National Assembly for **Wales**
Cynulliad Cenedlaethol **Cymru**

Renewable Energy in Wales

This research paper considers the role of renewable energy and provides a policy context at EU, UK and Welsh levels. The current Welsh energy mix is presented and renewable electricity generation compared with other EU member states. Technologies for renewable electricity, heat and transport fuels are considered in terms of technology, costs, and environmental impacts.

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Executive Summary

Energy generation - the production of electricity, heat and fuels to provide services such as lighting and transport - is the source of the majority of carbon dioxide (CO_2) emissions in Wales. As such, the use of renewable forms of energy generation, where no net CO_2 is emitted during the energy lifecycle, is growing in importance in Wales and internationally. Policies at the EU, UK and Welsh levels have been formulated with the aim of reducing carbon emissions: a key European target is that 20 per cent of all energies are to be supplied by renewables by 2020. At the UK level, the Renewables Obligation is a market driven system for increasing support for renewable technologies in electricity generation. The headline target in Wales is the annual production of 4 Terawatt hours (TWh) of renewable electricity by 2010, rising to 7 TWh in 2020.

The current electricity mix in Wales primarily consists of fossil fuel and nuclear powered centralised generating stations. In 2005 3.56% of Wales's electricity consumption was met by renewables and the 2007 consumption is estimated to be 3.60%. There are no data specific to Wales for either energy for heat use or the use of biofuels. In the UK as a whole, biodiesel accounted for 1.34% of diesel sales and bioethanol 0.59% of petrol sales. The picture is likely to be similar in Wales.

This paper breaks down energy generation into electricity generation, heat production and renewable transport fuels. The main types of technology within each of these categories are discussed along with cost and environmental implications.

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1 The Role of Renewable Energy

1.1 Renewable energy and climate change

In the face of a growing body of compelling scientific evidence, climate change as a result of man's activities has risen up the agenda for many governments. The vast majority of carbon dioxide (CO_2) emissions, the principal gas causing climate change, are a result of the use of non-renewable forms of energy, such as coal, oil and natural gas[1]. Non-energy emissions arise from processes such as the manufacture of cement, glass and aluminium, and gas flaring from steel plants[2]. In Wales, electricity generation, manufacturing and construction, and road transport make up 72.7% of all CO_2 emissions (Fig 1).

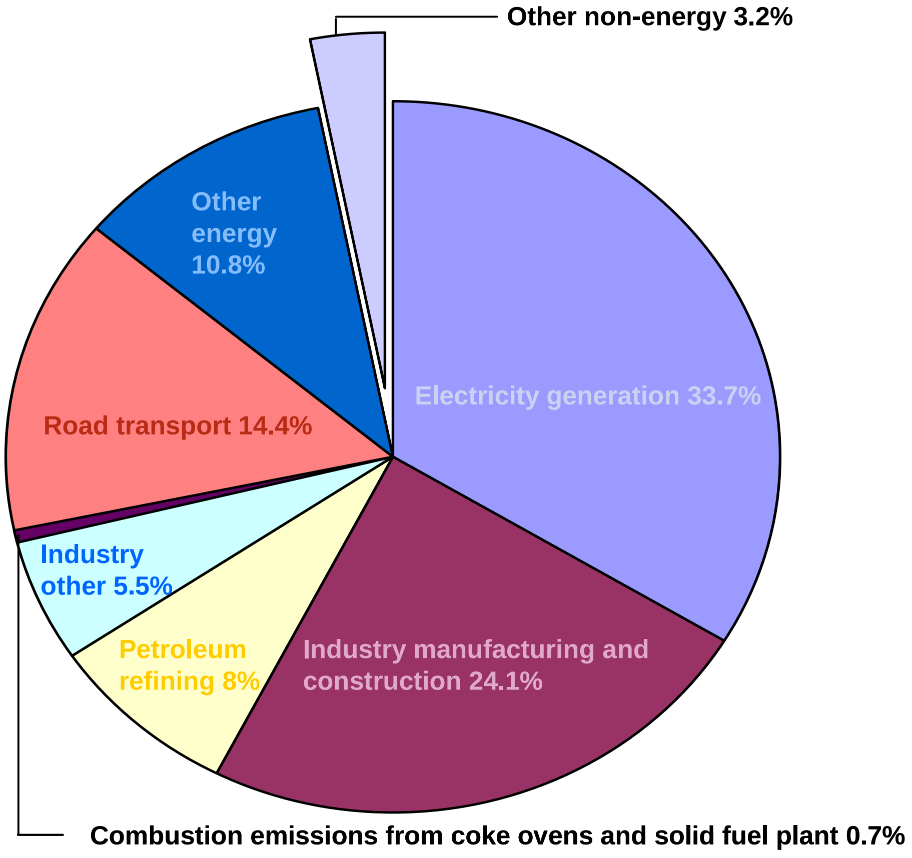

Figure 1: Emissions of CO_2 in Wales broken down by sector. The chart represents 41.7 Mt CO_2 of which 40.27 Mt were from energy. Figures represented are rounded to one decimal place but are from data that were calculated at full precision[3]

[1] AEA Technology, *Greenhouse Gas Inventories for England, Scotland, Wales and Northern Ireland: 1990-2005*, August 2007. http://www.airquality.co.uk/archive/reports/cat07/0709180907_DA_GHGI_report_2005.pdf
[2] *ibid* p. 15.

As energy comprises such a large proportion of CO_2 emissions, there is a need to seek alternative, sustainable forms which emit no net CO_2, if policy targets are to be met. Such energy forms are termed renewable energy and, according to the Department for Business Enterprise and Regulatory reform (BERR, formerly the DTI), include solar power, wind, wave and tide, and hydroelectricity. Solid renewable energy sources consist of energy crops, other biomass, wood, straw and waste, whereas gaseous renewables consist of landfill gas and sewage waste[4].

1.2 Renewable energy and security of energy supply

The recent change from the UK being a net exporter of gas and oil to a net importer[5, 6] has prompted much comment about an increasing reliance on other countries to provide for growing energy demand. In addition, increasing demand for fossil fuels has increased concern over the exposure that the UK, and therefore Wales, has to such changes[7]. The use of renewable energy from alternative sources can, therefore, reduce fossil fuel demand, improving security of energy supply[8], and buffering energy cost against fossil fuel price rises. The energy problems facing EU countries were recently highlighted in an EU green paper on energy. In summary they are:

- Rising dependency on imported energy
- Import reserves concentrated to a limited number of suppliers
- Increasing global energy demand
- Rapidly rising gas and oil prices[9]

In a recent report, the International Energy Agency (IEA) could not rule out a 'supply-side crunch in the period to 2015' and this would include 'an abrupt escalation of oil prices'[10].

2 Renewable Energy Policies

Renewable energy policy affecting Wales is set at the European, UK and Welsh levels. The central policies and targets are outlined below and more details can be found in the referenced policy documents.

2.1 Key European policies and targets

- A binding target of a 20 per cent share of renewable energies of overall EU consumption by 2020[11].
- A binding target of a minimum 10 per cent use of biofuels by 2020 {COM(2006) 848 final}[12].

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[3] *ibid*
[4] Department for Trade and Industry (now DBERR) *Energy White Paper – Our Energy Future; Creating a Low Carbon Economy,* February 2003. p. 131. http://www.berr.gov.uk/files/file10719.pdf
[5] DTI, *Our Energy Challenge: Securing Clean, Affordable Energy for the Long Term,* January 2006, p. 33
[6] DTI, *Meeting the Energy Challenge: A White Paper on Energy,* May 2007. http://www.berr.gov.uk/files/file39387.pdf
[7] *ibid* p. 7.
[8] Commission of the European Communities, *The Support of Electricity from Renewable Energy Sources* {COM(2005) 627 final}, December 2005 http://ec.europa.eu/energy/res/biomass_action_plan/doc/2005_12_07_comm_biomass_electricity_en.pdf
[9] Commission of the European Communities, *Green paper: A Strategy for Sustainable, Competitive and Secure Energy*, March 2006 http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2006:0105:FIN:EN:PDF, accessed 16 January 2008.
[10] International Energy Agency, *World Energy Outlook 2007 – Fact Sheet Oil* (2007) http://www.iea.org/textbase/papers/2007/fs_oil.pdf
[11] European Commission, *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: 20 20 by 2020: Europe's climate change opportunity, 23* January 2008, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2008:0030:FIN:EN:PDF

- To cut greenhouse gases by at least 20 per cent by 2020 and by 30 per cent in the context of a comprehensive international agreement[13].
- Increased support for renewable technology development through the Directive on Electricity Production from Renewable Energy Sources[14].

2.2 Key UK policies

The majority of the fundamental policies of the UK Government are laid out in the Energy White Paper[15] and supporting documents, and these are briefly explained below (details of technologies mentioned are explained in section 4):

- Ten per cent of the UK electricity demand to be supplied through renewables by 2010.
- A strengthening of the Renewables Obligation (RO, explained in section 4.1) up to 20 per cent. Additionally the RO scheme will be banded so that a mixture of renewable technologies are supported, not merely the least expensive[16].
- Planning reforms to reduce obstacles to renewables[17]. The continuation of the Low Carbon Buildings Programme with an extra £50 million announced in 2006 to provide grants to householders and organisations to install microgeneration technologies[18].
- Removal of current barriers to the connection of microgeneration installations to the National Grid (working with Ofgem and National Grid UK).
- Increased public sector involvement with the private sector to increase research and development of low carbon technologies[19]
- Combined Heat and Power (CHP) installations are to be exempted from the climate change levy and reformed planning guidance will increase the consideration given to CHP in new planning applications[20].
- The introduction of the Renewable Transport Fuels Obligation (RTFO) to require at least five per cent inclusion of renewable fuels in road transport fuels by 2010-11. This scheme commences on 15 April 2008[21].
- The establishment of the Energies Technologies Institute to be 50:50 funded between the public and private sector with £600 million[22]. Full operation was announced on 17 December 2007[23].

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[12] European Commission, *Communication from the Commission to the Council and the European Parliament Renewable Energy Road Map: Renewable energies in the 21st century: building a more sustainable future*, January 2007. http://ec.europa.eu/energy/energy_policy/doc/03_renewable_energy_roadmap_en.pdf
[13] *ibid* p. 5.
[14] European Commission, *Directive 2001/77/EC of The European Parliament and of the Council of 27 September 2001 on the promotion of electricity produced from renewable energy sources in the internal electricity market*, (September 2001) http://eur-lex.europa.eu/pri/en/oj/dat/2001/l_283/l_28320011027en00330040.pdf
[15] The Stationary Office, *Energy White Paper: Our Energy Challenge – Creating a Low Carbon Economy,* (February 2003).
[16] The Stationary Office, *The Energy Bill*, January 2008. http://www.publications.parliament.uk/pa/cm200708/cmbills/053/2008053.pdf
[17] *The Planning Bill*, Bill 71 2007-08
[18] HM Government, *Climate Change the UK Programme,* March 2006 http://www.defra.gov.uk/environment/climatechange/uk/ukccp/pdf/ukccp06-all.pdf
[19] The Stationary Office, *Meeting the Energy Challenge – A White Paper on Energy,* May 2007. pp. 216-234. http://www.berr.gov.uk/files/file39387.pdf
[20] *ibid.* p. 13.
[21] Department for Transport, *Reporting Within the Renewable Transport Fuel Obligation: Requirements and Guidance,* January 2008 http://www.dft.gov.uk/pgr/roads/environment/rtfo/govrecrfa.pdf
[22] Department of Trade and Industry, *Energy Technologies Institute Prospectus,* September 2006. http://www.energytechnologies.co.uk/assets/files/ETI_Prospectus.pdf,
[23] Energies Technologies Institute website http://www.energytechnologies.co.uk/

2.3 Key Welsh policies

> 'We are committed to ensuring that Wales adapts to changing energy production in a sustainable way that brings benefits to Wales's people[24].'
>
> Labour and Plaid Cymru, One Wales, June 2007

- Securing 4 TWh per annum of renewable electricity production by 2010 and 7 TWh by 2020[25].
- The Welsh Assembly Government has set out a commitment to sustainable energy production which will include the drawing up of an Energy Strategy that will cover 'diversified renewable energy generation and biomass'[26].
- A commitment to revise upwards the targets for energy derived from renewables, drawn from a range of sources[27].
- The Environment Strategy for Wales includes a commitment to 'renewable and low carbon energy generation'[28].
- An aim to encourage 800 MW of new on-shore wind electricity development by 2010[29].
- The Renewable Energy Route Map sets out the Welsh Assembly Government's intention to increase renewable energy, and estimates that up to 33 TWh of electricity could be generated in Wales by 2025 with a saving of more than 14 million tonnes of CO_2[30].
- Support for renewables through the planning system through Technical Advice Note 8 which includes the designation of areas for onshore wind development and advice to local authorities to adopt policies to encourage the use of renewable energy[31].

Of particular importance is the Microgeneration Action Plan for Wales, as small scale developments less than 50 MW are part of Wales' devolved competence. The plan contains the following targets[32]:

- To install 20,000 microgeneration heating units by 2012, with of the order of 100,000 by 2020,
- To install 10,000 micro-electricity units by 2012, rising to numbers in the order of 200,000 by 2020, and
- To have in place 50 combined heat and power and/or district heating systems by 2020.

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[24] Labour and Plaid Cymru, *One Wales: A Progressive Agenda for the Government of Wales*, 27 June 2007.
[25] Welsh Assembly Government, *Energy Wales: Route Map to a Clean, Low-Carbon and More Competitive Energy Future for Wales,* June 2005. http://new.wales.gov.uk/docrepos/40382/4038231141/40382112412/energyroutemape.pdf?lang=en
[26] Labour and Plaid Cymru, *One Wales: A Progressive Agenda for the Government of Wales*, 27 June 2007.
[27] *ibid* p. 32
[28] Welsh Assembly Government, *Environment Strategy for Wales,* May 2006. Link to Strategy
[29] Welsh Assembly Government, *Energy Wales: Route Map to a Clean, Low-Carbon and More Competitive Energy Future for Wales,* June 2005. http://new.wales.gov.uk/docrepos/40382/4038231141/40382112412/energyroutemape.pdf?lang=en
[30] Welsh Assembly Government, *Renewable Energy Route Map for Wales,* February 2008.
[31] Welsh Assembly Government, *Planning Policy Wales Technical Advice Note 8: Planning for Renewable Energy,* July 2005.
[32] Welsh Assembly Government, *Microgeneration Action Plan for Wales*, March 2007. http://new.wales.gov.uk/docrepos/40382/4038231141/40382112413/plane.pdf?lang=en

3 The Current Energy Mix

3.1 Electricity

Wales had an installed renewable electricity capacity of 543 megawatts (MW) of electricity generation in 2006[33]. It is worth noting, however, that most renewable sources are intermittent and, therefore, do not operate at their installed capacity. Most operate at a percentage, which in the case of onshore wind is about 20 to 40 per cent of the installed capacity[34]. For comparison, in 2006, nuclear power stations operated at a load factor of 69 per cent, combined cycle gas turbine stations at 54 per cent, and coal-fired stations at 66 per cent[35]. The actual contribution of renewable resources to Wales's electricity production is 4 per cent (Fig 2).

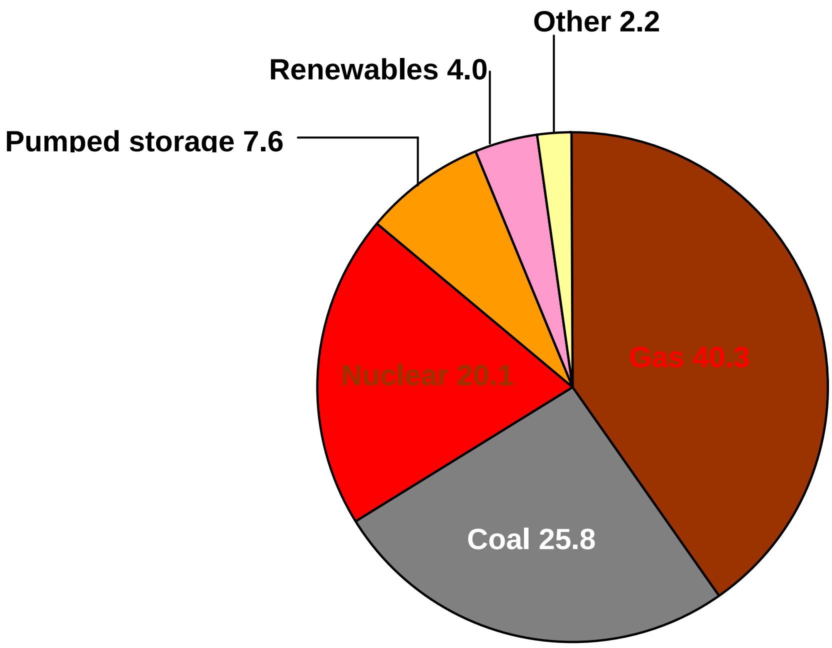

Figure 2 Percentage shares of electricity generation in Wales as at end-2006[36]. Source: DBERR

The majority of renewable electricity capacity installed in Wales is wind, followed by hydro (Fig 3). Solar photovoltaic accounts for a very small amount of generation but has grown rapidly since 2004 (Fig 3).

Based on the assumed capacity factors above, and assuming that no more renewables came online since the data were collected, the total output for renewables in 2007 was 1.787 TWh. Figure 4 shows that whilst renewables output is growing, it is not currently at the rate necessary to reach the 2010 Welsh Assembly Government Target of 4 TWh.

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[33] DBERR, *Energy trends September 2007*, http://www.berr.gov.uk/files/file41460.pdf
[34] Sustainable Development Commission. *Wind power in the UK: A guide to the key issues surrounding onshore wind power in the UK.* (May 2005) pp.17-18 http://www.sd-commission.org.uk/publications/downloads/Wind_Energy-NovRev2005.pdf
[35] DBERR, *Digest of United Kingdom Energy Statistics 2007*, p. 136, http://stats.berr.gov.uk/energystats/dukes07.pdf
[36] DBERR, *Energy trends December 2007*, p. 22, http://www.berr.gov.uk/files/file43304.pdf

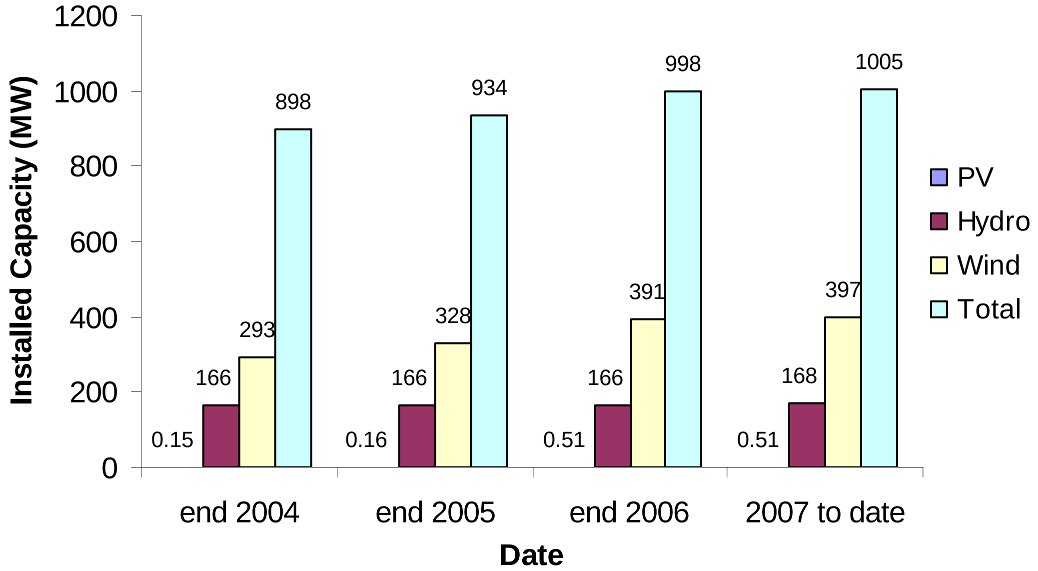

Figure 3 Growth in installed capacity electricity generation in Wales since the end of 2004. Sources: Scottish Power Manweb and Western Power Distribution. (PV = Solar Photovoltaic)

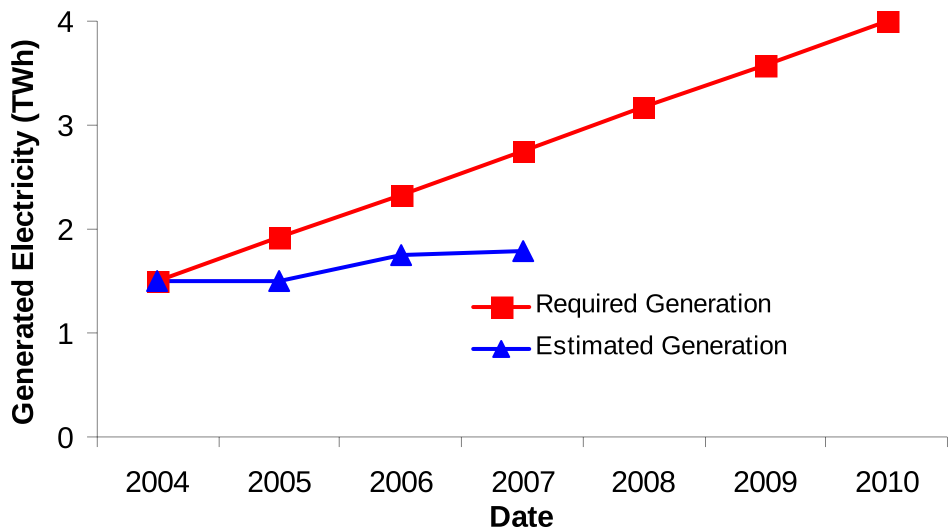

Figure 4 Electricity generation from renewables in Wales (power distribution area includes Merseyside), compared to the Welsh Assembly Government Target for 2010. The baseline year is 2004. The output data for 2007 may not be complete as all grid connections may not have been made at the time the data were collated. Data source for installed capacities: Scottish Power Manweb and Western Power Distribution. Annual generation estimate by Members' Research Service.

In addition to Wales-specific targets, Wales also has a commitment to UK and EU targets. This includes the aim for 10 per cent of electricity to be from renewable sources by 2010. In 2006 Wales consumed 4.0% of its electricity from renewables[37]. Of the 25 EU Member States in 2005, Austria's renewable electricity production was 64.2% and for the UK as a whole, renewable electricity production was 4.3%. When compared to the EU Member States, Wales was 19th of 26 for the use of renewables in electricity generation (Fig. 5).

[37] DBERR, *Energy trends*, December 2007, p. 22, http://www.berr.gov.uk/files/file43304.pdf

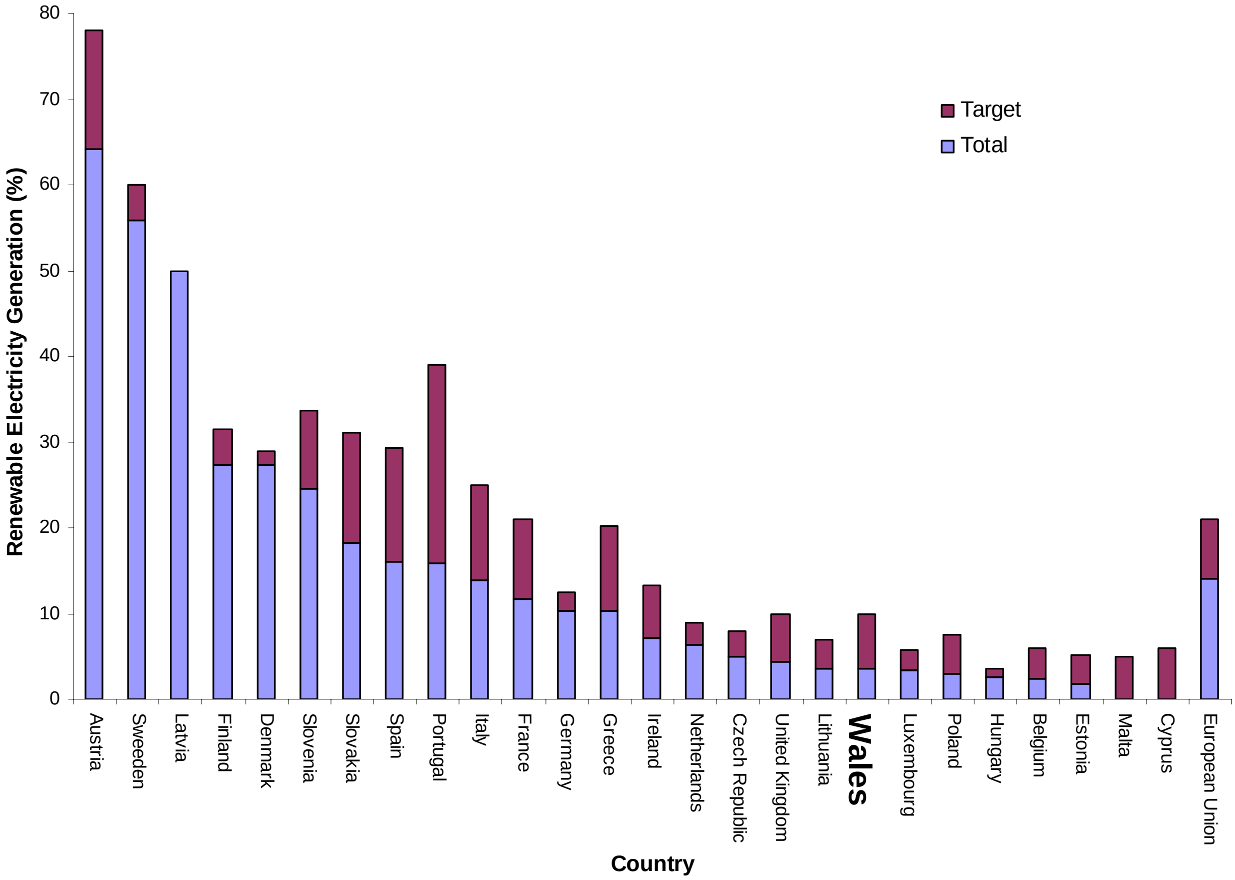

Figure 5 Renewable energy share in per cent for primary gross electricity consumption in EU countries in 2005[38]. Wales specific data from Department of Business Enterprise and Regulatory Reform[39]. All targets are for 2010[40].

3.2 Renewable heat

Due to the lack of a distribution network and the localised and generally small scale nature of heat generation, there are no Wales-specific data concerning the total consumption of renewable heat. The Renewable Energy Route Map for Wales highlights some of the larger biomass installations over 25 MW_{th}[41] but there are a number of smaller generation devices, such as solar thermal for individual homes, and Members' Research Service has been unable to obtain any reliable data on the number of such installations.

3.3 Renewable transport fuels

As with renewable heat installations, there are no specific data for the amount of biofuels consumed in Wales. The UK-wide consumption of biodiesel has grown steadily from 0.01% (2,300 tonnes) in 2002 to an estimated 1.34% (110,000 tonnes) in 2007. Bioethanol was introduced in

[38] EU Innovation and technological development in energy website http://ec.europa.eu/energy/res/index_en.htm
[39] Department for Business Enterprise and Regulatory Reform (DBERR), *Special Feature – Sub-national Electricity Figures2007* p. 50, March 2007 http://www.berr.gov.uk/files/file43859.pdf
[40] The target for Wales is the UK-wide 10 per cent target as Wales has no specific renewables target set as a percentage of total generation.

2005 and accounted for 0.33% of UK petrol sales equating to 62,900 tonnes, and rising to an estimated 105,000 tonnes in 2007, 0.59% of the petrol market[42].

4 Renewable Electricity Technologies

Energy use for the generation of electricity, heat and transport, accounts for a large proportion of CO_2 emissions in Wales and this paper considers what renewable energy technologies exist for each of these sectors, their prevalence in Wales, the potential they offer and any environmental concerns surrounding their use. Each technology is considered in turn and, for the sake of brevity, the technology is explained in the simplest of terms with references for readers requiring greater detail.

This section considers those technologies suitable for producing electricity for distribution. Only sources that are truly renewable, that is not requiring non-renewable energy input once established, such as pumped storage hydro-electric, are considered. This definition does not include the use of non-renewable energy for maintenance and repair requirements. This definition does, however, mean that energy generated from burning landfill waste or gas derived from landfill, is not considered here. In addition the use of partial renewables, such as co-firing of biomass with coal, as seen at Aberthaw power station, is not considered. Finally, carbon capture and storage technologies (CCS) in which fossil fuels are burned and the CO_2 captured and prepared for long term storage are also not considered. The UK Parliamentary Office of Science and Technology (POST) has produced a POSTNote summarising CCS technology[43]. The technologies considered here are:

- Biomass power plant
- Biomass combined (cooling) heat and power (CHP/CCHP)
- Hydroelectric
- Solar photovoltaic
- Tidal stream and wave generation
- Tidal range generation
- Wind turbines

In the UK electricity generators are subject to the renewables obligation (RO); an annually increasing percentage requirement on electricity suppliers to obtain electricity from renewable sources. For every megawatt of renewable electricity produced, generators are supplied with a Renewable Obligation Certificate (ROC) which can be sold to suppliers. The ROC serves as evidence of renewable electricity supply. The RO is set higher than the percentage of renewable electricity supply meaning that there are never enough ROCs to meet the obligation. In such instances suppliers can pay into a buyout fund set annually (£34.30 per MWh in 2007/08) if there are no ROCs on the market[44]. The price in the buyout fund is set high enough to ensure a market for ROCs. As well as selling ROCs, generators also receive money from the buyout fund at the

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[41] Welsh Assembly Government, *Renewable Energy Route Map for Wales.* February 2008. p.11. Some of the sites are at the construction stage and are not yet operational.
[42] BERR, *Special Feature – The UK Road Transport Biofuels Market,* December 2007. http://www.berr.gov.uk/files/file43824.pdf
[43] Parliamentary Office of Science and Technology, *POSTNote Number 238 Carbon Capture and Storage (CCS),* March 2005
[44] BERR, *How does the renewable obligation work (website).* http://www.berr.gov.uk/energy/whitepaper/consultations/renewables-obligation/page39555.html

end of each year. In this way the development of renewable electricity is encouraged. Recent proposed changes to the RO system will result in more ROCs being issued for more capitally intensive projects. For example, offshore wind will receive 1.5 ROCs, microgeneration 2 ROCs and tidal stream 2 ROCs per MWh[45].

4.1 Biomass

Biomass has been defined as:

> "…the biodegradable fraction of products, wastes and residues from agricultural (including plant and animal substances), forestry and related industries, as well as the biodegradable fraction of industrial and municipal waste"[46].

The main forms of biomass used to generate heat and electricity are:

- Direct plant products e.g. wood
- Animal derived products such as poultry litter and bone meal
- Plant derived products e.g. cardboard and waste wood and board
- Sewage or farm waste derived gas or biogas[47]

Sugars in plants can be fermented to produce alcohols, and oils from some plants can be turned into biodiesel, but these are used exclusively in transport (considered later). The following technologies can utilise solid biomass and biomass derived biogas.

4.1.1 Biomass power plant

The technology and installation size

The burning of biomass for the production of electricity alone is, in practice, limited to larger scale (tens of megawatts) plants. Small scale operations usually recover heat from the electricity generation processes which is then distributed (see section 4.1.2). The generation technology is similar to that employed in coal-fired power stations[48], producing steam to drive a turbine. An example of this technology will be found in Port Talbot, South Wales where a 350MW wood-fuelled plant is to be in full operation by the first quarter of 2011[49]. Biogas has a modest contribution to Welsh electricity and is estimated to have an installed capacity of 220 kilowatts (kW) shared roughly equally between sewage and farm waste digestion[50].

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[45] Welsh Assembly Government, *Renewable Energy Route Map for Wales,* February 2008.
[46] The Stationary Office, *Planning Policy Statement 22: Renewable Energy* (August 2004) p. 1. http://www.communities.gov.uk/documents/planningandbuilding/pdf/147444
[47] Anaerobic fermentation of such wastes produces gasses that can be burned in a turbine to generate electricity.
[48] Frank Kinght Merz, *Port Talbot Renewable Energy Plant: Non-technical summary,* October 2006. http://www.prenergypower.com/nontechnicalsummary.pdf
[49] Prenergy Power Ltd, website: http://www.prenergypower.com
[50] Dulas Ltd, *Wales Technology Map: Electricity from Renewable Energy sources (RES-e),* (publication date unavailable).

Cost

The installation and commissioning of these larger plants varies on a case by case basis. The 350 MW plant at Port Talbot is forecast to cost £400 million. A 14 MW biomass plant at Margam, due to be fully functioning in 2008 and estimated to provide enough electricity for approximately 31,000 homes, will cost £33 million[51].

The UK biomass strategy, in which the costs of biomass in the UK were analysed[52], concluded that, in general, the most cost effective use for biomass was in the generation of heat alone (considered later; Table 1)[53]. A major constraint is that the low density of biomass fuels results in high transport costs per unit of energy delivered. In addition, the location of biomass sources in the UK are poorly served by rail and, therefore, the majority would be delivered by road[54]. To minimise fuel transport costs, biomass plants can be located near to the fuel source but this limits the size of individual power stations. Such small scale plants cannot cost-effectively utilise large scale benefits such as pre-heating and are, therefore, less efficient[55].

The biomass plant to be built at Port Talbot will obtain its fuel supply by ship. This system ensures that the CO_2 emitted per tonne of transported carbon is low, between 1.9% and 3.4%, which equates to approximately 1.45 g/tonne per km by sea compared to 31.7 g/tonne per km by road[56]. This solution to fuel transport overcomes the limitation to plant size and therefore plant efficiency. A small biomass plant of 40 MW is likely to be 22 per cent efficient whereas the proposed Port Talbot plant has a predicted efficiency of 36 per cent[57] (for comparison, the thermal efficiency of coal fired stations in the UK was 36 per cent in 2006, nuclear stations were 38 per cent efficient, and combined cycle gas turbine stations were 49 per cent efficient[58]).

Fuel type

Unlike many renewable options, biomass renewables burn fuel. There are a number of different possible fuel sources. The cheapest fuel is contaminated waste wood; i.e. wood that has been treated or painted. Dedicated biomass crops, those grown solely for energy generation, include *Miscanthus*, or elephant grass, and short rotation coppice. *Miscanthus* is fast growing and harvested annually, whereas coppice, such as willow and poplar are slower growing and harvested every two to five years[59]. For ease of use fuel can be chipped or formed into pellets although at increased cost. For domestic systems the capital costs of pellet boilers and associated handling and storage facilities are lower than other systems, making the pellet system the most cost effective[60].

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[51] Welsh Energy Research Centre Press Release**,** *Welsh Commercial Scale Biomass Generation Plant Announced,* June 2006 http://www.eco2.uk.com/index.php?option=com_content&task=view&id=85&Itemid=35
[52] DBERR, *UK biomass strategy 2007* pp iii, iv (May 2007) http://www.berr.gov.uk/files/file39040.pdf
[53] *ibid.* p. iv
[54] *ibid.* p. iv
[55] *ibid* p. 28
[56] Frank Kinght Merz, *Port Talbot Renewable Energy Plant: Non-technical Summary* (October 2006) p. 7. http://www.prenergypower.com/nontechnicalsummary.pdf
[57] *ibid.* p. 7.
[58] DBERR, *Digest of United Kingdom Energy Statistics 2007*, p. 136, http://stats.berr.gov.uk/energystats/dukes07.pdf
[59] Department for the Environment, Food and Rural Affairs, *Growing Sort Rotation Coppice,* June 2002. http://www.defra.gov.uk/erdp/pdfs/ecs/src-guide.pdf
[60] DBERR, *UK Biomass Strategy,* May 2007. p. iii http://www.berr.gov.uk/files/file39040.pdf

Table 1 Biomass fuel price assumptions as calculated for the UK biomass strategy[61].

Biomass Type	Price Range (£ per GJ)
Waste wood (contaminated)	0.5-1.5
Forestry Woodfuel – logs	1.5-2.5
Straw	1.5-2.5
Arboricultural arisings	2.0-3.0
Forestry Woodfuel – chips	2.0-3.0
Waste wood (clean)	2.0-3.0
Miscanthus	2.5-3.5
Short Rotation Coppice (SRC) e.g. Willow	3.0-4.0
Imported biomass (including delivery)	3.5-5.5
Woodfuel pellets to industry/commercial	4.0-5.0
Miscanthus pellets to industry/commercial	4.5-5.5
SRC pellets to industry/commercial	5.0-6.0
Pellets to domestic (including delivery)	6.0-8.0

Environmental impact

The principal advantage of biomass generation over many other renewables is that it is not intermittent. The new power plant at Port Talbot will, for example, produce a consistent output of electricity providing a base load. The waste produced from burning biomass, which in the new Port Talbot plant will be less than 150,000 tonnes per year[62] from 2.5-3 million tonnes of wood burnt annually[63], can be sold for use in fertilisers or to the cement industry[64]. The potential ecological impacts of biomass have been well covered in an Agricultural Development and Advisory Service (ADAS) report[65], and indicate that the main area of concern is the growth of the wood fuel. Poor site choice could lead to the loss of areas of high biodiversity but the report also notes that replacement of intensive arable land may benefit important species such as the dormouse[66].

Concerns over biomass burning are:

- Pollution from the burning of wood
- The use of land to grow resources which may otherwise be used for food production
- Pollution from non-sustainable fuel transport
- Sustainability of wood supply

[61] *ibid*.
[62] Sinclair Knight Merz Ltd, *Environmental Statement: Port Talbot renewable Energy Plant: Non-technical Summary,* October 2006. p.10 http://www.prenergypower.com/nontechnicalsummary.pdf
[63] *ibid* p. 1.
[64] *ibid* p. 10.
[65] ADAS, Potential Impacts of Future Renewable Energy Technology on UK Biodiversity, February 2006. p. 15. http://www.defra.gov.uk/science/Project_Data/DocumentLibrary/SD0307/SD0307_3488_FRP.doc
[66] *ibid*.

4.1.2 Biomass combined (cooling) heat and power (CHP/CCHP)

In biomass CHP systems, the heat is first used to create steam to drive a turbine as in a conventional power plant. The remaining heat, which in conventional power stations is lost, is used to heat water or space. The heat is locally distributed and, as a result, installations tend to be localised, minimising heat loss to the ground through extensive distribution. These systems can also be fitted with an absorption chiller unit which uses heat energy to produce refrigeration. According to Wood Energy Ltd, electric powered summer cooling accounts for 10-12 per cent of total building electrical consumption and this is reduced to 1-2 per cent when using biomass[67]. In December 2007, installation of the UK's first biomass CHP unit at the Centre for Alternative Technology (CAT) in Machynlleth commenced. The system will be powered by woodchip sourced four miles from the plant, minimising transport emissions. The unit will generate 100 kW_e (electricity) and 250 kW_{th} (heat), enough to power approximately 40 to 60 homes[68].

4.2 Hydroelectric

The technology and installation size

Hydroelectric power refers to any system that generates electricity from the latent energy in freshwater as it falls with gravity. It is one of the most established technologies in the world and accounts for approximately 17 per cent of electricity generation worldwide[69]. Hydroelectric power can be employed at a wide range of scales, from large-scale plants able to power whole cities through to small plants supplying single households. The technology is well established and consists of a turbine which converts water pressure into rotational energy[70]. There are two main types of renewable hydroelectric set up:

- Impoundment – in which a barrage is built to collect a reservoir of water which is then fed through turbines.
- Diversion – in which water is diverted away from a river along a canal or pipe (a penstock) and then through a turbine. Diversion systems may not require the creation of a barrage.

Systems where water falls from a substantial height are known as 'high head'. Low head systems are normally those where a greater water volume falls over a lesser height.

Cost

As with all installations, large scale projects need to be costed individually as there are many site specific parameters that need to be considered. Whilst to some extent the same is true for small hydroelectric set ups, the British Hydropower Association have published estimated costs for low head and high head schemes for a 100 kW installation. The total estimated cost, which includes the machinery, civil works, electrical works (excluding grid connection) and external costs, such as

[67] Wood Energy Ltd Website, http://www.woodenergyltd.co.uk/technical/AbsorptionChilling.ashx
[68] Centre for Alternative Technology Press Release. *CAT Gets New Biomass Generator for Heat and Power,* 7 December 2007 link to CAT media pages
[69] The British Hydropower Association, *Hydrofacts Website* http://www.british-hydro.org/hydrofacts.html
[70] The British Hydropower Association, *A guide to UK Mini-hydro Developments*, January 2005. http://www.british-hydro.co.uk/download.pdf

deign and management and licence costs, is estimated to be £115,000 – £280,000 for low head schemes and £85,000 - £200,000 for high head schemes [71].

Environmental impact

The environmental impact of hydroelectric power installations is related to their size. Large installations will have major impacts on many aspects of a river environment. The following summary is, therefore, indicative and for large installations, impacts will be highly site specific. The Assembly Government considers that:

> '…the creation of new large volumes of water that would be required [for large scale schemes] is most unlikely to constitute sustainable development.[72]'

The International Hydropower Association has highlighted a number of areas for potential environmental impacts:

- Changes to water quality downstream of the installation affecting, amongst other variables, oxygen levels and water temperature
- Changes to sedimentation transport
- Effects on stream-side habitats and associated biodiversity
- Species loss through constriction activities
- Blockage to the passage of fish: This may be particularly important for salmonids, such as salmon and trout, which return to rivers from the sea for breeding
- The presence of pest species as a result of the creation of a new body of still water the reservoir
- Effects on human health related to river flow regulation and disease transmission
- Construction impacts such as dust and noise[73]

Not all of these impacts will apply to each installation; in particular, some of the impacts are more relevant to schemes that create new areas of standing water.

4.3 Solar photovoltaic (solar PV)

The technology

Solar PV converts inexhaustible sunlight energy into electricity. Light falls into one or two layers of a semiconductor, usually silicon, creating an electric current[74]. A solar panel, or module, is made up of multiple small solar cells and encapsulated, normally with glass to protect it from damage. Multiple modules can be connected to produce the desired level of installed capacity[75]. Although

[71] *ibid.* pp. 15, 16.
[72] Welsh Assembly Government. *Renewable Energy Route Map for Wales: Consultation on a Way Forward to a Leaner, Greener and Cleaner Wales,* February 2008. p. 21.
[73] International Hydropower Association, *Sustainability Guidelines,* February 2004. http://www.hydropower.org/downloads/IHA%20Sustainability%20Guidelines_Feb04.pdf
[74] Energy Savings Trust, *Solar Electricity Website* http://www.energysavingtrust.org.uk/generate_your_own_energy/types_of_renewables/solar_electricity
[75] PV-WEB, *Online Information Service of the British Photovoltaic Association*, http://www.greenenergy.org.uk/pvuk2/technology/whatispv.html

most productive on a sunny day, solar PV does not require direct sunlight and can still generate electricity on a cloudy day[76].

There are four main technology types used at household scale solar PV applications:

- **Microcrystalline silicon cells**. Currently the most efficient technology converting up to 15 per cent of sunlight into electricity. The more complex manufacturing process means that this technology is also more expensive than others.
- **Multicrystalline silicon cells**. These have a more granular texture than microcrystalline cells and, consequently, a lower efficiency of about 12 per cent. They are, however, cheaper to manufacture than microcrystalline silicon cells
- **Thick film silicon**. This is another type of multicrystalline silicon cell with a fine grained appearance due to a different manufacturing technique.
- **Other thin films**. There are other semiconductors currently in development using cadmium telluride (CdTe) and copper indium diselenide (CIS) which are cheaper and more efficient and may reduce the cost of future solar PV installations[77].

The installation size and cost of solar PV

The maximum size of solar PV installations is limited only by the space available. Historically, solar PV has been used for so-called 'off grid' applications, where isolated areas are supplied using solar PV panels connected to a battery[78]. Latterly, grid connected systems have become more popular; supplying electricity to the grid when not consumed at the site of generation. Such unused electricity is sold back to the electricity supplier through an export tariff providing an income for the system owner[79].

The installed capacity for solar PV is measured in kilowatt peak (kWp), the maximum output for the installed device under standardised conditions. According to the British Photovoltaic association, a south facing non-shaded and well angled solar PV array would generate approximately 750 kWh per kWp annually[80]. There are some large scale solar PV installations including one at Ford Motor Company Bridgend Engine plant installation with an installed capacity of 94.5 kWp at a total installation cost of £1.4 million in 1998[81]. In Germany, large solar PV parks have been established including the Bavaria Solarpark with 10 MW installed capacity[82]. An average household installation is between 1.5 and 3 kWp with an installed cost of between £5,000 and £8,000 per kWp[83] with a likely annual electricity bill saving of between £150 and £200[84]. As there are no moving parts in a Solar PV array, very little maintenance is required and systems have a lifespan of 20 to 30 years.

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[76] Energy Savings Trust, *Solar Electricity Website*
http://www.energysavingtrust.org.uk/generate_your_own_energy/types_of_renewables/solar_electricity
[77] PV-WEB, *Online Information Service of the British Photovoltaic association,*
http://www.greenenergy.org.uk/pvuk2/technology/types.html
[78] *ibid.*
[79] *ibid.*
[80] *Ibid.*
[81] DBERR, *Architecturally Integrated PV System at the Ford Bridgend Engine Plant*, 2001. http://www.berr.gov.uk/files/file16524.pdf
[82] PHOTON International Magazine, *New 10 MW Solarpark Completely Online in Germany,* January 2005. http://www.photon-magazine.com/news/news_2005-01_eu_feat_powerlight.htm
[83] DBERR, *Low Carbon Buildings Programme: Solar PV.* http://www.lowcarbonbuildings.org.uk/micro/solarpv/
[84] Energy Savings Trust. *Generate Your Own Electricity: Solar Electricity.*
http://www.energysavingtrust.org.uk/generate_your_own_energy/types_of_renewables/solar_electricity

Environmental impact

A study in the Netherlands concluded that no major hazards exist from the solar panels[85] and solar panels are thought to have one of the lowest impacts of all renewable energy technologies[86]. There is limited research into potential impacts of solar panels but it has been suggested that large amounts of solar PV and the resulting reflectance may affect bird behaviour[87]. The materials used in the manufacture of solar PV cells are considered to be disposable in a simple and environmentally friendly manner[88]. In a study by Utrecht University, in which the entire lifecycle of the product was analysed, solar PV systems were found to have emissions that were higher than wind and biomass energy to but substantially less than fossil fuels[89].

4.4 Wave and tidal stream

Wave and tidal power includes the following technologies:

- Tidal stream – where energy from currents generated by tides is converted directly or indirectly into electricity using a turbine.
- Tidal range – where energy can be derived from impounding a large volume of water on the high tide and then releasing it through low-head turbines once there is a sufficient height differential.
- Wave power – this covers a number of different emerging technologies that utilise the movement of waves either directly or indirectly (such as converting wave movement into air movement or oil compression) to generate power.

The technologies, a selection of which is shown in Annex A, are considered collectively here as it is an emerging industry with a wide variety of prototype devices being showcased. The one major exception is proposed exploitation of the tidal range resource on the River Severn (considered in greater detail in section 4.5).

The resource

The wave power resource in the UK as a whole is one of the greatest in the world and Wales in particular has a large resource (Fig. 6). Tidal range is of particular interest in the Severn estuary, as it is the second largest in the world and a potential barrage is close to areas of high population density[90]. The tidal stream resource is relatively sizeable off Pembrokeshire and Anglesey (Fig. 6).

[85] ALSEMA, E., NIEUWLAAR, E. (1997) *Environmental Aspects of Solar Cell Technology: Life Cycle Assessment of Photovoltaic Panels*. Netherlands Agency for Energy and Environment.
[86] ADAS, *Potential Impacts of Future Renewable Energy Technology on UK Biodiversity* (February 2006). P. 69 http://www.defra.gov.uk/science/Project_Data/DocumentLibrary/SD0307/SD0307_3488_FRP.doc, accessed 29 January 2008.
[87] *ibid.* p. 17.
[88] *ibid.*
[89] ALSEMA, E.A., and NIEUWLAAR, E., 2000. *Energy Viability of Photovoltaic Systems*. *Energy Policy*, 28 (14), 999-1010.
[90] Sustainable Development Commission, *Turning the Tide: Tidal Power in the UK,* October 2007 p. 11, http://www.sd-commission.org.uk/publications/downloads/Tidal_Power_in_the_UK_Oct07.pdf

Development

Unlike some other renewable technologies, wave and tidal stream technologies are in their infancy, with the industry being between 10-15 years behind the wind industry[91]. A report into financing the development of wave and tidal technology commissioned by the British Wind Energy Association (BWEA) determined that the main barrier to development of these technologies was a lack of financial support for the small to medium scale grid-connected generation stage which follows initial research and development[92]. The report, produced following consultation with stakeholders, concluded that the optimal way to support the development of this industry was through the creation of a marine performance fund in which finance would be provided to the company running a successful grid connected installation with funding amounting to £100 per MWh of electricity produced. As finance is only awarded following investment, the system should encourage investment in the most promising technologies. The suggested price of £100 per MWh is based on the award for a feed in tariff currently operational in Portugal[93]. Recent changes to the renewables obligation (see beginning of section 4) will provide two ROCs per MWh of electricity produced to wave and tidal technologies, increasing the level of support to almost the amount proposed in the BWEA report.

Environmental impact

In all cases, the impacts of these technologies will vary according to the site and the type of technology used. The Countryside Council for Wales (CCW) commissioned a comprehensive report into the environmental impacts of construction and operation of wave, tidal and offshore wind technologies[94]. The following impacts include some of those highlighted by the report:

- All marine technologies are predicted to have medium or large impacts during construction.
- Above sea components and associated shoreline buildings were seen as likely to have an impact in all technologies[95].
- The potential for noise and vibration caused by drilling and other construction activities to affect bird roosting, breeding and feeding behaviour, and migration of fish (including avoidance of the area), was rated as a medium risk[96].
- During operation, all technology types, with the exception of tidal stream, were predicted to have a medium to large impact on silting and sedimentation patterns, through the extraction of kinetic energy[97]. Wave technology could have an impact on shoreline structure through this effect, with potential impacts on high-energy systems such as dunes[98].
- Tidal stream technology has the potential to obstruct marine mammals[99].
- The use of antifoulants on underwater equipment is predicted to have a medium impact on the environment in all wave and tidal stream technologies.

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[91] BWEA, *Marine Renewable Energy* http://www.bwea.com/marine/intro.html
[92] BWEA and Climate Change Capital. *Into the Blue: Financing the Future of the Emerging Wave and Tidal Power Sector,* May 2004. http://www.bwea.com/pdf/intotheblue.pdf
[93] *ibid.* pp. 7-9.
[94] Countryside Council for Wales. *Potential Nature Conservation and Landscape Impacts of Marine Renewable Energy Developments in Welsh Territorial Waters,* February 2005
[95] *ibid.* p.21.
[96] *ibid.* p. 21.
[97] *ibid.* p. 22.
[98] Personal communication, Countryside Council for Wales, 9 May 2008.
[99] *ibid*

- The necessary lighting of structures to improve night time visibility and provide navigational aid was predicted to have a large visual disturbance on shore based wave generation sites and a medium risk of disturbance on near shore wave generation installations[100].
- All technologies were considered to present a small impact risk for collision with fish, sea mammals and birds, although this risk depends on site-specific factors.
- The presence of man-made structures at sea could have positive benefits through providing new roost site for birds, and some would provide an artificial reef structure although this was rated as a low impact[101].

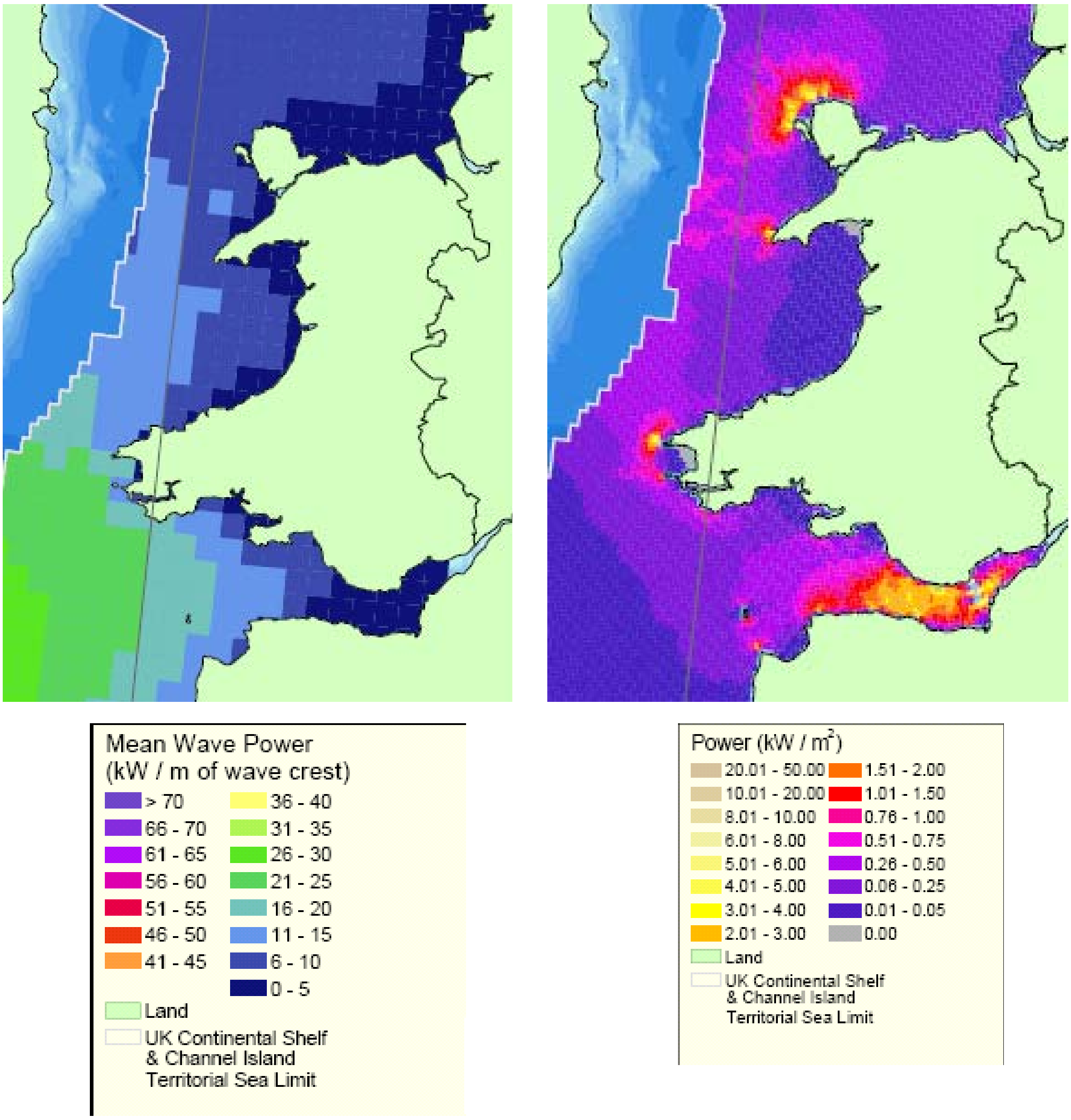

Figure 6: Wave power (left) and annual mean tidal stream power density (right) in Welsh territorial waters. Source: DBERR[102].

[100] Countryside Council for Wales. *Potential Nature Conservation and Landscape Impacts of Marine Renewable Energy Developments in Welsh Territorial Waters,* p. 22, February 2005.
[101] *ibid.* p. 23.
[102] DBERR, *Atlas of UK marine renewable energy resources,* December 2004, http://www.berr.gov.uk/energy/sources/renewables/explained/wind/page27741.html

4.5 Tidal range

Tidal range technologies exploit the potential energy created in a high tide. The technology requires water to be impounded and stored for several hours and therefore these technologies are large scale. There are two main types:

- Tidal barrage
- Tidal lagoons

Wales has a particularly large tidal range resource, with the majority concentrated in the Severn estuary which has the second highest tidal range in the world (Fig 7).

4.5.1 Tidal barrage

A tidal barrage consists of a wall built across an estuary or basin. As the tide rises, water passes through open sluices in the wall. At high tide the sluices are closed and the water impounded. As the tide falls the height difference between the impounded water and the sea level can be exploited and the impounded water is released back to the sea through conventional hydro turbines. To date only one large scale tidal barrage has been constructed at La Rance in Brittany, northern France. Opened in 1967, it generates 600 gigawatt hours (GWh) annually from a 240 MW installed capacity[103]. Two potential sites in Wales have been proposed as suitable for this type of generation; the Severn estuary and Loughor estuary.

A variety of different proposals for a tidal barrage across the river Severn have been proposed[104]. Of the proposals, the Cardiff-Weston scheme and the Shoots scheme are considered the most cost effective options[105] and, since electricity produced from a barrage is likely to be expensive, it is these schemes that are considered in this paper. This paper summarises detailed research published by the Sustainable Development Commission.

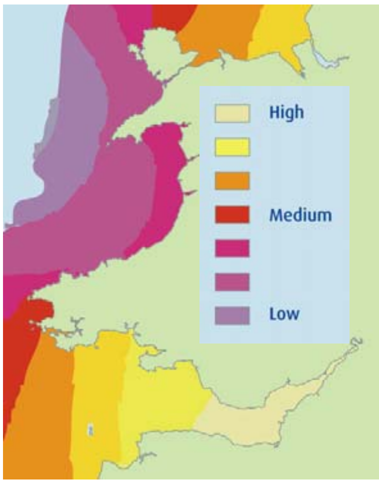

Figure. 7 Tidal resource around Wales. Source: Sustainable Development Commission.

The Cardiff-Weston Barrage

This 16.1 km long barrage between Lavernock Point and Brean Down, south west of Weston-super-mare would have an installed capacity of 8.64 GW and could generate 17 TWh of electricity annually[106]. The estimated construction costs of the barrage are £15 billion with a predicted cost of ongoing maintenance of £148.5 million annually (all 2006 prices)[107]. The cost of electricity generation has been estimated

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[103] The Sustainable Development Commission, *Tidal Power in the UK: Research Report 2 – Tidal Technologies Overview,* October 2007 p. 7. http://www.sd-commission.org.uk/publications.php?id=609
[104] For more detail see http://www.sd-commission.org.uk/publications.php?id=610
[105] *ibid.* p. 72.
[106] *ibid.* p. 73.
[107] Sustainable Development Commission, *Tidal Power in the UK: Research Report 3 – Severn Barrage Proposals* (October 2007) p.73. http://www.sd-commission.org.uk/publications.php?id=610

for a construction period lasting either 5 or 7 years and at a number of different discount rates[108], based on a 120 year lifetime (Table 2). The costs are greater than conventional and established renewable energy technologies but of a similar order to less established renewable options[109]. Such a barrage could save 3.2 or 5.5 million tonnes of CO_2 annually when compared to gas and coal fired power stations respectively[110]. Construction of the barrage would emit a large amount of CO_2, and it has been estimated that it would take between eight and eleven months of barrage operation to offset these emissions[111]. Based on experience from La Rance in Brittany, it is considered likely that the 216 turbines and associated plant would be overhauled every 30 years. High quality reinforced concrete has been shown to be durable in marine conditions and therefore, a design life of 120 years has been assumed[112]. The barrage would have a capacity factor of 22.5%[113].

Table 2: The estimated cost of electricity generated from the Cardiff-Weston barrage at four different discount rates and two different build time scenarios, with a repayment period of 40 years. For comparison the Shoots barrage costs (discussed below) are also included. Prices are for 2006 [114].

Construction Duration	Cost (p/kWh) at four discount rates			
	3.5%	8%	10%	15%
Cardiff Weston 5 year construction period	4.57	8.93	11.43	19.15
Cardiff Weston 7 year construction period	4.72	9.67	12.64	22.39
Shoots Barrage middle scenario	4.03	7.08	8.79	13.92

The construction of any barrage would probably require an Act of Parliament[115] and a range of EU Directives and UK laws would also apply to the development, many of which relate to environmental protection[116].

Decommissioning of this type of structure has not been undertaken before. There are currently no plans to decommission the barrage at La Rance. A study for the Sustainable Development Commission concluded that the cost of decommissioning may be of a similar order of magnitude to the construction costs and this did not include potential costs to return the site to pre-barrage conditions. Assumptions were, however, highly uncertain[117].

[108] The discount rate is the rate of return required by the investor. Commercial rates are about 8% but government can set rates to encourage the development of projects it deems favourable.
[109] Sustainable Development Commission, *Tidal Power in the UK: Research Report 3 – Severn Barrage Proposals* (October 2007) pp.3-4. http://www.sd-commission.org.uk/publications.php?id=610

[110] *ibid.* p. 111.
[111] *ibid.* p. 61
[112] *ibid* p. 59
[113] *Ibid* p. 91
[114] *ibid* p. 5
[115] *ibid* p. 117
[116] *ibid* p. 118
[117] *ibid* p. 5

The Shoots Barrage

The proposed Shoots barrage would be in a similar location to the current Severn road crossings. The barrage would be 4.1 km long with an installed capacity of 1.05 GW and a predicted annual output of 2.8 TWh[118]. The cost of construction has been estimated at £1.5 billion and would last for four years[119]. Unlike the Cardiff-Weston proposal, no major changes to current electricity grid structure are envisaged for the Shoots proposal[120]. Severn Tidal Power Group (STPG), which carried out studies into both the Cardiff-Weston and Shoots scheme, suggested that one of the effects of the Shoots barrage would be a net movement of sediment upstream, potentially reducing capacity and therefore generation output by half at some point between 10 and 100 years post construction[121]. Average power output during the peak electricity demand period (5pm-7pm) would be around 55 per cent of the maximum hourly average for the Shoots barrage, and 37 per cent for the Cardiff-Weston barrage, because the high tide at Shoots occurs one hour later than the high tide at the proposed Cardiff-Weston site[122]. The Shoots turbines would operate at a load factor of 32 per cent[123].

Environmental Impact

The River Severn is a site protected at all levels by designations such as Sites of Special Scientific Interest, Local Nature Reserves, National Nature Reserves, Special Protection Areas, Special Conservation Areas, and a Ramsar designation (Figs. 8 and 9)[124].

Figure 8 International designations for protecting high value habitats. Source: Sustainable Development Commission[125]

[118] *ibid* p. 3.
[119] *ibid*
[120] *ibid*
[121] *ibid* p. 22.
[122] *Ibid* p. 89.
[123] *ibid*
[124] The Sustainable Development Commission, *Turning the Tide: Tidal Power in the UK*, October 2007. pp. 89-93.
[125] The Sustainable Development Commission, *Turning the Tide: Tidal Power in the UK*, October 2007.

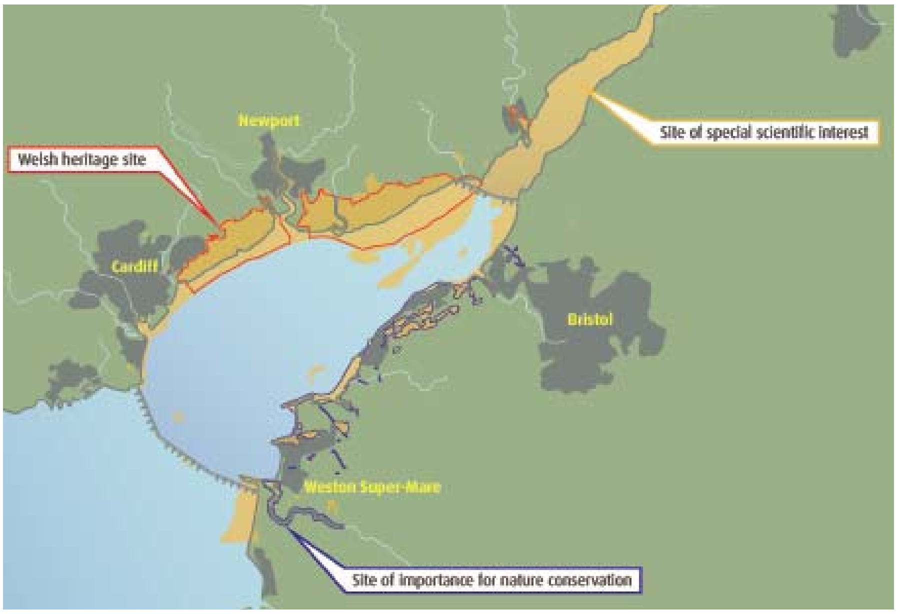

Figure 9 Local designations for protecting high value habitats. Source: Sustainable Development Commission[126]

Three statutory agencies responsible for the management of the countryside and biodiversity (the Countryside Council for Wales, The Environment Agency and Natural England) wrote a collective letter highlighting their concerns over the lack of adequate attention being paid to the environmental impact of a barrage on the Severn estuary. The letter states:

> 'In the 2003 energy white paper, the UK Government concluded that "*it is clear that plans for a Severn Barrage would raise strong environmental concerns and we doubt it would be fruitful to pursue it at this stage*". As the Government's statutory advisors on environmental issues, we do not see that new or further information has been provided that is a basis for changing that view.'[127]

Friends of the Earth Cymru is opposed to a barrage on environmental grounds, preferring tidal lagoons (see below). The Royal Society for the Protection of Birds is also opposed to the development of the barrage, citing environmental and economic factors[128]. Greenpeace gave a cautious welcome to the report by the Sustainable Development Commission on tidal power but stated that the 'jury's still out on the best way to reap the tidal power of the river without having huge environmental impacts on wading birds[129].'

A report on the potential nature conservation and landscape impacts of marine renewable energy in Welsh Territorial Waters by ABP Marine Environmental Research highlighted the following areas in which the impacts of barrage construction are predicted to be large[130]:

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[126] The Sustainable Development Commission, *Turning the Tide: Tidal Power in the UK*, October 2007.
[127] Letter from the Countryside Council for Wales, Environment Agency and Natural England/English Nature, *Severn Estuary Barrage,* May 2006
[128] RSPB, *Addendum to the Submission by the Royal Society for the Protection of Birds – Severn barrage.*(publication date not available) http://www.rspb.org.uk/Images/severnaddto06enreview_tcm9-132870.pdf
[129] Greenpeace UK Press Release, *Greenpeace on the Severn Barrage,* 1 October 2007.
[130] Countryside Council for Wales. *Potential Nature Conservation and Landscape Impacts of Marine Renewable Energy Developments in Welsh Territorial Waters,* February 2005

During barrage construction:

- Obstruction of views and visual disturbance through temporary installations such as access roads and construction yards and through movement of site traffic
- Visual disturbance through the construction of above sea components

During barrage operation:

- Changes in tidal energy, altering patterns of sedimentation, erosion, substrate type and suspended sediment
- Altering the ecology directly through changes in tidal energy
- Changing the tidal range, leading to a change in inertial habitat and possibly altering the ratio of upper, middle and lower shores.
- Disruption of river use by fish, including the blockage of migratory routes

These impacts would be greater with a larger barrage, particularly as the Cardiff Weston proposal would impound more river estuaries as well as a greater intertidal area.

4.5.2 Tidal lagoons

Tidal lagoons consist of an exclusion wall with turbine generators embedded in the wall. As the tide rises, water passes through the turbines, generating electricity until high tide. As the tide starts to ebb, the water is released from the lagoon back to the sea again via the turbines. No working example of a tidal lagoon has yet been constructed and estimates concerning lagoons are therefore speculative. One proposal for lagoons in the Severn barrage area is the Russell Proposal from 1981 (Fig. 10)[131]. This consists of three large lagoons each adjoining the land. The Sustainable Development Commission commissioned a report on non-barrage options by AEA Energy and Environment. The main conclusions were[132]:

- Russell lagoons would have an installed capacity of 2,835 MW generating 6.5 TWh annually.
- The lagoons would employ 30 turbines and save 2.8 million tonnes of CO_2 annually.
- As lagoons could be built consecutively, the first completed lagoon would generate income whilst the second and third were constructed.
- The lagoons would cover a large area, altering the river velocity on the remainder of the estuary. This may lead to changes in sedimentary distribution.
- Consecutive construction would also enable the construction of turbine housing caissons at or near to the installation site and over a longer time period than for a barrage.
- Progressive accumulation of silt within the lagoons may deplete the energy resource over time.
- Decommissioning of such a structure may be problematic with negative environmental impacts.

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[131] The Sustainable Development Commission. *Turning the Tide: Tidal Power in the UK*. (October 2007) p. 59 http://www.sd-commission.org.uk/publications.php?id=607
[132] Sustainable Development Commission. Tidal Power in the UK: Research Report 4 – Severn non-barrage options http://www.sd-commission.org.uk/publications.php?id=615

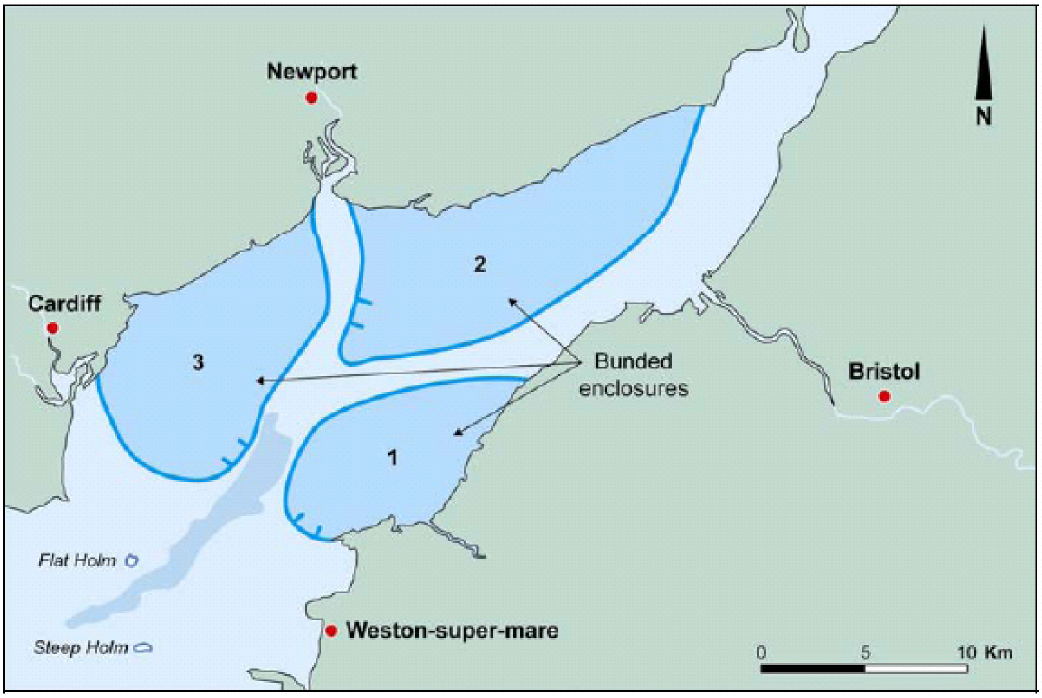

Figure 10 Russell Lagoon layout as proposed in 1981. Source Sustainable Development Commission[133].

Aside from the Russell lagoons, an American Company (Tidal Electric Ltd (TEL)) has proposed offshore tidal impoundments (OTIs), which operate under the same principles as lagoons but are not attached to the shoreline. TEL has made a proposal for an OTI off Swansea bay which was independently reviewed and costed by the then Department for Trade and Industry (DTI) and the former Welsh Development Agency (WDA, for cost comparison see Table 4). In addition, these reports were submitted to a third independent expert Mike Forde, Professor of Civil Engineering Construction at the University of Edinburgh, who considered the technical aspects for embankment construction[134]. Professor Forde's opinion was that the DTI/WDA lagoon construction cost estimates were conservative[135]. TEL has proposed that OTIs could be used in the Severn Estuary and claim that these could produce 21.3 TWh of electricity in the areas behind the proposed Cardiff-Weston barrage and a total of 32.9 TWh from the entire estuary. There is, however, no independent verification of these figures available. TEL has also proposed that lagoons could also serve as pumped storage systems, smoothing intermittency from other renewables, such as wind.

Table 3 Two different cost analyses produced by Tidal Electric Ltd and The DTI/WDA[136].

Organisation	Estimated Total Cost (£ millions)	Electricity Cost (p/kWh)	Predicted Generation (MWh/yr)
Tidal Electric Ltd	81.5	3.5	187,000
DTI and WDA	234	17	124,000

[133] Sustainable Development Commission: *Tidal Power in the UK: Research Report Four – Severn non-barrage options* (October 2007) http://www.sd-commission.org.uk/publications.php?id=615 p.35.
[134] *ibid.* p.5.
[135] *ibid.*
[136] AEA Technology, *Tidal Lagoon Power Generation Scheme in Swansea Bay,* April 2006.

Environmental impact

Friends of the Earth Cymru has described tidal lagoons as environmentally benign. A report for the Sustainable Development Commission considered that large lagoons could lead to erosion and impacts on the sediment distribution in the estuary, and a possible exacerbation of coastal flooding[137]. Migratory fish could also be affected.

4.6 Wind turbines

Wind turbines are a well established technology and the sector continues to grow rapidly. There are two main types of turbine technology; horizontal and vertical axis wind turbines (H/VAWT). Horizontal axis turbines have the rotor perpendicular to the wind flow making them look similar to an aeroplane propeller. Vertical axis turbines, also called Darrieus type turbines, have vertically arranged aerofoils which act like aeroplane wings.

Wind Resource

The UK, and Wales in particular, has one of the best wind resources, both off and on shore, when compared to mainland Europe (Fig. 11). Wind resource is often broken down into three stages:

- The theoretical resource: the total amount of wind available,
- The technical resource: the resource remaining when technical obstacles, such as urban areas, have been taken into account,
- The practical resource: the resource available when planning, environmental, and social constraints have been taken into account[138].

For example, the UK wind theoretical resource has been estimated at 1 million GWh of which 50,000 is considered the practical resource[139].

Whilst the resource is a useful indicator, it does not provide full information as the wind does not blow continuously, so turbines cannot generate at all times. Wind turbines generally do not operate at wind speeds below 3-4 metres per second (m/s), they reach their rated output at around 13 m/s and stop operating at wind speeds greater than 25 m/s to prevent turbine damage (Fig. 12). A wind speed of 25 m/s is approximately gale force 9 with the results that wind turbines can provide useful power 70 to 85 per cent of the time[140]. The load factor is a ratio of the actual energy produced by a turbine or wind farm and the maximum production of operating at capacity. The capacity factor varies with site but is generally between 20 and 40 per cent. For offshore developments capacity factors of 40 per cent are expected due to smoother wind patterns[141].

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137 AEA Technology, 2007. *Tidal power in the UK: Research report 4 – Severn non-barrage options*, Sustainable Development Commission, http://www.sd-commission.org.uk/publications/downloads/TidalPowerUK4-Severn_non-barrage_options.pdf
138 Sustainable Development Commission. *Wind power in the UK: A guide to the key issues surrounding onshore wind power in the UK.* (May 2005) p.14 http://www.sd-commission.org.uk/publications.php?id=234
139 *ibid.* p. 15
140 *bid.* p. 17
141 *ibid.* pp. 17-18

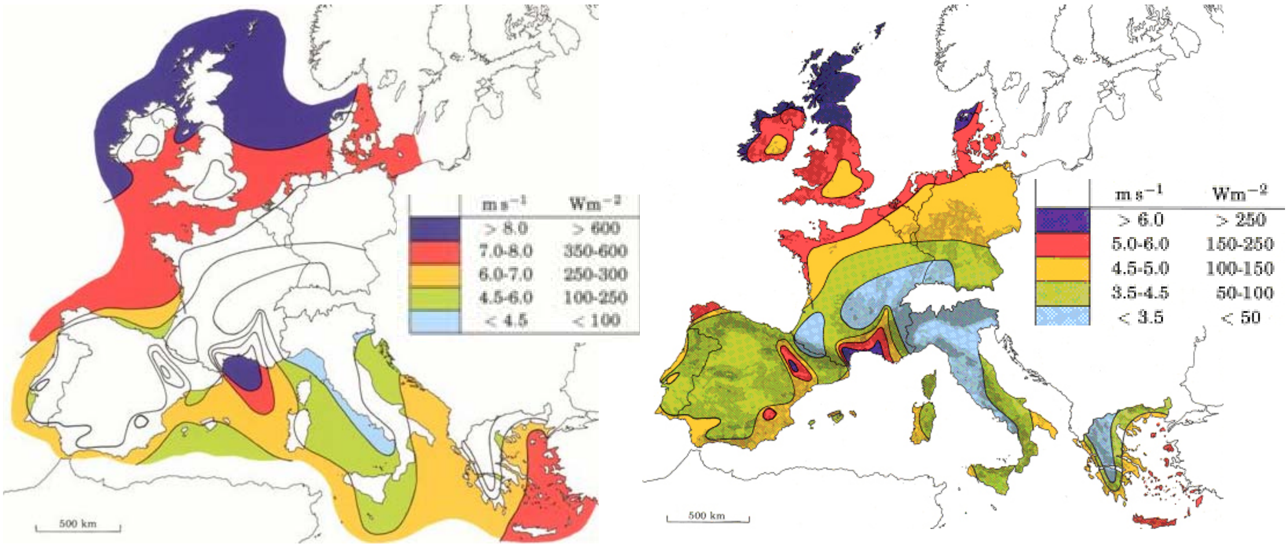

Figure 11 Offshore and onshore wind resources in Europe. The wind speeds are the minimum expected i.e. at low level (10 m) offshore and in sheltered terrain onshore. Source: Sustainable Development Commission[142].

Although wind turbines emit no CO_2 during operation, their construction does. Turbine manufacturer Vestas calculated for two sites in Denmark that onshore turbines offset their CO_2 emissions within eight months, with offshore devices requiring nine months[143].

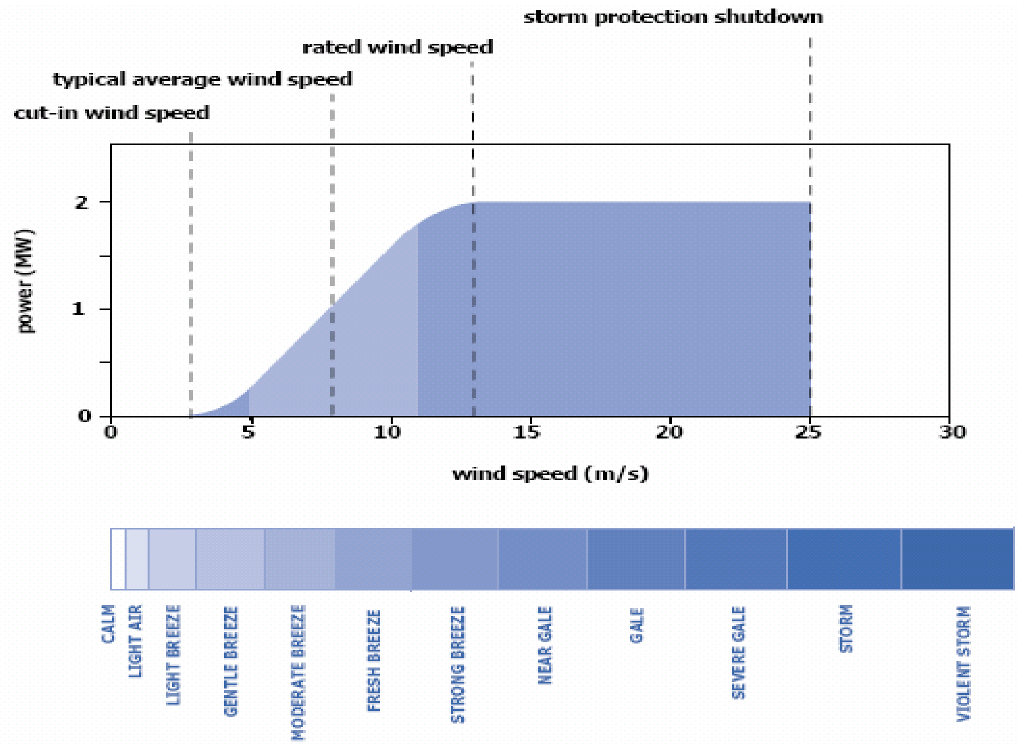

Figure 12 Typical power curve of a wind turbine. Source: BWEA[144]

[142] *ibid.* pp. 14,15
[143] Elsam Engineering. *Life Cycle Assessment of Offshore and Onshore Sited Windfarms,* October 2004 p.46. Vestas Wind Turbines Figures rounded to the nearest month.
[144] BWEA. *BWEA Briefing Sheet: Wind Turbine Technology,* September 2005 http://www.bwea.com/pdf/briefings/technology05_small.pdf

Reliability of supply

A criticism commonly levelled at wind turbines is unreliability of supply. As the power available is the cube of the wind speed, a small increase in wind speed leads to a large increase in power. For example a doubling of wind speed causes an eightfold power increase in turbine output[145]. The BWEA claims that fluctuations in wind supply are not discernable within normal energy demand requirements until wind power accounts for 20 per cent of supply[146]. Other organisations, particularly those opposed to the installation of wind turbines, claim that intermittency of supply requires a large amount of backup running at reduced capacity, known as a spinning reserve, which is a less efficient way of producing electricity[147]. The Sustainable Development Commission produced a report looking at wind power in the UK in 2005 and in addressing the issue of intermittency and energy balancing concluded the following[148]:

- Wind output can be quite accurately forecast within the time frames required for balancing electricity supply.
- Due to the lower load factor of wind (30-35 per cent) compared to fossil and nuclear power (approximately 62 per cent), wind will not be able to replace conventional capacity on a megawatt for megawatt basis.
- As wind penetration (the percentage of total electricity derived from wind) increases, both the capacity value and the ability of wind to provide firm capacity falls.
- The additional balancing requirement at high levels of penetration is a cost, not a technological, barrier to increased wind capacity.
- In the longer term, storage, such as compressed air, may alleviate wind variability.
- A major advantage of wind is that even large changes in wind do not cause the instantaneous large drop in power caused by faults in large centralised plant, making changes in wind more manageable.
- The reduction in efficiency by an increased spinning reserve at 20 per cent wind penetration will result in a loss of CO_2 emission saving of one per cent; i.e. 99 per cent of CO_2 emissions will still be saved[149].

Large scale onshore

As one of the lowest cost renewable energies, the development of onshore wind has benefited from the Renewables Obligation. There are currently 14 sites operational in Wales[150] with a total installed capacity of 180 MW[151]. In addition, three are under construction (Carno Expansion, CAT Repowering and Swansea Docks), eight have received consent and eight have been submitted[152]. Large scale onshore installations are one of the most cost effective forms of renewable energy and the cost is falling with improving technology. In the 1990s turbines had an installed capacity of

[145] BWEA. *Reference – Wind Energy Technology Website* http://www.bwea.com/ref/tech.html
[146] *ibid.*
[147] Etherington J.R. *The Case Against Windfarms,* 2006 http://www.countryguardian.net/The%20Case%20Against%20Wind%20%27Farms%27.pdf
[148] Sustainable Development Commission. *Wind Power in the UK: A Guide to the Key Issues Surrounding Onshore Wind Power in the UK,* May 2005 pp.22-26 http://www.sd-commission.org.uk/publications.php?id=234
[149] BWEA. *Offshore wind: Moving up a gear,* October 2007 p. 12. http://www.bwea.com/pdf/offshore/movingup.pdf
[150] Data extracted from DBERR, *Digest of UK Energy Statistics,* 2007 pp. 137-142.
[151] According to the BWEA website there are 25 operational wind farms in Wales http://www.bwea.com/ukwed/google.asp
[152] BWEA interactive map website http://www.bwea.com/ukwed/google.asp

approximately 600 kW whereas current installations are up to 2 MW. This means fewer turbines to service and a lower cost per kWh.

Large scale offshore

This is a rapidly growing area of wind technology. With higher load factors and lower turbulence, the BWEA predicts that the UK could occupy about 40 per cent of the world market by 2015, provided that supply chain limits, such as turbine and installation barge availability, are not imposed[153]. Offshore installations tend to use larger turbines, with commercially available turbines now in the range of 3.6 MW. Installations in Wales are North Hoyle (built and operating since 2004), Rhyl flats (under construction), Scarweather Sands (part consented) and Gwynt y Môr (application under consideration).

On 10 December 2007, the UK Secretary of State for Business, Enterprise and Regulatory Reform announced proposals to expand offshore wind generation, with a draft plan to allow companies to develop up to 25 GW of offshore wind by 2020[154].

Microgeneration

Small wind turbines to power a dwelling or small community can be mounted on poles or rooftops. A typical installation for a household would be between 2.5 and 6 kW[155]. Small turbines are highly susceptible to turbulence and sites which may initially appear suitable may turn out to be inappropriate. Both the BWEA[156] and DBERR[157] recommend that, ideally, a year-long site assessment using an anemometer is carried out. Where this is not practicable, a minimum local wind speed of 6 m/s and an obstacle free area are recommended[158]. Wind data by grid reference are available on the DBERR website[159]. The BWEA also highlights that larger systems may incur rates charges and that planning is likely to be required[160]. The recent amendment to the General Permitted Development Order[161] in England does, however, remove some planning restrictions on the installation of microgeneration technologies, including micro wind, and the Welsh Assembly Government has recently held a consultation into implementing similar changes in Wales[162]. As with other electricity microgeneration, excess supply can be exported to the grid if the system is so connected. Costs for systems are site-dependent, but are approximately £1,500 for a system below 1 kW, rising to £25,000 for larger 6 kW systems[163].

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153 BWEA website, *Offshore wind: the potential for offshore wind,* December 1996 http://www.bwea.com/offshore/overview.html
154 BERR, *The UK meeting the energy challenge with Europe,* 10 December 2007, http://www.berr.gov.uk/pressroom/Speeches/page42831.html
155 BERR, *Low Carbon Buildings Programme - wind turbines* http://www.lowcarbonbuildings.org.uk/micro/wind/
156 BWEA, *Reference: UK Windspeed Database* http://www.bwea.com/noabl/index.html
157 BERR, *Low Carbon Buildings Programme: Wind turbines.* http://www.lowcarbonbuildings.org.uk/micro/wind/
158 *ibid.*
159 BERR, *Wind Data Website* http://www.berr.gov.uk/energy/sources/renewables/explained/wind/windspeed-database/page27326.html
160 BWEA, *Small Wind Technologies: Building-integrated and Stand-alone Systems.* http://www.bwea.com/small/technologies.html
161 *The Town and Country Planning (General Permitted Development) (Amendment) (England) Order 2008* SI 2008/675
162 Welsh Assembly Government, *Lifting Palnning Barriers to Domesticv Micro-generation: Proposed changes to Permitted Development Rights,* July 2007
163 BERR, *Wind Data Website* http://www.berr.gov.uk/energy/sources/renewables/explained/wind/windspeed-database/page27326.html

Environmental impact

Wind farms can be contentious, with groups forming to resist or support developments within their locality, and opinions often polarising on either side of the argument. The visual and ecological impacts are two reasons frequently cited by those opposed to wind developments.

Onshore wind turbines have grown rapidly in size and generating capacity as the technology has developed[164]. Modern onshore turbines can reach a blade tip height (the maximum height of the rotor tip when at its zenith) of 120 metres, although wind farms with these large turbines are equipped to a lower density[165]. A continued increase in size for onshore turbines is thought unlikely due to the challenges of transporting such devices to site[166]. Another concern raised by opponents to onshore sites is the noise produced from the turbines. Much research has been carried out into noise production and turbine manufacturers have made substantial progress in reducing the turbine noise[167]. The noise in the immediate vicinity of one turbine is estimated at between 90 and 100 decibels (dB) at a standard wind speed and, based on this, the noise at a site 350 metres downwind of a group of 10 turbines would be between 35 and 45 dB. To place this in context, a car travelling at 40 mph at a distance of 100 metres is responsible for noise at approximately 55 dB whereas a quiet bedroom has a background noise of approximately 35 dB[168]. Whilst wind turbines emit more noise as their speed increases, so too does the level of background noise from the wind[169].

There are certain impacts associated with offshore wind farms. This paper summarises some of the main areas of concern but readers are directed the cited publications for more detailed information. One of the biggest issues is the visual impact of offshore turbines, although this depends on factors such as the distance offshore and the height above sea level of coastal viewpoints[170]. Noise is a concern during construction of piles, particularly the potential impacts on marine mammals[171]. As turbines grow in size so do their foundations and therefore the noise associated with their construction. The harbour porpoise has been shown to avoid sites during pile-driving operations[172]. The disturbance of the sea bed causes increased water turbidity and when suspended sediment settles, it may cover organisms such as shellfish[173]. Construction noise is not generally considered to be a problem for birds or at levels considered to be a nuisance to human populations, although this depends on the distance of the site from populated areas[174]. There have been isolated incidents of pollution as a result of construction but none of severe or lasting impact has, as yet, been reported[175].

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[164] Sustainable Development Commission, *Wind Power in the UK: A Guide to the Key Issues Surrounding Onshore Wind Power in the UK,* May 2005 p. 55. http://www.sd-commission.org.uk/publications.php?id=234
[165] *ibid.*
[166] *ibid.*
[167] *ibid.* p. 75.
[168] *ibid.* pp. 75, 78.
[169] BWEA. *Reference: Noise from Wind Turbines – The Facts.* http://www.bwea.com/ref/noise.html
[170] DTI, 2002. *Future offshore: A strategic framework for the offshore wind industry*, http://www.berr.gov.uk/files/file22791.pdf
[171] OSPAR Commission. *Review of the Current State of Knowledge on the Environmental impacts of the Location, Operation, and Removal/Disposal of Offshore Wind-Farms.* (April 2006) pp. 9-11.
[172] *ibid.* p. 10.
[173] *ibid.* p. 9.
[174] *ibid.* p. 13.
[175] *ibid.* p. 12.

Once constructed, offshore wind farms can operate as fish aggregating devices (FADs), with populations having been shown to increase significantly[176]. Such aggregation may be due to increased protection from predators but the reasons remain unclear[177]. There have been no reports of these farms having a barrier effect on fish or marine mammals[178]. The larger turbines used in offshore sites results in larger bases with the average being about 5 metres diameter. Based on a 5 m diameter pile at a site with no issues of scour, where water currents erode soft sediment as a result of pile installation, each turbine will have a 20 m^2 footprint. The use of concrete gravity base foundations[179] for the same diameter turbine mast would require a 30 metre diameter foundation which, if circular, would cover approximately 700 m^2 [180]. Many turbines are installed in areas with soft sediment, and depressions around the foundations where currents remove soft material, known as scour pits, develop. The spacing of 500 to 1,000 metres between turbines to avoid wind shadow should ensure that scour does not become contiguous between turbines. The presence of large amounts of cabling on the sea floor has led to concerns over the effect of electromagnetic fields (EMFs) on sea organisms. Research funded by the Crown Estate continues to investigate the effects on fish with an electro-sense, the sharks, rays and skates (elasmobranchs). Research so far has established that EMFs produced by undersea cabling are detectable by some fish species but has highlighted a lack of knowledge and the consequential need for a small scale field study to determine of the impacts of cabling on elasmobranchs[181]. A study is currently under way.

Above sea level collisions by birds with offshore turbines appears not to be a significant problem. Avoidance of the entire area does appear to occur in some species, particularly the common scoter, but also divers, guillemots and razorbills[182]. Herring gulls and little gulls, on the other hand, are attracted to the turbine sites following construction.

Aside from ecological impacts, concerns about radar interference have been raised by the Ministry of Defence.

As offshore wind farms are relatively recent developments, little is known about decommissioning, and ecological impacts are speculative. The removal of piles may lead to a loss of habitat for species attaching to the steelwork and will remove the FAD. Concerns about the use of explosives for installation demolition have also been raised[183].

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[176] *ibid.* p. 19.
[177] *ibid.*
[178] *ibid.* p. 20.
[179] Concrete gravity base foundations are where a large heavy concrete base sits on top of a prepared sea floor. This is an alternative to pile driving.
[180] OSPAR Commission, *Review of the Current State of Knowledge on the Environmental impacts of the Location, Operation, and Removal/Disposal of Offshore Wind-Farms,* April 2006 p. 13.
[181] COWRIE, *Electromagnetic Fields Review – The Potential Effects of Electromagnetic Fields Generated by Sub-sea Power Cables Associated with Offshore Wind Farm Developments on Electrically and Magnetically Sensitive Marine Organisms*, July 2005. http://www.offshorewindfarms.co.uk/Downloads/1351_emf_phase_one_half_report.pdf
[182] OSPAR Commission. *Review of the Current State of Knowledge on the Environmental impacts of the Location, Operation, and Removal/Disposal of Offshore Wind-Farms*, April 2006. p. 26.
[183] *ibid.* p. 27.

5 Renewable Heat Technologies

Renewable heat technologies generate heat which is not hot enough to generate steam and, therefore, electricity. This heat can provide or supplement the hot water supply, and/or space heating for buildings. There are three technologies considered here:

- Biomass heating
- Ground source heat pumps (GSHPs) and,
- Solar thermal

5.1 Biomass heating

Technology and cost

Biomass has been already been defined in section 4.1. The use of biomass for heating generally consists of wood burning in the form of logs, chips or pellets. There are two main types of biomass heating:

- Room heating wood burning stoves
- Central and water heating biomass boilers

Wood burning stoves are the cheaper option and provide living space heat with a capacity of between 6 and 12 kW_{th}. Wood burning stoves can be 80 per cent efficient and in some cases a back boiler may be fitted to provide hot water as well[184]. According to the Energy Saving Trust, space heating stoves cost about £3,000, with the savings dependent on the fuel replaced and how much the installation is used[185].

Biomass boilers can replace the entire central and water heating system in a house and can be fitted with an automatic fuel feed system to reduce the time spent tending the plant. The installed capacity can be up to 15 kW_{th} and installations cost between £5,500 and £12,000. These systems can also be built with a storage tank, capable of storing water at up to 90°C, allowing fuel combustion and heat use to be largely decoupled from one another[186]. These systems can save up to 8 tonnes of CO_2 annually and approximately £200 in reduced energy bills[187].

Larger systems capable of supplying communities or offices can be installed when coupled with low heat loss piping networks. One such system is in place at the National Botanic Gardens in Carmarthenshire where the Great Glass House, offices, and other buildings are heated using waste wood. Atlantic College in the Vale of Glamorgan has two 640 kW_{th} biomass boilers fuelled

[184] BERR, *Low Carbon Buildings Programme: Biomass.* http://www.lowcarbonbuildings.org.uk/micro/biomass/
[185] Energy Saving Trust. *Biomass Heating* (Website) http://www.energysavingtrust.org.uk/generate_your_own_energy/types_of_renewables/biomass
[186] BERR, *Low Carbon Buildings Programme: Biomass.* http://www.lowcarbonbuildings.org.uk/micro/biomass/
[187] Energy Saving Trust. *Biomass Heating* (Website) http://www.energysavingtrust.org.uk/generate_your_own_energy/types_of_renewables/biomass

by local wood, saving an estimated £30,000 a year in energy bills and some 525 tonnes of CO_2 emissions[188].

Environmental impact

The environmental impact is very similar to biomass use for electricity production.

5.2 Ground source heat pumps

Technology and installation size

The temperature of the ground at a depth greater than 1 metre is buffered against air temperature and, as such, remains relatively constant at between 8-12°C all year round[189]. Heat pumps are most commonly encountered in the form of refrigerators where heat is pumped out of the fridge allowing it to cool. Ground source heat pumps (GSHPs) operate by taking the warmth from the ground and supplying it to the building. The system consists of three components:

- **The ground loop**. Either a horizontal trench or vertical borehole into which a pipe containing a mixture of water and antifreeze is placed. The loop is typically a closed system.
- **The heat pump** which consists of three components
  - The evaporator, which takes the heat from the underground loop
  - The compressor, which pumps the water around the system
  - The condenser, which concentrates and releases the heat into the building's heat distribution system.
- **The heat distribution system** – The radiators or under-floor heating system that deliver heat to the building[190].

Horizontal ground loops are normally the most cost effective for small systems, and trench size can be reduced by using a coiled or 'slinky' pipe. The horizontal trenches are about 1.5 to 2 metres deep and the GSHP Association suggests that a typical three bed house with 120 m^2 of flooring would require two 30 to 40 metre long trenches[191]. Where sufficient space is unavailable, vertical bores of between 50 and 150 metres can be drilled. Whilst these systems benefit from higher ground temperatures, they are more expensive[192]. Although the heat can be supplied to traditional radiators, since the system does not generate high temperatures (typically 30-35°C), it is more efficient when supplied to an under-floor heating system. For every one unit of electricity used to power the pump, three to four units of heat are supplied to the building[193], although this is less, about 2.5 units of heat per unit of electricity, if heat is supplied using radiators[194]. It is worth noting

188 EGNI Biofuels, *Renewable Energy: A Guide to Help Public Sector Organisations in Wales Achieve Their Renewable Energy Targets.* (Publication date unavailable) http://www.switch2help.com/egni_brochure-111679002645.pdf
189 Ground Source Heat Pump (GSHP) Association, *Ground Source Heat Pumps – An introduction* p. 1. (Publication date unavailable) http://www.gshp.org.uk/documents/GSHPIntroduction_000.pdf
190 BERR, *Low Carbon Buildings Programme: Ground Source Heat Pumps.* http://www.lowcarbonbuildings.org.uk/micro/ground/
191 Ground Source Heat Pump (GSHP) Association, *Ground Source Heat Pumps – An Introduction.* p. 2. (Publication date unavailable) http://www.gshp.org.uk/documents/GSHPIntroduction_000.pdf
192 *ibid.*
193 BERR, *Low Carbon Buildings Programme: Ground Source Heat Pumps.* http://www.lowcarbonbuildings.org.uk/micro/ground/
194 Energy Savings Trust, *Domestic Ground Source Heat Pumps: Design and installation of closed-loop systems,* March 2004 http://www.gshp.org.uk/documents/CE82-DomesticGroundSourceHeatPumps.pdf

that air source heat pumps and water source heat pumps also exist and operate in broadly the same way.

Cost

A typical household system is estimated to cost £7,300 to £11,800 plus the additional cost of connection to the heat distribution system[195]. The GSHP Association estimates an installed cost of approximately £1000 per kW although cautions that the cost may vary greatly depending on site and building conditions[196].

Environmental impact

There are limited environmental impacts with GSHP systems. The principal concern is leaking from the ground loop polluting groundwater. Boreholes can also create hydraulic connections between water courses in different rock strata. In addition, heat extraction by the GSHP can alter the temperature in an aquifer which may be undesirable[197]. Environment Agency Wales is able to comment on proposals to help developers minimise potential impacts or future problems. As installations are normally on a building site, ground disturbance from building activities is inevitable. Developers may, however, need to take into account the ecological value of the land being dug for trenches.

5.3 Solar thermal

Technology

Solar thermal installations use the sun's heat to heat water. The installations have similar requirements to those of Solar PV such as facing in a predominantly southerly direction on an unshaded roof space. There are two types of solar thermal panel:

- **Evacuated tubes** - consisting of rows of glass tubes each with an absorber plate which heats the system's liquid, which is then sent to the hot water system via a heat exchanger.
- **Flat plate systems** - consist of one large absorber covered with glass or other transparent material. The heated water is fed into a hot water tank where it can be supplemented with conventional water heating on cool days.

A typical solar hot water installation in the UK ($4m^2$) will provide 40-50 per cent of a household's domestic hot water requirements, and deliver between 1400 and 2500 kWh of useful energy per year[198] (Fig. 13). Such a system would reduce carbon emissions by between 400 and 760 kg per

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195 *ibid.*
196 Ground Source Heat Pump (GSHP) Association. *Ground Source Heat Pumps – An Introduction.* p. 2. (Publication date unavailable) http://www.gshp.org.uk/documents/GSHPIntroduction_000.pdf
197 Energy Savings Trust. *Domestic Ground Source Heat Pumps: Design and Installation of Closed-loop Systems,* March 2004. http://www.gshp.org.uk/documents/CE82-DomesticGroundSourceHeatPumps.pdf
198 Energy Saving Trust, *New and Renewable Energy Technologies for Existing Housing*, undated, p. 9, http://www.energysavingtrust.org.uk/uploads/documents/housingbuildings/CE102%20-%20New%20and%20renewable%20energy%20technologies%20for%20existing%20housing.pdf

year[199]. The saving on hot water bills is approximately £40 annually although this depends on the system that is replaced or supplemented.

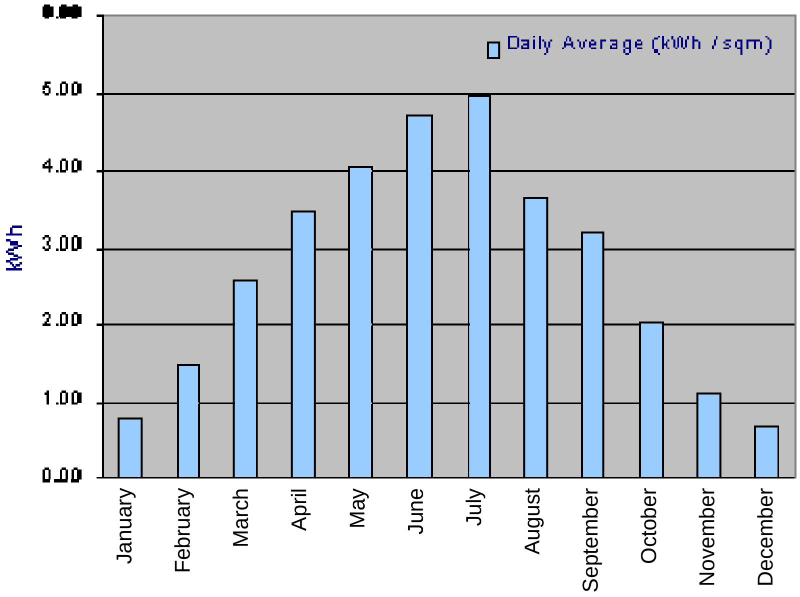

Figure 13 Daily average power output of a solar hot water system in Scotland. Source: Energy Systems Research Unit, University of Strathclyde[200]

Cost

According to the Energy Saving Trust, a typical system is likely to cost £3,200 to £4,500 but has very little ongoing maintenance costs[201]. When solar thermal is added to an existing building, the extant heating system will play a role in determining the cost. Some modern combination boilers are unsuitable to be used with solar and in homes where no water tank exists, one would have to be installed, increasing the cost.

Environmental impact

As with Solar PV, there are few concerns about the installed device. Other impacts are those from the manufacture of the materials, such as aluminium and glass, used to assemble the panel.

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199 *ibid*
200 Energy Systems Research Unit, *Urban Solar Water Heating*, http://www.esru.strath.ac.uk/EandE/Web_sites/01-02/RE_info/active_urban.htm
201 Energy Savings Trust. *Solar Water Heating* (Website) http://www.energysavingtrust.org.uk/generate_your_own_energy/types_of_renewables/solar_water_heating

6 Renewable Transport Fuel Technologies

Transport is regarded as one of the most difficult sectors in which CO_2 emissions can be cut. There are two main technologies that can be considered:

- Biofuels - including biodiesel and bioethanol,
- Hydrogen fuel cells

6.1 The biofuels - biodiesel and bioethanol

Biodiesel is made from vegetable oil, such as rape seed oil, or animal fats. Bioethanol, designed to replace petrol, is generally produced by fermenting crop sugars or starch with yeast[202]. Currently, bioethanol is produced directly from crops including sugar cane, maize and, in Europe, wheat[203]. The fuels derived from these methods are known as 1st Generation Biofuels. Fuels produced using, as yet, non-commercially developed processes such as lignocellulosis[204] of plant material or generation from municipal waste, are known as 2nd Generation Biofuels. Biofuels can be used immediately in mixes with conventional fuels of 10-20 per cent and only limited modification is required to allow vehicles to run entirely on biofuels (Fig. 14). In Brazil, about 75 per cent of new vehicles are capable of running on neat bioethanol[205]. An advantage with 2nd Generation biofuels is that they do not compete with food or animal feed resources – a problem that has led to accusations that 1st Generation biofuels lead to food price rises[206]. A report by the Low Carbon Vehicles Partnership claimed that the conversion of wood to biofuels would be a mistake as it could be used to much greater effect (a greater reduction in greenhouse gas emissions) if it were used to replace oil fired power stations[207]. There are currently no plants in Wales manufacturing bioethanol. Biodiesel is produced in Wales by a range of companies including Sundance Renewables, BioWales, Biosave and Bio Tech Oils UK Ltd.

Cost

The 'at pump' cost of both bioethanol and biodiesel is broadly comparable with conventional diesel[208] and ethanol burning fuel flex vehicles are no more expensive than the equivalent petrol vehicle[209].

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[202] E4tech for the Department of Transport and Energy Review Team, *UK Carbon Reduction Potential from the Technologies in the Transport Sector,* May 2006 p. 28. http://www.berr.gov.uk/files/file31647.pdf
[203] *ibid.*
[204] Lignocellulosis is the process of breaking down the cellulose, lignins and hemicelluloses in plants so that they can then be fermented. These constituents of plants are of no nutritional value and consist of leaves, stems etc.
[205] E4tech for the Department of Transport and Energy Review Team. *UK Carbon Reduction Potential from the Technologies in the Transport Sector,* May 2006 p. 29. http://www.berr.gov.uk/files/file31647.pdf
[206] A recipe for inflation, *Independent*, 27 February 2008 p. 42.
[207] Low Carbon Vehicle Partnership, *Biofuels in the European Context: Facts, Uncertainties and Recommendations,* December 2007 http://www.lowcvp.org.uk/assets/reports/2007%2012%20EC%20JRC%20biofuels%20facts%20and%20uncertainties.pdf
[208] Sundance Renewables Price Comparison Website http://www.sundancerenewables.org.uk/biodp/prices.htm
[209] Ford Motor Company, *New Ford Focus: Retail Prices and Consumer Offers 1st February 2008 to 31st March 2008,* February 2008 http://www.ford.co.uk/ie/focmca/-/focmca_pricelist/-/-/-/-#

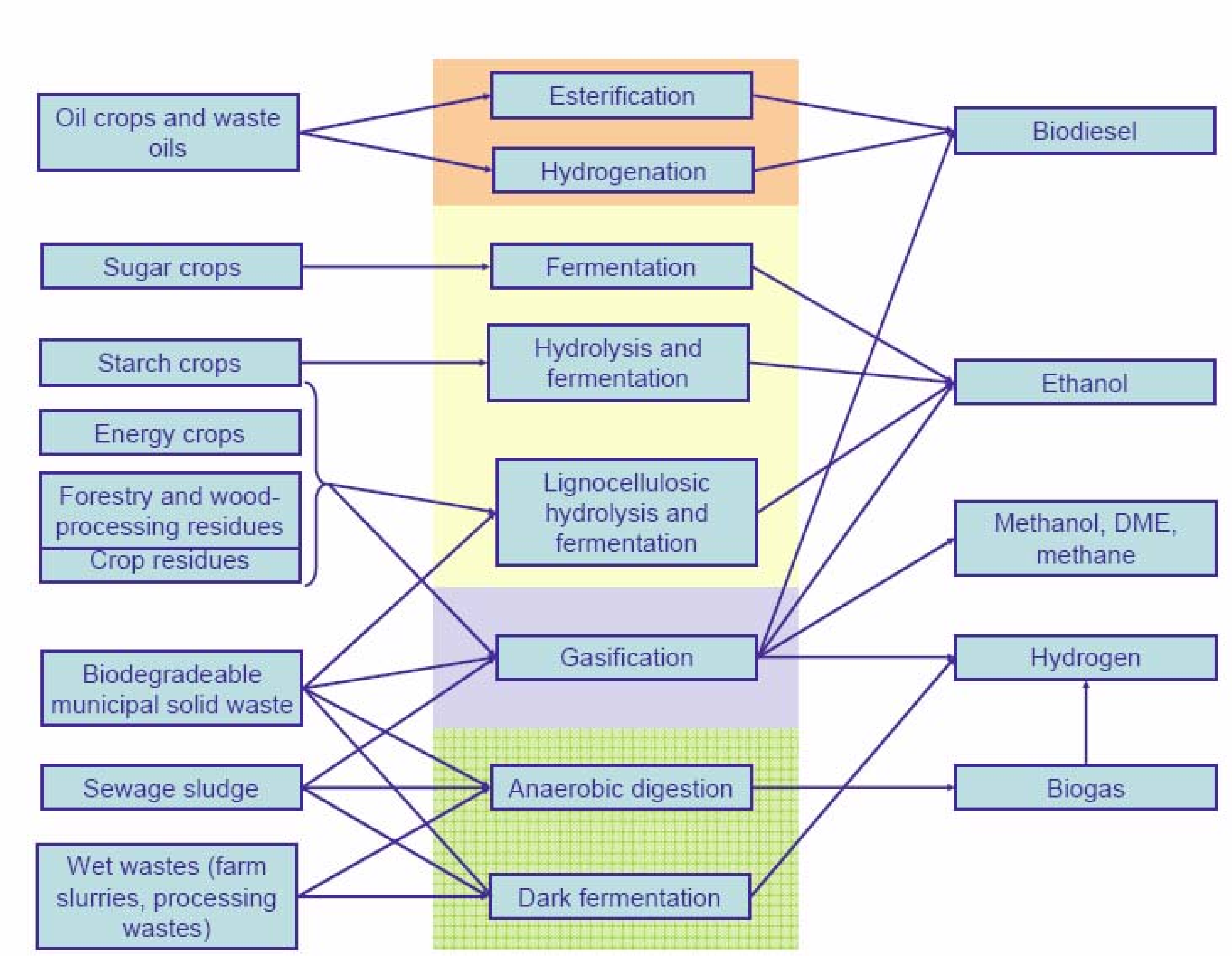

Figure 14 Feedstock, conversion processes and resultant products for biofuel production. Source: E4tech

Greenhouse gas emissions and environmental impact

The sustainability of biofuels has been questioned by a number of groups with a range of figures being presented on the levels of greenhouse gas (GHG) reduction achieved by biofuels. The Scientific Committee of the European Environment Agency has called for a suspension of the European biofuels target (to increase the share of biofuels used in transport to 10 per cent by 2020) until further studies on the environmental risks and benefits of biofuels have been completed[210].

The production of bioethanol from starch can have varying GHG emissions depending on how the production plant is fuelled. The optimum well-to-wheel[211] reduction has been estimated at 77 per cent where straw fuelled CHP is used, falling to a 7 per cent reduction where grid electricity is used[212]. Sugar beet is an alternative fuel source that could be grown in Wales[213], while the use of enzymes is estimated to offer a well-to-wheel reduction of between 73 and 94 per cent in GHG

[210] European Environment Agency, *Suspend 10 percent biofuels target, says EEA's scientific advisory body*, 10 April 2008, http://www.eea.europa.eu/highlights/suspend-10-percent-biofuels-target-says-eeas-scientific-advisory-body
[211] Well-to-wheel refers to a complete lifecycle analysis of the product from crop planting through to fuel combustion.
[212] E4tech for the Department of Transport and Energy Review Team, *UK Carbon Reduction Potential from the Technologies in the Transport Sector,* May 2006 p. 32. http://www.berr.gov.uk/files/file31647.pdf
[213] *ibid* p. 31.

emissions, including CO_2[214]. The production of biodiesel from rape seed oil is estimated to reduce well-to-wheel GHG emissions by 46 per cent compared to conventional diesel[215]. Recent research has suggested that the GHG reductions of biofuels could be overestimated because the release of nitrous oxide, a potent GHG, as a result of fertilising crops may reduce CO_2 savings[216]. Such emissions would need to be recalculated where otherwise waste material from a food or feed crop, is used. Companies making biodiesel from waste oil claim that it is a more sustainable way of producing biodiesel as the oil used would otherwise be disposed of as waste[217].

Aside from GHG emissions, biodiesel shows lower emissions of particulates, sulphur oxides (SO_x) and polycyclic hydrocarbons compared to its diesel counterpart, whilst oxides of nitrogen (NO_x) emissions can be greater. Bioethanol too shows emissions reductions compared with petrol although some harmful aldehyde emissions increase[218]. The growth of some crops requires high fertiliser inputs, which can have a negative impact on soil quality and possibly watercourses[219]. In addition, changing land use such as deforestation or peat bog draining, to provide areas for energy crop growth may negate any CO_2 savings as a result of increased land based GHG emissions[220]. As with other fuel based renewable technologies, much of the environmental impact is derived from fuel production, not emissions at the point of consumption. In addition, many of these impacts are known, which is often not the case for some emerging technologies.

6.2 Hydrogen fuel cells and internal combustion engines

Hydrogen fuel cells operate by combining hydrogen stored in the vehicle with oxygen from the air to produce heat, water and electricity. However, it should be noted that a recent report by WWF concludes that electricity is a more energy- and carbon-efficient means of powering automobiles than hydrogen[221].

The technology used for road vehicles is known as Polymer Electrolyte Membrane (PEM), favoured for having a solid electrolyte (liquid electrolytes can be hazardous) and a high power density[222]. Whilst the fuel cell itself has no moving parts, ancillary components necessary for successful operation do, introducing reliability issues[223]. An advantage with fuel cell technology is that the hydrogen fuel can be obtained from fossil sources whilst renewable sources, such as electrolysis of water using renewable electricity, are established. The timescale for commercial development of fuel cells depends on government policy and the automotive industry, but companies are working to develop fuel cell technologies, with anticipated production of fuel cell

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[214] *ibid* p. 33.
[215] *bid* p. 35.
[216] CRUTZEN, P.J., MOSIER, K.A., WINIWARTER, W., (2008). N_2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels. *Atmospheric Chemisrty and Physics*, 8, 389-395.
[217] Biosave Ltd Company Website http://www.biosave.co.uk/company.html
[218] Department for the Environment Food and Rural Affairs, Opportunities for Sustainable Substitution of Non-Renewable Materials with Materials Derived from Agricultural Crops, January 2006. http://www.defra.gov.uk/science/Project_Data/DocumentLibrary/NF0516/NF0516_3187_FRP.doc
[219] *ibid.*
[220] Department for the Environment Food and Rural Affairs, *Biofuels – Risks and Opportunties*, October 2007. p. 3. http://www.defra.gov.uk/farm/crops/industrial/energy/pdf/biofuels-risks-opportunities.pdf
[221] WWF, *Plugged in: The end of the oil age*, pp. 147, 133-149, http://www.wwf.org.uk/filelibrary/pdf/plugged_in_report.pdf
[222] E4tech for the Department of Transport and Energy Review Team, *UK Carbon Reduction Potential from the Technologies in the Transport Sector,* May 2006, p. 32. http://www.berr.gov.uk/files/file31647.pdf
[222] *ibid* p. 3.
[223] *ibid.*

vehicles between 2010 and 2015 on a commercial basis[224]. Fuel cell life is measured in hours (h) and needs to be 5,000 h for a vehicle to cover 150,000 miles. Demonstrator vehicles have been provided with fuel cells warranted for 2,000 hours and the hydrogen buses in London and other European cities, as part of CUTE (Clean Urban Transport for Europe), have already completed well over 2000 hours and are still running[225]. According to the research into sustainable transport fuels commissioned by the Department for Transport:

> 'Fuel cell vehicles offer possibly the best long-term potential given the extremely wide range of possible hydrogen sources, but require support in research, development and demonstration in the short term, and in the initial stages of commercialisation in the longer term. Monitoring and careful policy are required to ensure that low-carbon hydrogen is used, once appropriate.' [226]

In the United States, an experimental fuel cell car has been approved by the authorities to be used on the road, and a fleet of vehicles was supplied to the City of San Francisco in 2003[227].

Internal combustion engine

Hydrogen can also replace petrol in a traditional internal combustion engine (ICE). The principal advantages over fuel cells are the lower costs of the engine and the ability to run on a combination of fuels[228]. The principal disadvantage is a lower efficiency compared to fuel cells which also results in a reduced range and, therefore, fuel storage issues. One report describes the energy efficiency losses of hydrogen fuel as 'atrocious'[229]. In addition, internal combustion is not totally pollution free, with small emissions of NO_x although this can be removed using catalytic converters. One manufacturer has developed a number of car models capable of running on hydrogen[230].

Fuel source and cost

As with biofuels, the source of hydrogen fuel is central to the CO_2 emissions of a hydrogen fuel cell or ICE vehicle. Hydrogen fuel can be extracted from a wide variety of sources although many of these involve the use of fossil fuels. Biomass is a possible source of hydrogen as is any form of electricity which is used to power electrolysis of water to produce hydrogen. As with many areas of renewable technology the technological feasibility exists but there are significant financial and resource constraints. For example, there is a possibility, with research, of improving water electrolysis using fluctuating electricity sources such as wind[231], but there is resource competition with general electricity supply. In the short term, it has been argued that carbon emitting methods of hydrogen production such as steam reforming from natural gas or electrolysis using non renewable electricity may be necessary to catalyse the development of hydrogen use[232].

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[224] *ibid.*
[225] Schuckert, M. *What is CUTE* (May 2006) http://cute-hamburg.motum.revorm.com/presentations
[226] E4tech for the Department of Transport and Energy Review Team, *UK Carbon Reduction Potential from the Technologies in the Transport Sector,* May 2006. pp. 9,10. http://www.berr.gov.uk/files/file31647.pdf
[227] Honda Worldwide Website. http://world.honda.com/FuelCell/FCX/history/2003/
[228] E4tech for the Department of Transport and Energy Review Team, *UK Carbon Reduction Potential from the Technologies in the Transport Sector,* May 2006. p. 4. http://www.berr.gov.uk/files/file31647.pdf
[229] WWF, *Plugged in: The end of the oil age*, p. 111, http://www.wwf.org.uk/filelibrary/pdf/plugged_in_report.pdf
[230] BMW worldwide website BMW worldwide - environment
[231] E4tech for the Department of Transport and Energy Review Team, *UK Carbon Reduction Potential from the Technologies in the Transport Sector*, May 2006 pp.25-27. http://www.berr.gov.uk/files/file31647.pdf
[232] *ibid.* pp. 26-28

The cost of fuel cell production in 2006 was about £200-400 per kW, compared to £20-50 per kW for internal combustion engines. Estimates of costs come down markedly when automotive economies of scale (about 500,000 units annually) are factored in, with a cost of about £50 per kW[233]. Current hydrogen production at industrial levels leads to similar pre tax cost as petroleum. Storage and transport are however, complex and this can add substantially to the cost[234]. For hydrogen fuelled ICEs or fuel cells to be sustainable, the hydrogen source needs to be sustainable and costs for such production were estimated in 2006 (Fig 14)[235].

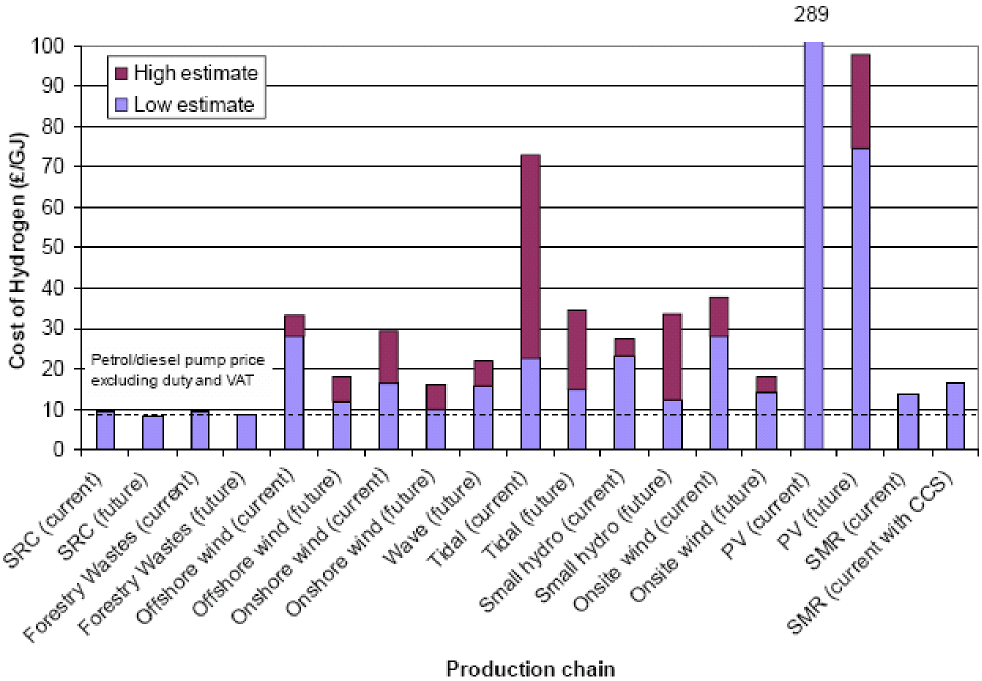

Figure 14 Estimated current and medium term future cost predictions for the production of renewable hydrogen in the UK. The cost of petrol and diesel is now higher due to price rises in crude oil. Source: E4tech[236]. SRC = Short rotation coppice, SMR = Steam Methane Reforming, CCS = Carbon Capture and Storage.

Environmental impact

The impact of hydrogen vehicles when operating is very low, so the major impacts relate to the hydrogen source, such as biomass or renewable electricity, whose impacts have been considered earlier in this paper. The production of platinum is the major source of pollution in terms of fuel cell manufacture. Fuel cells currently require approximately 56 grams of platinum per car, a ten-fold reduction from 1994, and part of a continuing trend with an ultimate aim of 0.56 g per cell[237]. Catalytic converters, obligatory in all new cars sold in the UK, require 0.14 g per car as well as another metal, palladium[238]. Unlike catalysts, the platinum in fuel cells is more easily recovered at the end of the fuel cell's life. It is estimated that 98 per cent of the metal could be recycled if fuel cells were in mass production[239]. The mining of platinum does have environmental impacts,

233 *ibid.* p. 4
234 *ibid.* p. 25
235 *ibid.* p. 26
236 *ibid.*
237 Department for Transport, *Platinum and Hydrogen for Fuel cell Vehicles,* January 2006. p. 2. Link to report
238 *ibid.*
239 *ibid.*

including CO_2 emissions of 6.4kg per gram, or about 360 kg per fuel cell with current technology. Atmospheric pollutants from platinum mining include sulphur dioxide ammonia, chlorine and hydrogen chloride, and ground water is also affected[240]. A report conducted for the Department of Transport concluded that the environmental effects of switching from petrol and diesel to hydrogen would probably have a positive environmental and climate change impact although the use of hydrogen as aviation fuel could be problematic as hydrogen acts as a catalyst in the high atmosphere leading to the breakdown of ozone[241].

[240] *ibid.*
[241] *ibid.* p. 4.

Annex A

Table 4 Some of the technologies for utilising wave and tidal stream energy. The list is not exhaustive but does cover all the broad types of technology employed

Device Name	Company Name	Energy Source	Technology type	Project progress/ Installation location
AquaBuOY	Finavera Renewables	Wave	Two stroke hose pumps pressurise sea water	Not yet installed. Plans for an installation in Figueira de Foz, Portugal.
Cygnet	Swan Turbines Ltd	Tidal Stream	Seabed mounted horizontal axis turbines which are removed to shore for servicing[242]	Medium scale demonstrator project commenced in 2007
EB Frond	The Engineering Business	Wave	Sea bed mounted in shallow water, a paddle at the end of a long arm moves with the waves pressurising hydraulic fluid to supply a generator	Still at small scale prototype stage.
Limpet	Wavegen	Wave	An onshore device; incoming waves displace air powering a turbine. The suction created by retreating waves also powers the turbine.	Islay (0.5 MW)
PowerBuoy	Ocean Power Technologies	Wave	Vertical movement over waves is turned into mechanical energy and transferred to an energy generator	New Jersey and Hawaii and Northern Spain (construction commenced)[243]
Pelamis	Ocean Power Delivery	Wave	A line of four hinged tubes ride waves and as hinges are moved hydraulic rams force oil through electrical generators	European Marine Energy Centre, Orkney
Rotech Tidal Turbine	Lunar Energy	Tidal Stream	Bi-directional horizontal axis turbine housed in a symmetrical 'funnel' duct.	Pembrokeshire, construction to start in 2008.
Seaflow (prototype) Seagen (commercial)	Marine Current Turbines	Tidal Stream	Simply put, an underwater wind turbine. Seagen employs two rotors per device. Blade pitch is controlled to utilise	Lynmouth, Devon (Seaflow) Strangford Narrows, Northern Ireland (Seagen, under construction)

[242] A director of Swan Turbines informed Members' Research Service that, contrary to some publications and the appearance on the Swan Turbines website, the rotor is not telescopically raised above the waterline for servicing.
[243] Ocean Power Technologies Inc: *Making Waves in Power.* http://www.oceanpowertechnologies.com/about.htm

			bidirectional tidal flow.	Skerries, Ynys Môn (Seagen, proposed)
SperBuoy	Embley Energy	Wave	An oscillating water column displaces air which is funnelled through a turbine generating electricity.	Plymouth Sound, One fifth scale prototype
Stingray	The Engineering Business	Tidal Stream	Sea bed mounted, a hydroplane is attached to an arm. As water passes over the hydroplane it moves up and down pressurising oil to drive a generator	150 kW installation at Yell Sound Shetland successfully run and removed
TidEL	SMD Hyrdovision	Tidal Stream	Anchored to the seabed, buoyant twin rotors swing into the direction of current and rotate, generating electricity	Tested at 10th Scale at the New and Renewable Energy Centre
Wave Dragon	Wave Dragon ApS	Wave	A floating structure with long arms which funnel waves and magnify their height and into a reservoir. Water falls back to the sea via turbines	Demonstrator project Nissum Bredning Fijord, Denmark Plans for a 4-7 MW Welsh demonstrator installation in 2008 off the Pembrokeshire coast

Annex B

Glossary of Terms

Watt	A measure of instantaneous power or capacity
Kilowatt (kW)	1,000 Watts
Megawatt (MW)	1,000 kW
Gigawatt (GW)	1,000 MW or 1 billion watts
Terawatt (TW)	1,000 GW
Watt hour (Wh)	one Watt expended for one hour. Watts are normally used to refer to the nominal capacity of an installation whereas Wh and multiples thereof are used to refer to actual energy generation over a given time period of an installation or group of installations.
Wp	The number of watts emitted by a solar photovoltaic panel under standardised conditions of light and temperature.