis**	To review the evidence on the costs of nuclear power generation on behalf of the Sustainable Development Commission in the light of the Government's 2006 Energy Review.
4	**Comment on the method and assumptions**	The study gathers and comments on other work into nuclear costs. Relevant tables from the review are provided below. In some cases, it uses the information gathered as a basis for making a judgment about appropriate costs.
5	**The source's key conclusions**	The full costs of nuclear power are as hard to calculate today as they ever have been, particularly when trying to apply overseas experience to UK circumstances. The most problematic area is capital costs. As these represent approximately 60-75% of total generating costs, it makes overall accurate cost estimation difficult given the sensitivity of this to overruns and variations in the cost of capital. Accurate cost assessment is hampered by many factors including difficulties in estimating costs of decommissioning and waste disposal, the way in which the industry is financed (with or without government support), and the variation in fuel cycle costs because of their dependence on the technology being used. Industry cost estimates must be treated with caution – they tend towards 'appraisal optimism'. There are wide divergences in cost estimates (see the various tables below). These estimates do not capture the real uncertainties of current UK circumstances which need to take account of issues like the costs of decommissioning or waste disposal.
6	**Comment on conclusions**	This is an authoritative report because it compiles and reviews in a rigorous and systematic way previous studies and evidence on the costs of nuclear power. Its conclusions are principally about the reliability or uncertainty of data from the nuclear industry rather than on the merits (or otherwise) of nuclear in relation to other source of generation. The uncertainties revealed in the review about definitions and allocations of nuclear cost continue to cast doubt on the economic case for increased nuclear generation in the UK.

Cost information within the SDC report

Representative proportions of electricity generating costs (%)			
	Nuclear	CCGT	Renewable (wind)
Construction or capital (including interest during construction)	60-75	30-40	85-90
Fuel	5-10	50-65	0
Operations and Maintenance	8-15	5-10	5-15
Back end (waste and decommissioning)	*	0	0
* denotes uncertainties such as whether spent fuel is reprocessed or treated as waste.			
Source: Table 3.1 of SDC report, adapted from 'International Energy Agency (2001) 'Nuclear Power in the OECD'.			

Different cost estimates: capital costs				
Original source	Year	Capital costs /kW	First / nth unit	Included/excluded
DTI	2003	£1070-1400	Not known	Not known
RAE	2004	£1150	Probably nth	Not clear
Oxera	2005	£1150-1625	£1,625 first £1,150 nth	Includes 30% contingency for first reactor, licensing, public enquiry, start up costs
NEA/ IEA	2005	$1100-2500	Probably variable	Overnight costs only
Areva	2005	€1252	Nth	Includes start up costs
Tarjanne & Rasmussen	2000	€2160	First	Not known
Scully	2004	$1000-1600	$1,600 first $1,000 nth	Appears to exclude owner's cost / contingency. No financing included.
MIT	2002	$2000	Not specified	Includes adjustments of 10% for contingency plus 10% for optimism.
University of Chicago	2004	$1080-1980	Variable according to estimate.	Excludes financing costs. Owner's costs included. Plus first of a kind engineering costs for higher estimates.

Different cost estimates: Fuel, O&M, and back-end				
Original Source	*Source year*	*Fuel cost*	*O&M cost*	*Back-end*
DTI	2003	N/A	N/A	N/A
RAE	2004	0.4p/kWh	0.45 p/kWh	Decommissioning costs within capital cost
OXERA	2005	0.3p/kWh	0.35p/kWh	£500m fund at 40 years
NEA /IEA	2005	0.28-1.18 USc/kWh	46-108USD/kW	Decommissioning included in construction cost
Areva	2005	0.44€c/kWh	€c51/kW	Decommissioning €6.5/kW
Tarjanne and Rissanen	2000	0.1€c/kWh	0.34€c/kWh	N/A
Scully	2004	0.5USc/kWh	0.5USc/kWh	$400m fund at 40 years
University of Chicago	2004	0.3USc/kWh	0.56USc/kWh	$300m fund
MIT	2002	0.15USc/kWh (fuel plus O&M)		N/A

Estimated load factors									
DTI	RAE	Oxera	NEA/IEA	Areva	Finland	Scully	MIT	Univ. Chicago	SDC report conclusion
85	85	95*	85	90.3	91	90	75-85	85	85
* The SDC report suggests the Oxera figure is optimistic given it exceeds any consistent historic world performance.									

Overall cost estimates from six studies				
Study	Method	Assumption about no. of units built	Central results	Sensitivity/ range
MIT	Levelised	Not clear, poss. 1st.	6.7USc/kWh	4.9-7.9c
RAE	Levelised	Not clear	2.26p/kWh	2.44p
NEA/IEA	Levelised	Not clear	3USc-5USc/kWh	-
Chicago	Levelised	1st unit	6.2USc/kWh	5.2c-7.1c
Scully	Levelised	1st unit	3.8-4.2USc/kWh	3.4c-3.7c
Oxera	Levelised	1st unit	Produces internal	IRR of 10.6%-13.6%

			rate of return (IRR) of 8-11% (nominal while market may need 14-16%)	(8th unit).

1	**Source Title**	**'The Costs of Generating Electricity: A study carried out for the Royal Academy of Engineering'**
	Author	PB Power
	Date of publication	March 2004
2	**Abstract**	None provided
3	**Purpose of the research / analysis**	To provide decision makers with simple, soundly based indicators of cost performance for a range of different generation technologies and fuels.
4	**Comment on the method and assumptions**	Focuses on nine well established technologies appropriate to the UK, as well as those likely to establish themselves over the next 15-20 years. (Hydroelectric and solar are excluded from the analysis). Solely concerned with generation costs and not electricity prices. Does not consider extending the life of existing plant, but concentrates on costs of new plant. Has sought to develop a 'robust approach' to the issue of intermittency, which involves adding an additional cost to cover the provision of standby generation. For small levels of wind penetration, the equivalent firm capacity added to the system is estimated to be 35% of the installed capacity.(The UK Energy Research Centre report on the 'Costs and Impacts of Intermittency' refers to a range of estimates for 'capacity credits' equaling 20-30% of installed capacity when up to 20% of electricity is sourced from intermittent supplies). Costs include capital costs of generating plant and equipment, the cost of fuel (if applicable), and operating and maintenance costs. An allowance is included in the capital cost estimates for nuclear for decommissioning. For other technologies the analysis assumes that decommissioning is cost neutral. 'Reasonable benchmarks' have been used to estimate fuel costs, taking account of historical prices and key drivers affecting future fuel prices. A base cost of coal at £30/tonne and of natural gas at 23 pence per therm has been used, with sensitivity analyses examining the impact of plus or minus 20% in fuel price. A notional cost for CO_2 emissions within a range of £0-30 was used.
5	**The source's key conclusions**	The cheapest form of baseload generation from future new plant is by constructing combined cycle gas turbine (CCGT) plant to burn natural gas. For peaking operations, open-cycle gas turbines are the most appropriate. Renewables are generally more expensive than conventional technologies, due in part to their immaturity and limited scope for economies of scale. Fluctuations in the source of energy also adversely affects units costs of generation and the reliability / security of supply. CCGT plant become a better option than coal as the cost of CO_2 increases, due to the low carbon content of natural gas. The study concludes that the costs of generating electricity from nuclear plant are less than coal and

		integrated gasification combined cycle (IGCC) plant an considerably cheaper than selected renewables. The costs of generating electricity with respect to carbon dioxide emission costs makes nuclear even more attractive.
6	**Comment on conclusions**	The study rightfully highlights the difficulties in making cost comparisons but does not always set out its own assumptions about costs. For example, it does not provide information about the costs of nuclear decommissioning within the capital cost structure. The study's conclusions on renewables are notable in that the RAE conclude that renewables costs are approximately three times those of other forms of generation. In the case of renewables, the potential cost downsides of immature technologies, small markets, and intermittent supply are emphasized rather than the potential cost upsides of renewables growth through learning-by-doing, growing economies of scale, and detailed understanding of the effects and costs of variable supply. The study's assumptions on nuclear power, by contrast, are consistently more optimistic. This leads to the report's conclusion that nuclear is a competitive low cost (and, of course, low carbon) form of generation.

1	**Source Title**	**'The Economic Future of Nuclear Power'**
	Author	University of Chicago
	Date of publication	August 2004
2	**Abstract**	'Developments in the U.S. economy that will affect the nuclear power industry in coming years include the emergence of new nuclear technologies, waste disposal issues, proliferation concerns, the streamlining of nuclear regulation, a possible transition to a hydrogen economy, policies toward national energy security, and environmental policy. These developments will affect both the competitiveness of nuclear power and appropriate nuclear energy policies. A financial model developed in this study projects that, in the absence of federal financial policies aimed at the nuclear industry, the first new nuclear plants coming on line will have a levelized cost of electricity (LCOE, i.e., the price required to cover operating and capital costs) that ranges from $47 to $71 per megawatt-hour (MWh). This price range exceeds projections of $33 to $41 for coal-fired plants and $35 to $45 for gas-fired plants. After engineering costs are paid and construction of the first few nuclear plants has been completed, there is a good prospect that lower nuclear LCOEs can be achieved and that these lower costs would allow nuclear energy to be competitive in the marketplace. Federal financial policies that could help make early nuclear plants more competitive include loan guarantees, accelerated depreciation, investment tax credits, and production tax credits. In the long term, the competitiveness of nuclear power could be further enhanced by rising concerns about greenhouse gas emissions from fossil-fuel power generation.'
3	**Purpose of the research / analysis**	Carried out on behalf of the US Department of Energy. Compares nuclear competitiveness with coal and gas-fired generation. Used a financial model to generate a range of scenarios.
4	**Comment on the method and assumptions**	Examines three different 'overnight' costs for nuclear plants depending on how much 'first of a kind engineering' (FOAKE) costs are included. The three different costs are: $1200 per kW, $1500 per kW, and $1800 per kW. Coal plant are included with overnight capital costs of $1189 to $1338 per kW CCGT plant are estimated at $590 per kW. Gas prices are constant in most scenarios, while coal prices are expected to fall from 2003 levels. Construction time for a nuclear station is assumed to be 5.3-9.3 years. The cost of capital is assumed at 10% on loan capital and 15% on equity. Assume a load factor of 85%.
5	**The source's key conclusions**	First nuclear power unit will have a levelized power cost of $47-71 per MWh, depending on the cases taken. CCGT and coal plants will be in the range of $33 (for coal) to $45(for gas-fired

		plant) per MWh. A fourth or fifth nuclear plant without FOAKE costs and assuming a 3% learning by doing component, a 5 year construction period, and no 3% premium risk on financing will produce power at \$34-36 per MWh.
6	**Comment on conclusions**	The conclusion that first nuclear power is considerably more expensive than CCGT and coal is consistent with other independent (i.e., non- industry) studies. The conclusion that costs can be substantially reduced through multiple production (leading to economies of scale, learning by doing) is comparable to cost assumptions often used for other generating technologies.

1	**Source Title**	**Decentralising UK energy: cleaner, cheaper, more secure energy for the 21st century. Application of the WADE economic model to the UK.**
	Author	World Alliance for Decentralized Energy (WADE)
	Date of publication	March 2006
2	**Abstract**	None provided
3	**Purpose of the research / analysis**	Carried out on behalf of Greenpeace in the context of the UK Energy Review. Seeks to quantify the benefits for the UK in adopting a decentralized energy system. Uses the WADE model to compare traditional centralized generation (CG) systems to decentralized energy (DE) systems using local generation, under the same conditions for growth, fuel costs. The work examines two baseline scenarios for the UK (nuclear CG and decentralized renewables, DE) and a third 'Greenpeace' scenario (providing an alternative approach as described below). The core input assumptions and parameters are summarized in the table below:

Scenario	Centralised nuclear	DE/ Renewables	Greenpeace
Demand growth	Total load 0/5%, peak load 0.7%	Total load: 0.5%; peak load 0.7%	Total load: -0.5% and peak load -0.3%
New generation capacity: transmission, distribution modality	100% CG	75% DE, 25% CG	
New generation capacity: generation technology mix	Initially, most new capacity added is CCGT. However, the CCGT share is reduced as the share of renewables and nuclear energy increases. No new nuclear generation is built until 2018, when it is increased as rapidly as possible to maximise the capacity of new plant built by 2023.	Initially, new decentralized capacity is mostly gas-fired district scale CHP, but its share falls over the 20 years period in favour of gas fired micro CHP, renewable (such as high quality biomass) CHP and other small-scale renewables. New centralised capacity is purely renewable: mainly onshore and offshore wind, with an increasing amount of biomass energy.	For CG no nuclear, coal or oil-fired plant are built. Initially, most new CG is gas, but the share of renewables rises sharply to almost 90% of new capacity built in year 20. New DE is primarily gas to begin with, but the share of renewables is increased sharply, so that by year 20 they constitute almost 100% of new DE capacity built that year.
Final renewable share of generation	14.4% (currently 4.9%)	24.9% (currently 4.9%)	27% (DE case) to 31% (CG case).
Final installed CHP capacity	2.6GWe (currently 4.9 GWe)	33.7 GWe (currently 4.9 GWe)	2.6GWe (CG case) to 25.9 GWe (DE case).

4	**Comment on the method and assumptions**	Input data for the UK baselines scenarios is set out in Annex 1 to the report, with the sources for these inputs detailed at Annex 2. Annex 3 contains the assumptions used for each generation scenario. (Annex 4 sets out the full results). *Annex 1:* Information is provided on existing generation and capacity, CO_2 factors used, system growth properties, pollution (in PM10, SOx, and NOx), heat rates/ fuel consumption, yearly retirement and future growth determination, average operating, maintenance and fuel expenses; transmission and distribution costs for new capacity, and capital / investment costs. *Annex 2: overview of key data sources for different cost categories*

		Capital costs: For centralized generation: WADE sources, Uranium Information centre, The Economics of Nuclear Power For decentralized: WADE, various. For transmission & distribution: WADE, various. O&M costs: For centralized generation: WADE, various For decentralized (CHP): Jon Slowe (DELTA Energy & Environment), WADE applied to Republic of Ireland. Fuel costs: For centralized generation: DTI, COGEN Europe; Uranium Information centre; WADE, various For decentralized: DTI, WADE, COGEN Europe. All figures used in the model application are from 2003. *Annex 3:* For each scenario, assumptions are made about the proportions of new generation capacity over a 20 year period.
5	**The source's key conclusions**	Decentralized energy is more cost effective in reducing UK CO_2 emissions than centralized generation including a nuclear component, and reduces reliance on fossil fuels. Decentralizing the energy system could reduce the UK's CO_2 emissions from electricity generation by 17% more than centralized nuclear generation by 2023. A scenario where 75% of new generation capacity is decentralized lowers the cost of electricity by 6% compared to a scenario where all new capacity is centralized and ambitious installation rates for newly built nuclear power stations were pursued. Decentralized energy reduces reliance on fossil fuels. Costs and CO_2 emissions are strongly influenced by fuel prices and electricity demand. A decentralized, high-renewable energy system could reduce CO_2 emissions in the UK by almost 30% more than a centralized system where ambitious installation rates for newly built nuclear power plants were pursued.
6	**Comment on conclusions**	The WADE conclusions are based on scenarios which contain a number of visionary or aspirational assumptions about a future decentralized energy system which includes a high proportion of energy derived from renewables. While the assumptions are clearly stated, and reference is made to existing markets where decentralized energy generation is widespread, the analysis is based on circumstances which are very different to those which currently exist in the UK, and some might regard the assumptions as unrealistic. The implications, costs, and barriers to transforming the market in this way are not explored. The conclusions need to be viewed with this in mind.

1	**Source Title**	**'The New Economics of Nuclear Power'**
	Author	World Nuclear Association (WNA)
	Date of publication	Not stated (but after 2005)
2	**Abstract**	None provided
3	**Purpose of the research / analysis**	The aim is to 'highlight that nuclear build is fully justified on the strength of today's economic criteria' and to promote understanding of this complex topic. The context for the report is the position of nuclear power within governments' requirements worldwide for security of supply, reducing GHG emissions, and providing economic supplies of fuel. Nuclear, like other areas, must be able to demonstrate that it is cost effective and safe in a liberalized energy market environment.
4	**Comment on the method and assumptions**	The report distils recent studies by government and academic institutions, and incorporates nuclear industry expertise from WNA members. Important assumptions: • capital costs account for approximately 60% of the levelized cost of electricity of a new nuclear plant, about 20% of the investment in CCGT plants, and up to 90% of a renewable energy project. • limited information exists on construction costs given lack of new builds in the 1990s and high costs of construction in the US in the 1980s and 1990s. • Capital cost estimates vary significantly. Important reasons why include: o Discount rates used (i.e. the cost of capital). o First-of-a-kind engineering costs – these are sometimes included and sometimes not. o Some estimates include reductions for 'learning by doing'; others do not. o Some estimates are for building two or more reactors simultaneously on one site. • Defines capital costs as expenditure on equipment, engineering and labour (so-called 'overnight costs' mostly covering engineering-procuring-constructing) which are exclusive of interest and financing cost during construction. • Construction interest costs are recognized as an important element of total capital costs – and can reach 30-40% of the overall expenditures incurred by construction. The industry believes that the construction period can be as low as 4 years, as opposed to the 5 or 7 year period included in some analyses. • Capacity factors of nuclear plants around the world have increased by ten percentage points since 1990, from 70-80%. In particular countries, the improvement is even more dramatic – for example, in the United States from 66% to 90%. Levels of 90% and above have been achieved by many plants in Europe and Asia for many years. • O&M costs are affected by many country specific factors. In Finland and Sweden, 'levels of 1€ cent per kWh have been achieved'. In Germany, 'spent fuel charges tend to be higher so marginal costs are usually around 1.4€ cents per kWh. In France, the combined O&M and fuel cost for EDF's fleet of plants has also been quoted at 1.4€ cents per kWh'. • In general, O&M costs tend to represent about 20% of total costs. • 'Relative stability in the overall generating costs of nuclear power plants'…due to 'lower uranium and enrichment prices together with

		new fuel designs allowing higher burnups'. • 'O&M costs have now stabilized at levels competitive with other base-load generation'. These costs are 'generally low relative to those of alternative generating technologies'. • 'The example of France (58 reactors) shows that industrial organization and standardization of a series of reactors allowed construction costs, construction time and operating and maintenance costs to be brought under control'. • The high proportion of capital costs to operating costs makes nuclear power a baseload energy source.
5	**The source's key conclusions**	The principal conclusion of the report is stated to be as follows: 'In most industrialized countries today, new nuclear power plants offer the most economical way to generate base-load electricity – even without consideration of the geopolitical and environmental advantages that nuclear energy offers'.
6	**Comment on conclusions**	The study, prepared by a WNA working group, cannot be described as objective. While claiming to be 'authoritative' some of its statements and claims simplify the advantages of nuclear generation and fail to do justice to the complexity of economic and environmental concerns about nuclear power. The paper reviews the different elements of the economics of nuclear power, citing examples of good industry practice and drawing on data from other studies, to make its claims for nuclear's benefits. It does not, however, make detailed economic comparisons with other forms of generation and does not discuss complicating factors such as planning constraints, public opinion, waste or decommissioning.

1	**Source Title**	**'Future Marine Energy: Results of the Marine Energy Challenge: Cost competitiveness and growth of wave and tidal stream energy'.**
	Author	Carbon Trust
	Date of publication	2006
2	**Abstract**	None provided
3	**Purpose of the research / analysis**	Presents the findings from the 18 month 'Marine Energy Challenge' a programme of engineering support to accelerate the development of marine renewable energy technologies. The aim of the study was to: • Determine what affects the costs and performance of marine renewables, and the costs of electricity generated from wave and tidal stream. • Assess the potential for future cost reduction to see if they can become cost competitive with conventional generation. • Determine whether these approaches could supply large quantities of electricity and make a material contribution to energy supply and carbon emission reduction.
4	**Comment on the method and assumptions**	Describes capital costs for both first prototypes and first production models, since these can be estimated reasonably well and comparisons are instructive. Allow only batch production benefits (small economies of scale) between the two stages. The capital cost figures represent today's technologies manufactured in small volumes. Figures are given per unit installed generating capacity (£/kW) since this allows comparisons with other technologies (e.g. offshore wind). Costs of energy for first production models are based on the reported capital costs and technology-specific estimates of performance levels and O&M costs. These were developed in detail by bottom-up calculations of annual average energy production and reference to O&M strategies and procedures (as far as defined). The following general assumptions apply to the figures quoted: • devices are installed in farms of 10 MW total installed capacity. This is broadly indicative of the size of early stage developments; actual first projects (or first stages of projects) may be smaller. • the project rate of return is 15%. This is based on discussions with energy project investors about risk/ return expectations. 15% is higher than some projects using conventional and renewable technologies achieve, but reflects investors' perceptions about current technology risks for marine renewables. The study identified 'lowest-cost' groups of wave energy converters and tidal stream energy generators, which are subsets of the whole technology range. These groups were selected using engineering judgment and are therefore partly subjective, but this shortcoming is outweighed by their usefulness over other descriptions. Each lowest-cost group consists of several fundamentally different concepts, so should one prove technically unviable and/or more expensive than estimated, there is an alternative route to the same cost. This gives confidence that the lowest-cost groups are reasonable indicators of current costs.

		Information on their breakdown of capital costs for different types of technology are provided below.

Figure 4 a) Breakdown of capital costs for a wave farm

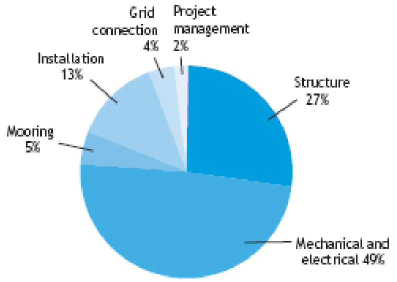


Figure 4 b) Breakdown of capital costs for a tidal stream farm

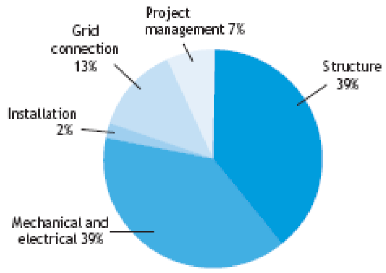
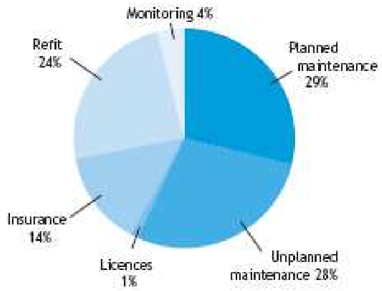


Figure 4 c) Breakdown of operation and maintenance costs for a wave farm



5	**The source's key conclusions**	In terms of the industry's status and potential: 15-20% of current UK electricity demand could be met from wave and tidal stream energy. The market size is difficult to estimate but large enough to warrant interest in commercial development. Interest in wave and tidal stream energy has grown significantly recently but it is still in early stages of development when compared to other renewables and conventional generation. In terms of current costs of energy: wave energy farm estimates are of 12-44 p/kWh. Tidal stream farms have estimated costs of 9-18 p/kWh, with central estimates in the range of 12-15p/kWh. These costs are far higher than current conventional methods and reflect the early stage of development. On future costs: cost reduction potential is significant assuming concept design developments, design optimizations, economies of scale, and learning in production. Long term learning rates could be 10-15%. For tidal stream, learning rates of 5-10% are estimated. For marine energy to become competitive will require (as a necessary but not

		sufficient condition) the installation of (at least) hundreds of megawatts of capacity. Fast learning or a step change in cost reduction is also necessary. Future growth relies on several interconnected factors such as finance availability, the readiness to invest in technology, risk management, links to electricity networks, and environmental and regulatory factors. The report recommends public support for more R&D in the context of a clear long term framework, and an acceleration of private investment in wave and tidal stream farms to improve designs and maximize cost reductions.
6	**Comment on conclusions**	The study is open about the current non-competitive cost of wave and tidal stream power. Clear cost breakdowns (of capital and O&M costs) are available from pilot and demonstration projects launched to date. The wide ranges of future potential costs also highlight the uncertainty about future development. The dominant sense which emerges from the description of the market, as well as the information on costs, is that wave and tidal stream power are very much in their infancy and cannot contribute much to the UK's generation portfolio for at least a decade or two. Several factors need to come together for this form or generation to be competitive in future, and there is of course uncertainty as to whether this will ever be the case.

1	**Source Title**	**The economics of nuclear power: analysis of recent studies**
	Author	Steve Thomas (Public Services International Research Unit – PSIRU)
	Date of publication	July 2005
2	**Abstract**	None provided
3	**Purpose of the research / analysis**	The objective of the paper is to identify the key economic parameters affecting nuclear power, commenting on their determining factors and reviewing the assumptions in main forecasts of the past five years to identify how and why these forecasts differ. The paper also seeks to identify what guarantees and subsidies the government might have to offer to encourage nuclear plants to be proposed by the private sector.
4	**Comment on the method and assumptions**	This study does not present its own cost estimates but reviews those provided in other studies and comments on the different approaches.
5	**The source's key conclusions**	A range of factors (such as public opposition, poor economic performance, increased competition in electricity markets) have resulted in a slow-down of new nuclear orders. These factors affecting the nuclear generation market have been strongly felt in the UK. Despite its poor economic performance, nuclear has continued to provide a base load and contributed to UK greenhouse gas minimization. To continue to meet greenhouse gas targets, new nuclear capacity may be needed in the UK – from 7-10 units (depending on the chosen design). With nuclear power facing political and public opposition in several European countries, the UK may need to pursue new and untried designs. There is a huge degree of variance in the assumptions made for the key determinants of nuclear economics (outlined below) from forecast to forecast. These factors together account for the variations in nuclear costs and the complexity of making comparisons. These uncertainties contribute to the uncertainty about nuclear's future in the UK. Past cost and performance projections have proved to be inaccurate, suggesting caution is necessary. • Forecasts of construction costs: these have been notoriously inaccurate and for the future are highly uncertain. All nuclear power plants currently on offer require a large amount of on-site engineering, the cost of which might account for about 60 per cent of total generation cost. Costs also increase if design changes are necessary. • Construction periods and required lead time are often difficult to predict and to control. • For future plant, there will be risk that they cannot perform at the rate expected by the design. • The cost of capital: this varies from country to country and from utility to utility, according to the country risk and the credit-rating of the company. There will also be a huge impact from the way in which the electricity sector is organized. If the sector is a regulated monopoly, the real cost of capital could be as low as 5-8 per cent but in a competitive electricity market, it is likely to be at least 15 per cent. • Non-fuel operations and maintenance costs have in the past proved difficult to control. • Fuel cost fluctuations. • Variations in accounting lifetimes. • Decommissioning costs and provisions.

		• Costs of insurance and liability. In the face of these uncertainties and past over-optimism about economic performance, the author concludes that government subsidy or guarantees would probably be needed to support the construction, operation, maintenance, fuel purchase, and decommissioning of new nuclear generation. The author's comparison of the assumptions made in recent forecasts of generation costs is reproduced below.
6	**Comment on conclusions**	The conclusions, which set out the various areas where ambiguity and inconsistency influence the analysis of nuclear costs, accurately capture the problems with information identified in other studies. The analysis suggests considerable caution is required when considering nuclear cost estimates - despite industry optimism, Capital costs (at around £1100/KW) are double what is often assumed to be the competitive level against combined cycle gas fired generation. Forecasts of O&M costs and operating efficiencies also tend to be over-optimistic. The cost of capital will also have a significant impact on overall costs if the plant owner is required to assume genuine economic risk. The conclusion, that government guarantees or subsidies would be needed if new build was required, is arguably the clearest statement of the challenges facing nuclear in the sources reviewed.

Table 8. Comparison of assumptions in recent forecasts of generation costs from nuclear power plants

Forecast	Construction cost (£/kW)	Construction time (months)	Cost of capital (% real)	Load factor (%)	Non-fuel O&M p/kWh	Fuel cost (p/kWh)	Operating life (years)	Decommissioning scheme	Generating cost (p/kWh)
Sizewell B	2250 3000	86	-	84	1.15	0.7	40	Part segregated, part cash flow	6 ?
Rice University									5.0
Lappeenranta Univ	~1300		5	91	0.5	0.2	60		1.6
Performance & Innovation Unit	<840	-	8 8 15	>80			30 15 15		2.31 2.83 3.79
Scully Capital	500 600 700 800	60		90	0.55	0.28	40	£260m accrued over 40 year life of plant	
Massachusetts Institute Technology	1111	60	11.5	85 75	0.83	-	40 25		3.7 4.4
Royal Academy of Engineers	1150	60	7.5	90	0.45	0.4	40	Included in construction cost	2.3
Chicago University	555 833 1000	84	12.5	85	0.56	0.3	40	£195m	2.9 3.4 3.9
Canadian Nuclear As	1067	72	10	90	0.49	0.25	30	Fund. 0.03p/kWh	3.3
IEA/NEA	1100-2500	60-120	5 10	85	0.38-0.90	0.15-0.65	40	Included in construction cost	1.2-2.7 1.8-3.8
OXERA	1625 first plant 1150 later unit			95	0.35	0.3	40	£500m in fund after 40 years life	

Notes:
1. Sizewell B operating costs are the average for all eight of British Energy's plants including seven AGRs as well as the Sizewell B PWR.
2. The MIT O&M cost includes fuel.

1	**Source Title**	**'The costs of supplying renewable energy'**
	Author	Enviros Consulting (for DTI)
	Date of publication	February 2005
2	**Abstract**	None provided
3	**Purpose of the research / analysis**	To provide a detailed analysis of the supply curves for each low cost renewable technology based on their economic and technical characteristics, as well as resource availability. The report also provides cost and capacity information for higher cost renewables (although in less detail).
4	**Comment on the method and assumptions**	The 'low cost' technologies covered are landfill gas, onshore wind, sewage gas, small scale hydro, biomass/coal co-firing. The 'high cost' technologies covered are biomass (stand alone), offshore wind, PV, advanced conversion technologies, and tidal/ wave. Models created for each technology draw on four elements: calculation of the maximum resource potential, a detailed bottom-up analysis of the costs of generation at different levels of output, changes in these costs over time and build rates. In relation to power generation costs, these are built up from analysis of capital, operating, and financing elements at different scales of plant. Cost assumptions have been validated as far as possible through discussion with industry participants. Several cost factors are common to all technologies, namely grid connection and grid upgrade costs, transmission charges, business rates, discount rates, and planning permission. For landfill gas: o Capital costs comprise costs of site preparation, generating equipment, grid connection / upgrade, and development costs. o Sites without caps require roofs (assumed to cost £220,000 per hectare, with small sites 3.4 hectares, medium sites 10.9 hectares and large sites 16.8 hectares). o Cost of wells / hectare: £10,032 o Cost of pipework for hectare: £7,125 o Cost of extraction equipment per hectare: £9,861. o Cost per MW (e) of 0.25MW generating engine: £980,000 o Cost per MW(e) of 1 MW generating engine: £700,000 o Grid connection engineering costs: £45,000/MW o Grid upgrade costs: £82,000/MW o Project development costs assumed to be 15% of total capital costs. o Planning permission cost: £187,500 per site. o Operating costs comprise maintenance costs (13-15% of site preparation and engine costs), business rates (£15,000/MW/year), and generation charges (£2,500/MW/year). o Financial discount rate of 7.9% Onshore wind capital costs comprise: o Site preparation (£91,000 per site) o Turbines (£548,000) and foundations (£43,000) o Grid connection (£55,000/MW) and upgrade (£82-95,000/MW) o Project development (10% of total project capital costs) and planning (£187,500 per site). Onshore wind operating costs comprise: o Maintenance (£5% of capital expenditure) o Business rates (£2,110/MW)

		o Use of system charges (£2,500 per year). o Land costs (£4,000-£9000 depending on location) Discount rate of 7.9% Project lifetime of 15 years. Sewage gas capital costs: o No site preparation costs; trivial planning costs o CHP turbine cost £552,000/MW o Grid connection $45,000/MW o Grid upgrades: £82,000/MW o Capitalized project development costs of 5% of capital expenditure at £30,000/MW. o Operating costs of 0.025£/KWh generated; equal to £55,000/years per MW. o Negligible business rate change. o Annual GDUoS charges of £2,500/MW o Negligible land costs. o Discount rate of 7.9% o Project lifetime of 15 years. Hydro capital costs comprise site preparation, turbine cost, cost of grid connection and upgrade, and cost of project development. Maintenance costs: o 10% of capital costs for all installations. o Business rates are from £8,000-18,000. o Annual GDUoS charge of £2,500MW/year. o Water abstraction costs of ££1,400 (1.25-20MW) and £8,700 (20MW). Discount rate of 7.9%. Project lifetime of 25 years.
5	**The source's key conclusions**	With the exception of biomass and co-firing and assuming a brown (i.e. conventional fossil fuel) power price of £30/MWh no technology is able to generate commercially without some form of financial support. With regard to each technology: Landfill gas: o Rapidly approaching saturation in the development of new low cost sites o In a mid-growth mid-diversion short term scenario, an additional 300MW is achievable at a cost below £45/MW/h from 2003 levels. o Increases in LFG production from new sites will outweigh the decline from wastes in historic sites. o Learning effects are slight in LFG. o Given past build rates, low cost project opportunities would be exhausted within four to five years. o There is considerable uncertainty in these figures. Onshore wind o Costs vary widely between sites with average wind speed the key factor in influencing the economics. o The maturity of technologies suggests that future learning effects will be small. o Three bands of future economic viability are discernible – low cost (under £50/MWh), medium cost (£50-60/MWh) and high cost (£60-

		80/MWh). o Slight fall in future capital costs could lead to increased available capacity of low cost sites. o The rate of development of new sites is an important factor, which could result in the rapid exhaustion of low cost sites. Sewage gas: o Scope for further development is limited by regulatory factors. Hydro: o Generation costs depend on the size of the unit, the load factor and are also site-specific. o Although generation costs are high, there is scope for significant future development. Costs of large hydro plant are anticipated to fall by up to 10% and over 20% for micro and small scale.
6	**Comment on conclusions**	The study provides a greater level of disaggregated cost information than most other studies of other technologies. The principal conclusion that the low cost technologies require some form of government support is of course dependent on factors such as the cost of fossil fuels, the volatility of which will influence the relative viability of renewable sources.

1	**Source Title**	**'Alternative fuels for transport and low carbon electricity generation: A Technical note'**
	Author	Robert Gross and Ausilio Bauen (ICEPT)
	Date of publication	October 2005
2	**Abstract**	None provided
3	**Purpose of the research / analysis**	Provides an overview and summary of current knowledge and future projections of the costs of a range of alternative energy sources for electricity generation and transport markets.
4	**Comment on the method and assumptions**	-
5	**The source's key conclusions**	Information from a range of sources is gathered in a single table, reproduced below, including comments from the paper's authors. The list of references provided by the authors, which accompanies the table, is also reproduced verbatim below.
6	**Comment on conclusions**	The paper usefully compiles current cost information from a number of sources. The authors' broad comments on the factors influencing cost trends are consistent with those in other sources. The cost estimates for nuclear are at the higher end of the range of estimated costs but reflect the view that industry cost estimates tend to be very low. Estimates for future wind electricity are more optimistic than in some other studies, derived in part from strong learning curve evidence and potential market growth.

Technology	Current cost *(UScents/kWh)*	Medium term projections	Comments
Present fossil fuel plant			
1 Gas CCGT Coal	3-4 3.5-4.5	Depends on fuel prices	Unclear. Gas price and volatility increasing. Modest capital cost decreases[5] and efficiency gains may be offset by rising fuel prices
Very low carbon electricity technologies			
2 Carbon Capture and Storage (CCS)([678]) Nat. Gas with CCS IGCC Coal with CCS	 NA NA	 4 – 6 5 – 8	Costs based on engineering assessment, as yet no market experience to permit learning rate derivation. The techniques are well known but not tested for this application.
3 Nuclear Power ([9],[10])	5 – 7	4 – 8	Industry provides very low cost estimates. MIT and PIU rather higher nos. Low historical learning rate.
4 Biomass ([1112]) Co-firing with coal Electricity CHP-mode	 2.5 – 5 5 – 15 6 – 15	 2.5 – 5 5 – 9 5 – 12	Costs vary widely depending on conversion technology, scale and feedstock cost.
5 Wind Electricity ([13],[14]) onshore offshore	 5 - 8 9 - 12	 2 – 4 3 – 8	Learning curve evidence and strong market growth (30 % pa), with good engineering data allows robust assessment for onshore. Offshore less certain as experience is limited, but engineering assessment, learning rate extension/proxy indicates strong potential.
6 Tidal Stream/Wave[15],[16],[17]	13 – 20	<15	Future costs difficult to estimate due to immaturity of technologies. Estimates draw on parametric models of hypothetical costs. Uncertainties are large for these technologies. Installed capacity roughly doubled during 2004, through new demonstration projects.
7 Grid connected PV([18]) 1000 kWh/m^2/year (temperate) 2500 kWh/m^2/ year (tropics)	 50 – 80 20 – 40	 15 – 25 5 – 15	Robust learning curve evidence and strong market growth (25 % pa) suggest costs should decline strongly to 2020 and beyond. Recent cost reduction trends appear to have declined[19], likely due to temporary factors (price increase due to high demand) or indicative of longer term problems. Neglects offset costs (e.g. building materials displaced by PV façade).

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