Synthesis of energy technology medium-term projections

Alternative fuels for transport and low carbon electricity generation: A technical note

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Alternative fuels for transport and electricity generation: A technical note on costs and cost projections

Contents

Introduction

This note provides an overview of current knowledge and future projections on the costs of a range of 'alternative' energy sources for electricity generation and transport markets. The focus is on low carbon options, and the note includes the major renewable sources for electricity generation, nuclear power, capture and storage of CO2 from fossil fired power stations, and the principal bio-energy options for both electricity and fuels.

There is a considerable body of recent work on the cost of low carbon technologies. In the UK a substantial amount of analysis was done in the run up to the UK Government Energy White Paper[1], to which the authors contributed[2]. Important international efforts date from the same period[3]. Important costs have been revisited recently, in both UK and international contexts[4]. This note pulls together key sources of current and future projections of costs of bio energy for fuels and all low carbon sources of electricity in a single simple format.

This is of interest because rapid rises in the price of oil and gas have changed the 'benchmark' against which unconventional options must be compared. Also because as experience is gathered in key technologies, and as the passage of time permits increasing scrutiny of earlier estimates, it is important to take stock of existing projections.

In the remainder of this note we bring together evidence from a wide range of sources on both costs and cost projections, and summarise this in tabular form. The tables are explained, caveats provided and the numbers therein expanded upon through a series of technology specific notes.

Current and projected medium-term costs of electricity generating technologies.

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).

Notes. The table shows typical busbar generating costs and medium-term (2020/2025 except 2, which is also 2012) cost projections for low carbon generation. All costs inflated from time of study to 2005, and converted at purchasing power parity rates; UK£ converted at 1.50 £/$. Cost projection methodologies in the studies are diverse.

Biofuels: Current Costs and 2020 Projections (UScents/litre)

Technology	Current costs *UScents/l [$/GJ]*	2020 Projections *UScents/l [$/GJ]*	Comments
Gasoline / (diesel) cost for oil crude @ c. $50/barrel (FOB Gulf cost)	0.34 / (0.37) [10.4 / (10.0)]	Dependent upon oil supplies	
Ethanol from sugar cane (Brazil)	0.29 [13.5]		Commercial ethanol production in Southern Brazil. Some scope for cost reduction.
Ethanol from corn (US)	0.29 – 0.32 [13.5 – 14.9]		Commercial ethanol production in US. Some scope for cost reduction.
Ethanol from grain (UK)	0.38 – 0.65 [18.0 – 30.6]		Commercial ethanol production in UK. Some scope for cost reduction.
Ethanol from cellulosic crops (UK)		0.31 – 0.73 [14.4 – 34.2]	Cost projection for commercial plant based on engineering analysis.
Biodiesel from rapeseed (UK)	0.59 – 1.48 [18.0 – 45.0]		Commercial biodiesel production in UK. Some scope for cost reduction.
F-T diesel from coppice (UK)		0.58 – 0.97 [16.2 – 27.0]	Cost projection for commercial plant based on engineering analysis.

Further detail by technology

Electricity Generation

CO2 Capture and storage
The cost range provided is based upon 2012 figures derived from a paper written by MIT's Howie Herzog in 1999 and utilized by the IEA Greenhouse gas programme figures amongst others[20]. The upper figures are from the workshop on generating costs hosted by DTI in 2001 as part of the Energy White Paper analysis process, in the attempt to reach consensus between industry and academic experts[21]. There appears to be little work on the cost ranges implied by the very wide range of different pipeline and repository combinations that can be envisaged.

Nuclear Power
Manufacturers of advanced PWR stations, the most likely candidates for 2020 build, have quoted very low costs – 2.2 p/kWh (around 3.5 Cents) for the average cost of a series build in UK conditions[22]. The 2020 range presented here is based upon sensitivity analysis undertaken by UK govt researchers that took the industry figures as a starting point, but also considered a range of potential cost related changes and over runs[23].There is a diversity of estimates on nuclear costs. This range encompasses those of the UNDP/WEC, MIT and others[24].

Biomass
The historic learning rate for biomass appears to be 15%[25], but complications associated with the move from conventional combustion to gasification cycles and in assessing energy crop costs reduce the scope for direct application of historic learning. The costs cited also reflect engineering cost estimates of biomass gasification electricity and CHP plants in the UK and Sweden once technologies are utilized on a wider scale[26].

Wind
Engineering assessment and learning rate analysis tend to concur at least until around 2015 for onshore wind[27]. Costs from different analytic approaches for offshore show a considerable degree of agreement[28]. There is not enough data for a learning curve unique to offshore development. Nevertheless a downward cost trend is already evident – costs fell by more than 50% between the Vindeby development in 1991 and more recent developments such as Middelgrunden (2000) and Horns Rev (2002)[29]. Despite this early progress recent projects have not come to fruition as rapidly as expected, capital costs remain higher than predicted and market growth has been slower than expected[30]. Engineering considerations indicate future potential through dedicated and larger marine turbines, and economies of scale and learning by doing in installation and maintenance.

Wave
The Portuguese tariff of €0.22 /kWh is viewed as highly attractive by developers of existing (largely demonstration stage) machines surveyed in a recent industry study[31]. On future costs, wave energy devices under development in the UK have been subject to rigorous and independent assessments of probable capital and generation costs should commercial scale development be realised, using a parametric model costs for the leading devices are mostly under 10 p/kWh (or 15 cents)[32].The methodology assumes commercial scale deployment. The Danish government has undertaken similar reviews of prospective costs, but based on more immediate prospects, and most devices fall in the range 10 – 20 DKK/kWh (~9 – 18 p/kWh, 13 – 27 cents)[33].

Biofuels

Costs vary widely depending on location for existing bioethanol and biodiesel technologies. New processes for the production for ethanol synthetic diesel from lignocellulosic materials could expand the accessible resources base and, possibly, lead to reduced biofuel production costs. The biofuel cost estimates for the UK are based on Woods and Bauen (2003)[34]. The UK based costs have been converted to dollars using a current exchange rate of $1.8/£.

Biodiesel
<u>Biodiesel from rapeseed.</u> The cost of rapeseed delivered to the biodiesel conversion plant is estimated to range between $18 and $32/GJ RME. Conversion costs are estimated to be about $11/GJ RME. Current revenues from co-products (straw, glycerine and animal feed) are estimated to range between $2.7 and $11.7/GJ RME. Therefore, the cost of biodiesel could range between $18/GJ RME (in the absence of co-product revenues) and $45/GJ RME (including co-product revenues of $11.7/GJ RME). This is equivalent to a range of $0.6 to $1.4 per litre.

<u>Synthetic diesel from biomass.</u> Synthetic biodiesel can be produced from biomass-derived synthesis gas production followed by a Fischer-Tropsch process. However, while the FT-diesel is produced from coal in large scale commercial operations (e.g. Sasol plants in South Africa), there is no commercial scale experience with FT-biodiesel production. FT-biodiesel production is currently at the demonstration stage (e.g. Choren plant in Germany). Engineering modelling studies have produced cost estimates for FT-biodiesel production. It is estimated that FT-biodiesel production from short rotation coppice wood in relatively large

scale facilities (400 MWth biomass input) could be between $16 and $27/GJ FT-biodiesel (57 to 97 UScents/l), excluding electricity credits. Surplus electricity sales could result in an income of between $1.4 and $4.1 per GJ FT-biodiesel. The wood feedstock cost component is estimated to be between $5.9 and $14/GJ FT-biodiesel.

Bioethanol

Ethanol from wheat grain. The cost of wheat grain is estimated to be between $16 and $23/GJ EtOH. The conversion process costs are estimated to be between $7 and $13/GJ EtOH. The influence of co-products on the price of ethanol could be significant, with the potential value of the co-products estimated to range between $5 and $11/GJ EtOH, depending on whether electricity is also available as a co-product from plants equipped with combined heat and power generation. Ethanol production costs from wheat grain is estimated to be between $18 and $31/GJ EtOH, equivalent to between 38UScents/l and 65UScents/l, the latter excluding co-product credits.

Ethanol from corn. The US has a large production of fuel ethanol from corn. The costs of ethanol from corn in the US are estimated to be between $0.29/l and $0.32/l[35].

Ethanol from sugarcane. Fuel ethanol has been produced from sugarcane commercially in Brazil since the 1970s, mostly in integrated sugar and ethanol production plants. Significant cost reductions have been achieved since the inception of the Brazilian ethanol programme[36], and current production costs are estimated at $13.5/GJ EtOH, equivalent to 29UScents/l.

Ethanol from wheat straw and wood from short rotation coppice. Lignocellulose hydrolysis processes are at the demonstration stage and costs of future commercial plant are based on projections using engineering models. Ethanol production costs from wheat straw could lie between $16 and $27/GJ EtOH, equivalent to 34 to 58UScents/l. Ethanol production costs from SRC wood could lie between $14 and $34/GJ EtOH, equivalent to 32 to 77UScents/l. UK-specific feedstock costs are estimated to lie between $45 and $63 per tonne (dry) for delivered straw ($6.5 and $9.5/GJ EtOH), but during periods of high demand these may be much higher (e.g. up to $100/t), and between $36 and $72 per tonne (dry) for delivered SRC wood chips ($4.3and $9/GJ EtOH). Conversion costs are estimated to lie between $9 and $16/GJ ETOH. Some revenues may be derived from electricity sales.

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