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HEALTH & SAFETY LABORATORY

Emerging Energy Technologies Programme: Background Report

RSU/10/08

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This report was compiled before the outcome of the May 2010 General Election was known. References to "the Government" or "Government policy" therefore refer solely to the Labour administration governing before the election on 6 May 2010.

For an update on the Coalition Government's programme for energy and climate change visit:

http://programmeforgovernment.hmg.gov.uk/energy-and-climate-change/

For an update on the 2010 budget statement for energy and climate change visit:

http://www.decc.gov.uk/en/content/cms/news/budget_june10/budget_june10.aspx

To read the 2nd annual progress report (June 2010) from the Committee on Climate Change visit:

www.theccc.org.uk/reports/progress-reports/2nd-progress-report

To read the Coalition Government's first Annual Energy Statement (27 July) visit:

http://www.decc.gov.uk/assets/decc/what%20we%20do/uk%20energy%20supply/237-annual-energy-statement-2010.pdf

This report and the work it describes were funded by the HSE. Its contents, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect HSE policy.

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EXECUTIVE SUMMARY

HSE's Emerging Energy Technologies (EET) programme has been established to produce (and to share with HSE's key regulatory partners):

- a coherent organisational strategy for HSE's regulation of the emerging non-nuclear energy technologies; and
- guidance to enable HSE's divisions to plan and deliver against this strategy.

The programme has two phases. The first phase will report on the status of five work streams covering each of the following technology areas:

- carbon catpure and storage (CCS);
- natural gas storage and LNG imports;
- renewable energy;
- distributed generation;
- clean coal technologies;

and present design options for the EET strategies. The second phase will deliver the organisational strategy and guidance.

This report was commissioned to provide an overview of the context for emerging energy technologies in order to inform the first phase of the EET programme. Its aims are to describe:

- the context for the emerging energy technologies in terms of international, EU and domestic government priorities, framework agreements and goals;
- the impact of these factors on the development and deployment of the technologies;
- other factors and constraints that may affect development and deployment;
- scenarios of the UK energy mix now, in 2020 and in 2050;
- the high level implications for HSE.

Chapter 2 covers the first three of these aims by introducing the key drivers of the search for alternative energy technologies and the policy and legislative frameworks under which developments will occur. The current UK energy mix, still heavily reliant on oil, coal and gas, is described. International, European and domestic policies and legislation and the resulting UK targets for carbon emission reductions, renewable energy and other developments are outlined. Funding and support for emerging energy technologies and other factors that are key to or may influence the development of alternative energy sources are considered, including infrastructure issues.

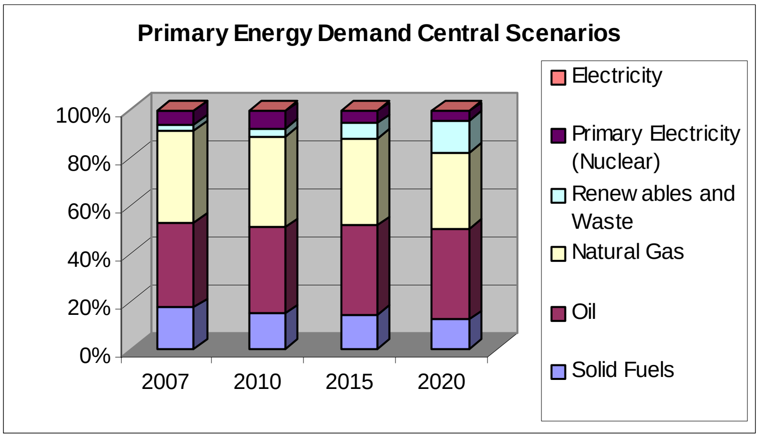
Chapter 3 describes a sample of the many energy scenarios and models that have been published by government, the energy industry and others. The limitations of trying to anticipate the future energy mix are discussed, but despite the difficulties, some consistent messages come through. The findings of the Committee on Climate Change provide examples of the key actions that it believes will be necessary:

- Decarbonisation of electricity generation and increased efficiency in the use of electricity are key elements in carbon reduction. The residential sector is important in terms of improved efficiency in appliances.
- From the 2020s decarbonised electricity plays a greater part in car and light van sectors and in domestic heating.
- Overall electricity demand increases, supplied by a combination of nuclear, renewables (predominantly wind) and fossil fuel with CCS.
- Significant investment in low carbon generation is needed – early action is called for.

Within the scenarios it is generally accepted that coal and gas will continue to provide the basis for the UK's energy supply, probably alongside new nuclear. As electricity replaces other fuels in vehicles and buildings, overall demand for electricity will increase. Given the role of coal and gas in electricity generation, the introduction of carbon capture technology appears to be vital to meet carbon emissions targets. An increase in our gas storage capacity would be necessary if the UK wishes to import significantly more gas to replace waning North Sea sources. Developments in CCS are under way, but it will be beyond 2020 before any significant impact will be made.

In the short term the UK's efforts to increase the contribution from renewable sources will be focused on a rapid expansion in wind energy capacity and a growth in the production of energy from biomass. The growth in wind energy necessary to meet the UK's renewables target is formidable. In the longer term wave and solar energy will become more significant and pilots are under way or imminent. Hydrogen has a potentially important role, and opinions differ on how big a role it will play and how quickly it will become widely used. Pilot projects over the next five years will mean that HSE will have to become involved in transportation and storage issues.

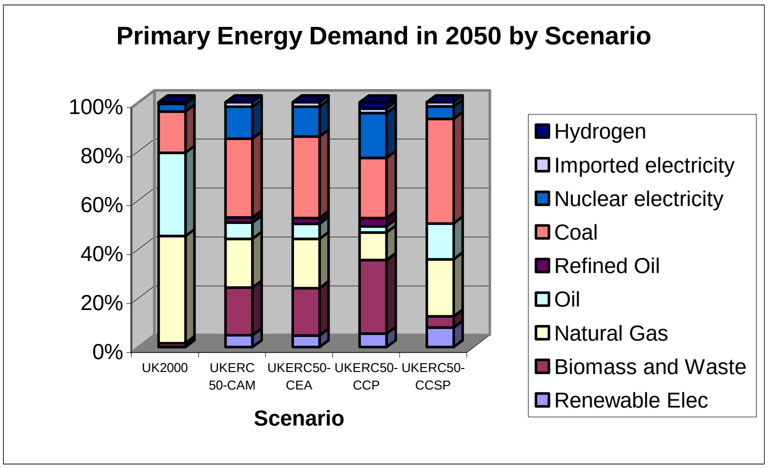
Unsurprisingly, since 2020 is much closer, and so has less scope for change and development, there is considerable overlap between the various scenarios. Nevertheless, there is no such thing as a typical scenario, but if a single example were required, then the LCTP Central scenario for primary demand could be used for 2020.



Primary energy demand central scenarios (%)*

Moving forward to 2050, there is much greater divergence of ideas, some indication of which can be seen in the range of options presented in just one set of four scenarios produced by the UKERC.

* Source: DECC, Low Carbon Transition Plan 2009



UKERC scenarios, primary energy demand 2050 (%)[†]

Chapter 4 gives an overview of the main technical areas defined by the Government's 2006 Energy Review, namely

- Carbon capture and sequestration;
- Gas storage and liquefied natural gas;
- Renewable energy sources;
- Distributed generation (and the related topic of electricity storage, including the use of hydrogen);
- Clean coal technologies.

In addition there is a section on infrastructure issues.

Each section gives a brief introduction to the technology, its present state, developments under way or planned, and dependencies and barriers. Potential health and safety implications of the technology are considered.

Chapter 5 contains brief conclusions, summarising the contents of the foregoing chapters.

HSL Futures Team
May 2010

[†] Source: UK Energy Research Centre 2009

1 INTRODUCTION

The way energy is produced and used is changing dramatically in the 21st century. There are many reasons for this but the original impetus stems from three related goals:

Climate Change – establishes the overriding need to cut carbon dioxide and other green house gas emissions.

Energy Security – the ending of UK self-sufficiency as offshore gas and oil supplies decline has coincided with a period of volatility in oil and gas prices.

Fuel Poverty – the numbers of households in fuel poverty have begun to increase again following many years of decline.

The UK wants energy that is sustainable, secure, and affordable, but how is this to be achieved? The range of options includes:

- reducing energy use – for example in the built environment by insulation;
- increasing energy efficiency - making electrical equipment more efficient and effective;
- switching energy source – for example to use renewable sources in energy generation; and
- carbon capture.

In reality it is likely that all will be utilised in order to meet the ambitious UK Climate Change target of an 80% reduction in greenhouse gas emissions by 2050 and there is already evidence of this in, for example, Local Authority lead home insulation schemes, the phasing out of traditional light bulbs and the push to renewable energy sources. What this also makes clear is that there are no simple answers. Carbon Dioxide reduction, for example, could be achieved in the UK simply by switching to nuclear power generation, but this brings with it questions such as end of life and availability of raw materials. Renewable energy offers many benefits but has yet to demonstrate continuity of supply. Globally the picture is even more complex. Worldwide there is enough energy but it is often in the wrong place; could a global energy grid resolve this? What about the wrong sort of energy? Can technology deliver 'clean coal'? When considering future developments how much allowance should be made for technological change? In order to explore the complexity of issues in play, many organisations (governmental, commercial and educational) have turned to scenarios, pen portraits of the future. These scenarios explore the different ways in which the goals can be met.

Against this background and with the wealth of information available through scenarios, HSE has commissioned this report to provide background information for its Emerging Energy Technologies (EET) Programme, which has been established so that HSE can, as far as possible, anticipate and prepare for health and safety issues arising out from the energy sector in the coming years. The EET programme will consider the options for energy supply, what will influence their development and what the emerging technologies might mean for health and safety. However, before moving on to consider what can be learned from the scenarios, it is important to be clear both where the UK is now and what are the drivers for change.

This report therefore considers first the context for emerging energy technologies in terms of the various drivers for change, the political and economic environment and some of the potential barriers to progress. The report then considers some of the many scenarios and models available in an attempt to gain some idea of what the future energy mix might be in the years up to 2050. An appreciation of the potential energy mix will help HSE to focus its planning, research and resource allocation on the right technological areas. Finally the report gives a brief summary of the key technological areas and some of the potential implications for health and safety of the introduction and expansion in the use of these technologies. These implications will receive more detailed specialist study in the individual work streams of the EET programme.

2 THE CONTEXT FOR EMERGING ENERGY TECHNOLOGIES

2.1 THE CURRENT POSITION

Fossil energy currently accounts for over 80% of world energy use.[1] In the UK the availability of indigenous fossil fuels (coal and North Sea gas) literally fuelled an industrial revolution and led, with the introduction of nuclear power, to an energy system which is well embedded both technologically and institutionally. This energy system produces economies of scale and has a well established and fit for purpose infrastructure and well developed supporting technologies.

The sources of the UK's primary energy consumption in 2008 are shown in Figure 1.[2] Total energy consumption was 234.4 Mtoe.[‡]

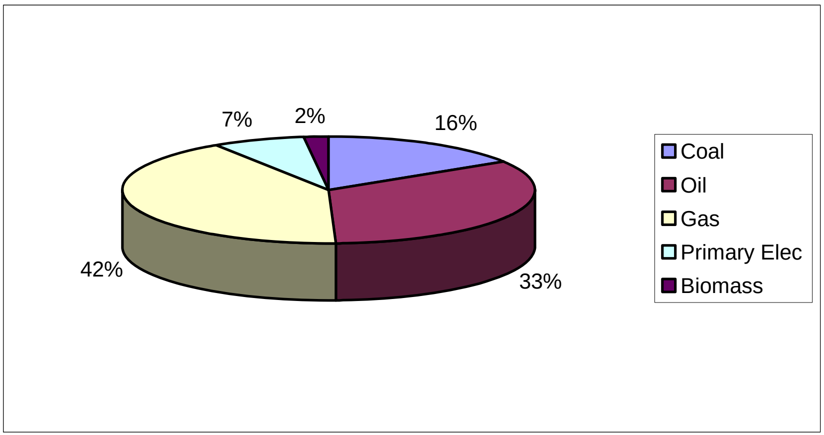


Figure 1 Composition of UK primary energy consumption 2008[2]

However this historically comfortable position is now being disturbed. The UK's gas reserves are in decline and the UK is now a net importer. Ageing UK coal fired plant is being decommissioned as a result of, for example the introduction of the Large Combustion Plant Directive. Similarly, if there are no more life extensions, the majority of the existing nuclear facilities will be retired by 2020. Climate Change is setting an increasingly high profile and international agenda, driving the need to move towards a low carbon economy. Alongside measures to trap carbon dioxide generated fossil fuel sources, an increase in the use of renewable energy sources will be crucial. Renewables (including biomass and waste) accounted for only 5.3 Mtoe or 2% of UK energy in 2008, with a target of 15% by 2020. A breakdown of renewable sources in 2008 is shown in Table 2.2. In health and safety terms perhaps the most difficult challenge is to deal with the transition from the traditional and well understood to the new and less well known. How will the infrastructure perform when it is no longer almost wholly accepting power from a small number of centralised providers? What are the implications of new plant both in terms of day-to-day running and maintenance? What further avenues will be explored through research and development? What might be the effect of overseas activities such as the exploitation of shale gas in the USA, which could result indirectly in an increase in the availability of LNG, leading to increased imports into the UK?[3] All of these questions and many more need to be considered as the agenda for change develops, but what can be learned from the drivers for change?

[‡] See Appendix 5 for an explanation of units of measurement used in this report

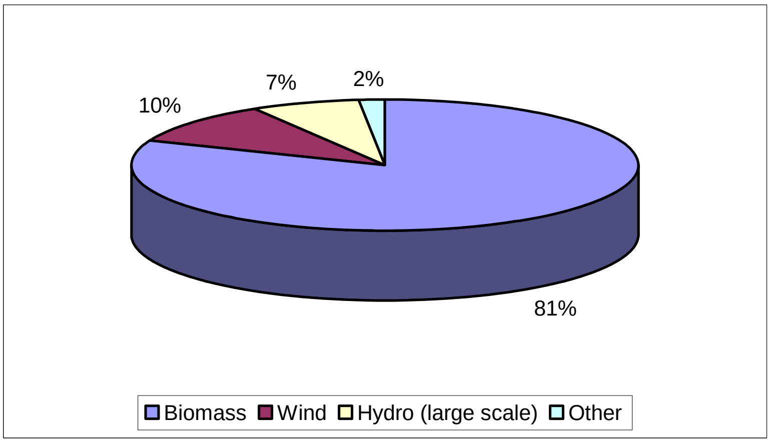


Figure 2 Contributions to UK renewable energy 2008[2]

2.2 LEGISLATIVE AND POLICY DRIVERS

2.2.1 International policy

The United Nations Framework Convention on Climate Change (UNFCCC)[4] provides the overall framework for international action to tackle climate change. It sets out an objective of stabilizing greenhouse gas concentrations The Convention requires the development and regular update of greenhouse gas emissions inventories from industrialised countries, with developing countries also being encouraged to carry out inventories. Countries who have ratified the framework agree to take climate change into account and to develop national programmes to slow climate change down.

The Kyoto Protocol,[5] adopted in 1997, is the key international mechanism agreed to reduce emissions of greenhouse gases. Unlike the UN Convention, which *encourages*, the Protocol sets binding targets for reducing greenhouse gases emissions, which equate to an average of five per cent reduction, relative to 1990 levels, over the five-year period 2008-2012. Under the Protocol, countries must meet their targets primarily through national measures. However, it also offers them an additional means of doing this by way of three market-based mechanisms: Emissions Trading, the Clean Development Mechanism (CDM) and Joint Implementation (JI).

As the current Kyoto Protocol period draws to a close a new agreement was considered in Copenhagen in December 2009. . Prior to the conference, difficulties in reaching a binding agreement were already apparent. These included the potential for inhibiting the expansion of emerging major economies and the inability of poorer nations to contribute to climate change mitigation.

For example, the difficulties experienced in passing a Bill to limit greenhouse gas emissions by the USA Legislature demonstrates the pressures that many governments are facing in promoting climate change policies, which may effect the Copenhagen outcome.[6]

Both China and India are reluctant to accept binding international curbs on carbon emissions.[7]

In addition, the 27 EU leaders disagree over how to share the cost of helping poorer states fight global warming. Poland and nine central and eastern European states contend they cannot afford to contribute in proportion to their emissions. This would leave wealthier states such as Germany, Britain and France bearing more of the cost.[8]

All of this meant that the most that could be expected in Copenhagen was a political agreement based on voluntary national pledges.[9]

The Copenhagen Accord [10]

As predicted the Copenhagen talks on climate change did not produce any binding obligations on member countries to reduce carbon emissions or for Industrialised countries to commit to implement economy-wide emissions targets by 2020 on the basis of pledges of individual countries. This in the main was due to the economic and political costs to governments in committing their countries to binding agreements. The arguments for taking action to combat global warming have not yet been won in the majority of countries, especially where action could lead to higher taxes and unemployment, as in developed countries, or an obstacles to growth, as in the emerging economies such as China.

It did, however, commit to setting up a Climate Fund to support projects, programmes, policies and activities in developing countries, on mitigation, deforestation, capacity building, and technology development and transfer. There is no detail as to how this fund will be administered.

Following the Copenhagen talks, Brazil, India, China and South Africa, known as the "BASIC"[11] group, met to agree a common position ahead of further UN climate talks. The result of which has led to fifty-five countries formally pledging to cut or limit their carbon emissions (out of 192). The date for doing this had been 31 January 2010 but has been made flexible by the UN. Other countries making a commitment include the US and all EU countries including the UK. The 55 nations between them emit 78 per cent of the world's greenhouse gases.[12]

2.2.2 European policy

In response to the Kyoto Protocol the EU has pledged that it will reach a 20 per cent share of energy from renewable sources by 2020. Each member state has been assigned a national target based on its share of renewable energy production in 2005 and its per capita GDP. The UK's target of 15% is lower than the average because of the UK's low starting point (2% renewables compared with the EU average of 9%).

The EC Sixth Environmental Action Programme (2002-2012)[13] provides a framework for European environmental policy up to 2012. The action plan highlights that action is needed to reduce global emissions (it is left to member states as to what they will do), particularly after 2012 when Kyoto's targets expire, in order to limit global warming to two degrees Celsius. A new Directive from Europe will allow for the auctioning of half the allocation of Carbon Credits from 2013 in place of free allocation.[14]

The EU is dependent on external sources of energy but has neither an internal mandatory policy nor a coherent and coordinated external policy for energy.[15] Growing global energy demand, highly volatile prices for oil and gas and increasing resource nationalism[16] resulted in the Commission's Green Paper 'A European Strategy for Sustainable, Competitive and Secure Energy' (2006),[17] which identified three main EU objectives: sustainability, competitiveness and security of supply. The European Council endorsed this in 2007 in an energy action plan for the period 2007-2009.[18] This called for the development of a common approach to external energy policy to be speeded up.

One of the major challenges for a strong, common European energy policy is the reluctance of member countries to transfer part of their control over their energy security management to EU institutions.[19] This unwillingness is more persistent where there is liberalisation of domestic energy markets. Dependence on imported energy varies among the EU member countries. For example, Spain, Portugal and Cyprus do not source gas from Russia. All of Finland's gas imports come from Russia but it depends less on Russian gas imports than Slovakia or Latvia. Germany depends heavily on imported gas with almost 40 per cent of its gas coming from Russia. Differences in dependencies on imported energy among the EU member states has led to reduced levels of urgency to arrive at a common energy policy. [20]

2.2.3 National policy and legislation

The UK Government has agreed to several legally binding emissions reduction targets relative to base year (1990) emissions:[21]

- 12.5 per cent Green House Gases (GHGs) from 2008–2012 (Kyoto Protocol)
- 34 per cent CO_2 by 2020 (Budget 2009 – increased from 26% in Climate Change Act 2008)
- 80 per cent GHGs by 2050 (Climate Change Act 2008)

The independent Committee on Climate Change (CCC) has recommended 5-year carbon budgets based on European targets, with a CO_2 reduction for the period 2018–2022 of between 29 per cent and 40 per cent (depending on the Copenhagen outcome - see below para 2.4.5).[22]

Following the Energy Review of 2006[23] and HSE's response[24] an Energy White Paper[25] was produced in 2007 which, among other things, identified the need to do something in response to Climate Change, and recommended setting targets. These recommendations came into law through the Climate Change Act 2008,[26] which set targets that were even more demanding than those in the 2007 White Paper. Interim targets and five-year carbon budget periods will be used to ensure progress towards the 2050 target. The Climate Change Act also requires the Government to assess the risk to the UK from the impact of climate change and to both publish and regularly update a programme setting out how the UK will address these likely impacts. The Act further introduced powers for the Government to require public bodies to carry out their own risk assessment and make plans to address those risks.

The Carbon Reduction Commitment, introduced by the UK Climate Change Act, is a national level trading scheme for the UK. Specific policies, relating to the countries that make up the UK set out the likely effects of climate change on the countries and regions and how the targets are to be achieved in order to create a balanced approach across all sectors and parts of the UK.

A summary of the key UK targets arising from international, European and domestic initiatives is shown in Table 1.

Table 1 Key UK energy and emissions targets

Target	*Target Date*	*Origins*
Reduce green house gases by 12% on 1990 levels	2012	Kyoto[5]
Reduce green house gases by 20% on 1990 levels	2010	Domestic
Reduce green house gases by 34% on 1990 levels (was 26% in Climate Change Act)	2020	Budget 2009
Reduce green house gases by 80% on 1990 levels	2050	Climate Change Act 2008[26]
Increase proportion of total energy derived from renewable sources to 15% (cf EU average of 20%)	2020	EU
Increase proportion of electricity generated from low carbon sources to 40%	2020	Low Carbon Transition Plan[27]
Increase proportion of electricity generated from renewable sources to 30%	2020	Low Carbon Transition Plan
Increase proportion of vehicle fuels from renewable sources to 3.25% (was 5%)	2009/10	Road Transport Fuel Obligation
Increase proportion of vehicle fuels from renewable sources to 5%	2013/14 (was 2010/11)	Road Transport Fuel Obligation

2.2.4 Planning legislation

While the legislation on Climate Change acts as a driver, it has also become clear that other legislation such as that for planning approval could delay progress. This was apparent in cases such as the third runway for Heathrow but it also, perhaps unexpectedly, applied to the switch to sustainable energy. Although their overall purpose is to improve the environment, renewable energy installations can also be seen as having adverse environmental impacts, leading to challenge by local interest groups at the planning stage. This can result in delays and in some cases even the abandonment of projects.

The Planning Act 2008,[28] which came into force on 1 October 2009, was enacted to reduce much of the bureaucracy surrounding planning permission for major infrastructure developments in the UK and so simplify the process for planning consent to be given. It provides for a new independent Infrastructure Planning Commission to take decisions on nationally significant energy infrastructure projects, which came into effect from 31 March 2010. To assist the commission in its work, national policy statements (NPS) have been produced, which set the national case for infrastructure development and also the policy framework for the infrastructure planning commission decisions. These statements also address other standard issues such as safety, where appropriate, and identify any special considerations that the commission should take into account including the desirability of mitigating and adapting to climate change. The first tranche of NPSs has been prepared by the Department of

Energy and Climate Change (DECC) and addresses energy infrastructure and ports. Further NPSs could follow during 2010.[§]

A list of relevant national, European and international legislation and policy is given in Appendix 1.

2.2.5 Responsibility for emerging energy technologies within government departments

Direct climate change responsibilities rest with the Department for Energy and Climate Change (DECC), including those areas directly related to the climate change bill, international climate change negotiations and carbon emission reductions.

Based within DECC, the Office of Climate Change (OCC) works across government to support analytical work on climate change and the development of climate change policy and strategy. The OCC is a shared resource for all departments. In addition, within DECC it leads the development of the Department's overall strategy. Given the complexity of the climate change and energy challenge OCC has a distinctive role and crosscutting way of working with other departments. On 17 March 2010, DECC announced its Carbon Capture and Storage (CCS) Industrial Strategy outlining an industry worth up to £6.5 billion and sustaining up to 100,000 jobs by 2030. At the same time, a new Government Office of CCS[29] took up work driving the development of CCS policy, technology, regulation and funding. The strategy outlined the funding mechanism for up to three more CCS demonstrator projects in addition to the current competition for a post combustion CCS demonstrator project.

The Department for Environment, Food and Rural Affairs (Defra) holds portfolios such as: waste, climate adaptation and air pollution, the natural and marine environment (water, coastal erosion and flooding), wildlife and rural affairs, sustainable development, domestic climate change adaptation, and air and local environmental quality activities.

The Department for Business Innovation and Skills (BIS) promotes open and competitive markets, proportionate regulation, an enterprise and innovation culture, skilled people, thriving universities, life-long learning and world-class science, technology and research. One of the most important areas of opportunity for the UK's future economic growth is seen as the low carbon sector. The development of a skilled workforce, necessary for the transition to the low carbon economy is also part of the BIS remit.

Planning Legislation comes under the remit of the Department for Communities and Local Government. This Department, created in 2006, promotes building more and better homes, reducing homelessness, improving local public services, regenerating areas to create more jobs, working to produce a sustainable environment and tackling anti-social behaviour and extremism. The Department sets UK policy on local government, housing, urban regeneration, planning and fire and rescue. It has responsibility for all race equality and community cohesion related issues in England and for building regulations, fire safety and some housing issues in England and Wales. The rest of its work applies only to England.

[§] There are 7 current Energy NPS's: overarching NPS for energy; fossil fuel electricity generating infrastructure; renewable energy infrastructure; gas supply infrastructure and gas and oil pipelines; electricity networks infrastructure; nuclear power generation; and ports. The remainder of the NPS's are planned to be drafted and approved between 2010 and early 2012 and cover: national network; waste water; hazardous waste; water supply; and airports.

A list of bodies (including funding bodies) involved in the development of emerging energy technologies is given in Appendix 2 while a timeline for government policies on emerging energy technologies can be found at Appendix 3.

2.3 ECONOMIC DRIVERS

2.3.1 The economic arguments for adopting emerging energy technologies

Two reports, The Stern Review report,[30] which presents the economic and ethical perspective for reducing 'greenhouse gases' and the report from the House of Lords Select Committee on Economic Affairs: The Economics of Renewable Energy,[31] published in November 2008, present the economic arguments for the switch to renewable energy sources. The latter report does not consider renewable energy in isolation from the rest of the UK energy system and it supports measures to include nuclear plants as an essential element of the UK's energy mix. It also casts doubt whether, under current policies and with current resources, it will be feasible to increase the share of renewable energy in the UK to meet the 2020 target.

This is partly because the economic case for Emerging Energy Technologies is not clear-cut. Following the liberalisation of the UK energy market, the price of electricity was so low that it was not economically attractive to develop alternative energy sources, unless they could be developed at a low cost to provide electricity predictably at competitive wholesale prices. This is why UK energy remained dominated by fossil fuels and nuclear power. The cost of electricity from onshore wind farms, for example, even at good locations would only be comparable with that from fossil fuel generators when the prices of oil, gas and coal are very high or allowance is made for the price imposed for carbon emissions permits. It is more expensive than nuclear generated power, base cost 7 pence per kWh, as opposed to around 4 pence per kWh for the other technologies.[31] Further this does not take into account the additional costs of integrating more renewable generation into Britain's grid. The base costs of generation of electricity from onshore wind are likely to remain considerably higher than those of fossil or nuclear generation and the costs of generation of marine or solar renewable electricity are higher still.

The Stern Report

Looking at the economic arguments more broadly, the Stern Report, using robust economic and climatic models, concluded that, "the cost benefits of strong, early action on climate change outweigh the impacts of climate change of doing nothing". The report's central finding is that climate change could cost an equivalent of 5-20 per cent GDP over the long term, but the world would only have to bear a cost equal to about 1 per cent of GDP annually to stabilize atmospheric concentrations of carbon dioxide. The report called for the implementation of policies to put a price on greenhouse gas emissions (for example, through an emissions tax or cap-and-trade programme), actions to stimulate the development of new climate-friendly technologies, and remove barriers to behavioural change. This was based on global greenhouse gas emissions peaking over the next 10-20 years and then declining by up to 3 per cent per year thereafter. A number of commentaries on the Review have challenged elements of the analysis that led to its conclusions. Others, however, have supported the underpinning science and the conclusions.[32] This typifies the position highlighted earlier. Consensus with regard to climate change issues and responses is rare.

The House of Lords Select Committee on Economic Affairs: Summary of Main Findings

This major study concluded that:

- Most of the extra renewable generation is expected from wind turbines, which offer the most readily available short-term enhancement of renewable electricity at a relatively cheap base cost but produce electricity only intermittently.
- There would be little investment in renewable electricity generation without government support.
- Most of the increase in renewable energy in Britain is expected to come from electricity generation.
- Electricity represents only a fifth of the country's energy consumption, with an anticipated rise from 5–6 per cent renewable sources now, to 30–40 per cent in 2020.
- Greater use of renewable energy is expected to increase energy costs. But the cost of non-renewable sources of energy can also arise because of volatility in oil and gas prices.
- Renewable energy sources can be markedly less reliable than fossil fuels in generating energy to meet peak demand, e.g. wind turbines produce no power without wind. To provide an acceptable level of security, it is necessary either to have strong interconnections to other countries i.e. a so-called Supergrid (which the UK lacked) or to build a significantly higher level of overall capacity than in an equivalent system without wind power. Both options significantly add to the cost of electricity.

The technical (including health and safety) challenges and costs of backup generation on a scale large enough to balance an electricity system with a high proportion of intermittent renewable generation are still uncertain. The UK grid has sufficient overcapacity for the next 5-10 years but because of the variability of most renewable supplies, strategies are needed for their integration with present supplies, for backup in the case of transmission failure, and even to deal with excess capacity due to over production. The need to part-load conventional plant to balance the fluctuations in wind output does not have a significant impact on the net carbon savings. The total extra annual cost of increasing the share of renewable energy sources for electricity generation from 6 per cent to 34 per cent in 2020 has been estimated at £6.8 billion or the equivalent of an extra £80 a year for the average household. Emissions of carbon dioxide would be reduced by 52 million tonnes a year.[33] The willingness of consumers, whatever their views on greenhouse gas reduction, to pay for this is unclear.[34] [35]

2.4 FUNDING AND SUPPORT FOR EMERGING ENERGY TECHNOLOGIES

Funding and grants for the development of emerging technologies are devolved through a number of agencies (see para 2.4.3 and Appendix 2). The Government's strategy for the development of emerging energy technologies has been based on the premise of not supporting particular technologies or sectors on principle but targeting areas identified as having the potential to take a leading global role, and where proportionate government intervention can unlock long-term competitive potential for British based firms, in particular in key sectors where the UK has the potential to take a leading global role, because of natural resources, strong tradition, skills base or other advantages.[36] These include:

- Carbon capture and storage
- Offshore wind generation

- Marine energy
- Nuclear energy
- Low carbon vehicles

This approach does not rule out supporting other sectors and emerging technologies. The strategy (set out in a number of documents: Building Britain's Future: New Industry, New Jobs;[37] The Low Carbon Industrial Strategy;[38] The UK Renewable Energy Strategy; [39] Building a low carbon economy: unlocking innovation and skills,[40] An industrial strategy for CCS development in the UK [41] sets out where the opportunities are greatest and the further action that it needs to take to address market failures and barriers to help unlock opportunities for British based firms

The Renewables Obligation Certificate (ROC) is the main financial support scheme for renewable electricity projects in the UK.[42] It places an obligation on UK suppliers of electricity to source an increasing proportion of their electricity from renewable energy. The design of the RO means that the total payment to renewable generators, over and above the market price they receive for their power, is fixed. The extra cost is passed on to the consumer. Some see the RO rewarding the least capital-intensive technology.[43] The UK will introduce banding of the RO, which gives some technologies more than one ROC. Whilst power companies valued a stable investment framework and prefer to retain the RO in the British market,[44] there is support for the adoption of a feed-in tariff for small-scale generation.[45]

The Climate Change Levy (CCL)[46] is the second form of subsidy available to the industry. It is a tax paid by non-domestic consumers on their energy use. In 2008, this levy was 0.43p/kWh on electricity. This levy is used to fund government spending and energy saving policies. The utility earns its money by selling renewable electricity to non-domestic users, since renewable power sold to business is tax exempt from CCL. This means the utility can retain the difference.

The UK's competitive energy markets and ROC method have not led to significant new renewable energy capacity, some argue because the UK's approach is complicated and expensive to administer. Nevertheless the Government announced in December 2008 that it intended to raise the level of the RO to increase year on year to 15.4% in 2015/16. This may improve the investment case for wind. There are of course alternative views which have been published, e.g. that it is the removal of institutional barriers and timely incentives for grid upgrades that will increase the likelihood that targets will be met.[47]

Feed In Tariffs (FITs)[48]

The UK currently gets around 5.5 per cent of its electricity from renewable sources, which will need to increase to around 30 per cent to meet the 2020 target for all energy. The Government estimates that small scale renewable installations could meet 2 per cent of electricity demand in 2020. Heat from renewable sources will also need to rise to around 12 per cent from its current 1 per cent, to meet the 2020 targets.

From 1 April 2010 households and communities who install low carbon electricity technology such as solar photovoltaic (PV) panels and wind turbines, up to 5 megawatts, will be paid for the electricity they generate. The level of payment depends on the technology and is linked to inflation. They will get a further payment for any electricity they feed into the grid. The scheme will also apply to installations commissioned since July 2009 when the policy was announced. A typical 2.5Kw solar PV installation could offer a homeowner up to £900 and save them £140 a year on their electricity bill.

The Renewable Heat Incentive (RHI)

The RHI will start operating in April 2011 allowing surplus electricity, generated domestically through clean energy, such as PV's to be exported back to the national grid. Under the proposed tariffs the installation of a ground source heat pump in an average semi-detached house, with adequate insulation levels, could receive up to £1,000 a year. Ofgem will be responsible for making payments direct to heat generators. This is a world first in providing incentives for renewable heat. As the scheme is linked to inflation, the tariffs, calculated to offer between 5 and 8 per cent return on initial investment, could increase the rate of return to between 7 and 10 per cent.

2.4.1 Budget 2009

Budget 2009

The 2009 Budget[49] announced £405 million for low carbon industries including:

- Support for the development of a British based offshore wind industry and to help accelerate the development and deployment of wave and tidal energy in the UK,
- Setting up a Marine Renewables Proving Fund to support testing and demonstration of pre-commercial renewable devices.
- Additional funding to support low carbon industries and advanced green manufacturing.
- A further £50 million in funding for the Technology Strategy Board,
- £90 million to fund detailed design and development work (two FEED studies) for the carbon capture and storage demonstration competition.
- Additional funding for interest free loans to businesses investing in the refurbishment of the UK's energy infrastructure to handle renewable technologies, including micro-generation

In particular, the following initiatives were identified:

Carbon capture and storage (CCS) technologies

The Government set out proposals for a new regulatory and financial framework to drive the development of CCS by providing financial support for up to four commercial-scale CCS demonstrations in Britain covering a range of CCS technologies.[50]

Smart grids

The Government will provide up to £6 million of funding to support early stage development of trials of key technologies consistent with a vision for smart grids (see para 4.7.4) in the UK this will complement other sources of funding for network innovation, such as through the IFI. Some other EC countries such as Italy are quite advanced in the adoption of this type of demand side management.

Micro-generation

The Community Sustainable Energy Programme[51] will provide £8 million to community-based organisations for the installation of micro generation technologies, such as solar panels or wind turbines. It will also provide £1 million for project development grants that will help community organisations establish if a micro generation and energy efficiency installation will work for them. There is also £45 million available for small-scale renewable electricity and heat technologies, through the Low Carbon Buildings Programme – Phase 1,[52] which gives up to £2,500 per property towards the cost of micro generation technologies.

2.4.2 Financial incentives in the EU

The EU has announced two funding packages designed to contribute to CCS demonstration. :

- The European Energy Programme for Recovery (EEPR)[53] amounting to €1.05 billion for CCS to be distributed between seven EU Member States with €180 million assigned for the UK.
- 300 million EU Emission Trading System allowances from the New Entrant Reserve to be used to support up to twelve CCS demonstrations.[54]

On 9th December 2009, the European Commission approved 15 energy projects, including six CCS projects, which will significantly contribute to the economic recovery of the EU. Five of the six CCS projects, including the UK's Hatfield IGCC project operated by Powerfuel, will receive a grant of €180 million with the sixth project receiving €100 million. Hatfield is the only one of the six CCS projects that will use IGCC technology to capture CO2.

The UK renewable and energy projects are also eligible for up to £4 billion of new capital from the European Investment Bank (EIB) through direct lending to energy projects and intermediated lending to banks.

The main financial support scheme for renewable electricity projects adopted by other countries in the EC is the feed in tariff, which guarantees a price to the producer. The feed-in tariff system has allowed a number of European countries, such as Germany, Denmark, Spain and Portugal, to install significantly more renewable energy capacity than the UK at lower cost.

2.4.3 Non-government bodies involved in the UK's emerging energy programme

The Pew Centre[55] recommended that policy-makers should channel new funds for research and development through multiple agencies because this will 'improve performance in fostering innovation'. The UK Government has followed this line by devolving its climate change agenda through a number of agencies. A list including these organizations can be found at Appendix 2.

2.4.4 Low carbon economic areas

Recognizing that each region and locality has particular sets of low carbon challenges and capabilities and that government support to overcome the barriers to market has to be concentrated, the UK is developing Low Carbon Economic Areas (LCEAs) to accelerate low carbon economic activity in areas where Britain's existing geographic and industrial assets give particular locations clear strengths.[38] [56] Using a combination of public and private funding, the total investment is around £100 million, of which up to a further £10 million on top of the Wave Hub funding will come from central government. Each LCEA will be a partnership of regional and sub-regional bodies and partners led by the region's RDA and relevant Local Authorities. There is an explicit commitment for LCEAs to work across agencies and network outside of their area. This gives HSE an opportunity to work with the LCEAs in order to influence health and safety practices in emerging industries (most likely to be small businesses).

2.4.5 Carbon budgets

The Climate Change Act 2008 introduced five year "carbon budgets", which limit the total greenhouse gas emissions allowed in each five-year period, beginning in 2008 to 2050.[57] The

Government agreed with the Committee on Climate Change's approach on carbon budgets and has set the levels of the budgets for the period 2008-2022. These ‘interim’ budgets require a reduction in greenhouse gas emissions by at least 34 percent by 2020, relative to 1990 levels. In May 2009, the levels of the first three carbon budgets were approved by Parliament and are now set as follows:

Table 2 Carbon Budgets to 2020

	Budget 1 (2008-12)	***Budget 2 (2013–17)***	***Budget 3 (2018–22)***
Carbon budgets ($MtCO_2e$)	3018	2782	2544
Percentage reduction below 1990 levels	22	28	34

To ensure that every part of government takes responsibility for delivery of the UK’s carbon budgets, the Government is introducing a system of departmental carbon budgets. This approach will serve as a pilot that will be reviewed ahead of the second budget period (2013-2017). Under this new system, each government department will hold its own carbon budget made up of two elements: one representing its relative degree of influence on reducing emissions from each sector of the economy; and one reflecting the emissions from the part of the public sector that it has responsibility for.

2.4.6 Private sector involvement in emerging energy technologies

Some major companies involved in renewable energy are concerned over the current barriers to renewable energy investment and generation by the corporate sector.[58] A survey by KPMG showed that prices being paid for renewable energy companies are rising because the projected growth in demand for renewable energy projects is creating upward price pressures throughout the world. However, their report also warns of the possibility of a bubble in the renewable energy sector.[59]

Conversely, owing to the recession and a collapse in the carbon price:[60] many global scale companies have cut back on their investment in renewable projects and some major manufacturers have closed production facilities for renewables equipment; energy commentators have said that renewable energy targets cannot be realised and should be scaled back to achievable levels;[61] and a group of more than 40 businesses have written to the energy and climate change minister warning of the threats to a host of emerging energy projects unless something is done.[62] The main concern is that there is not enough funding available to ‘kick start’ and develop alternative energy supplies. Reliance on the private sector will not achieve the necessary levels of alternative energy supply required to meet the 2020 obligations, which could lead to an over-reliance on gas, nuclear and coal for energy generation. Equally, the acceleration in alternative energy technologies introduction post 2020 both to meet both energy demand and climate change targets cannot be secured by public investment alone – the market must take over. At the turn of the recession in late 2009, early 2010 there are signs that investment interest in emerging energy technologies is picking up. In the run-up to the 2010 General Election in the UK all main parties indicated they would encourage faster introduction of emerging energy technologies into the UK economy, including more local generation schemes.

2.4.7 Broader economic factors affecting emerging energy technology policy

A further consideration of the economic effects of emerging energy technologies is whether they create a 'net benefit to society' as there is potential conflict between local interests and the national interest)[63] Relevant factors include benefits from:

- Enhanced competitiveness of UK industries and businesses from both reliable and affordable access to appropriate energy services;[64]
- Wider socio-economic effects such as impact on fuel poverty and effects on specific groups e.g. such as low income or elderly;[64]
- Building and running energy infrastructure compared to the loss of opportunity stemming from the failure to provide sufficient energy infrastructure in terms of their effects on employment, income, skills, technology and exports;[65]

Potential costs are found in:

- The risk that cheaper reliable energy supplies in the short term could lock businesses into higher reliance on energy and greater vulnerability to supply disruptions and price rises in future;[66]
- The likelihood that climate change policy will make energy more expensive and/or scarcer to businesses in future;[66]
- The likelihood of growing business/export opportunities for renewable, small scale and energy saving technologies and shrinking ones for carbon intense and centralised ones.

2.5 INFRASTRUCTURE

One key determinant of how energy supplies will develop into the future is the ability of a national grid system to take the outputs from the new technologies and deliver them to consumers. Both the Electricity Networks Strategy Group[67] and the National Grid[68] have published and used scenarios to aid their planning.

The key principle by which both Grids have evolved and operated is that of 'least regret', that is making any necessary minimum commitment so that the Grid can be ready to deliver to required timescales. For nuclear power, for example, construction times for any new power station are so lengthy as to allow time for the grid to be upgraded when decisions are finalised. Conversely renewable energy sources can come on stream in much shorter timescales. Here, in order to be sure that the Grid is ready on time, preliminary work, such as applying for any necessary planning consents, may be done in advance of a final commitment to the renewable development. This is necessary if the Grid is to be ready in time to take the renewable supply. Overall there is recognition that it would be unacceptable for renewable energy to be available but not able to be connected to users. Having said that, in the National Grid scenarios the combined expansion and reinforcement Grid costs range from £10 to £17 billion over the period to 2020.

The Electricity Networks Strategy Group scenarios focus largely on Wind energy and analyse the likely sites of wind farms and the issues surrounding connecting these to the Grid. Overall there is confidence that the Grid can cope, and this view is supported by other scenarios. For example, the Sinclair Knight Merz analysis suggests, "that the network may not require significant additional reinforcements provided that conventional plant flexes to allow access to wind generation". At the same time ENSG recognise that some of the network solutions incorporate the use of technologies that have not hitherto been employed in the UK energy system, e.g. HVDC (High Voltage Direct Current). This coupled with the predicted volume of renewables may represent a significant technical challenge to the Grid and potentially to health and safety.

While the electricity grid is preparing to be ready to allow renewables onto the grid at the appropriate time, the gas grid faces different challenges. Alongside the need for the gas grid to cope with gas from waste, which is not always as pure as gas from fossil sources, it also has a key role in energy security through increased gas storage, which is becoming more important as import dependency increases. From 2014, the EC requires member states to have the capacity to deliver the total gas demand needed during a period of sixty days of exceptionally high demand during the coldest period statistically occurring every twenty years.[69] However, UK storage has changed little since 2000/01 and most plans to increase storage capacity are experiencing slippage. Periods of peak demand are not well covered by existing storage. The position will only improve if progress on new storage facilities now goes to plan and does not meet further delay. In offshore underground gas storage there are technical challenges with marine construction and well drilling; onshore there are difficulties arising from planning objections.

Therefore, while the base case that the grid will be able to support energy developments is made, so this should not inhibit the development of the emerging energy technologies, these scenarios indicate that many aspects of uncertainty remain.

2.6 OTHER FACTORS INFLUENCING THE DEVELOPMENT OF EMERGING ENERGY TECHNOLOGIES IN THE UK

2.6.1 Steel supply

Demand for steel and other metals and ores is now beginning to increase after the recession, with China leading the demand.[70] As such, prices are beginning to rise but are still much lower than 2008. Forecasts show prices increasing beyond 2010. This could impact on both the investment decisions and the actual construction of wind turbines, for example. That said, there is an overcapacity worldwide for steel processing but this could rectify itself as the world economy emerges from recession. In addition, there have been slippages in offshore installations owing to quality issues of some steels produced in the Far East. Meeting development targets in the face of a shortage of suitable quality materials would present increased safety challenges.

2.6.2 Land availability for biomass

Land available in the UK for growing biomass is limited, and farmers might be reluctant to commit themselves to a crop (like willow) that can only be harvested after several years.[71] Taking land out of food production would also adversely affect UK Food Security. Between these positions, some in the biomass sector claim that crop rotation between food and bioenergy enhances production of both overall.

Landfill gas is currently the largest source of biomass generation in Britain. However, there is little scope for growth in the short term as most large landfill sites are already being exploited and use of landfill gas may even decline as existing sites are depleted. Any growth in biomass generation will likely come from burning more waste and/or energy crops or else from imports, which could mean price volatility due to competition for resources.[72]

2.6.3 Solar power

Raw materials are a limiting factor for making photovoltaic cells (PVCs). Silicon, CdTe and another thin-film technology based on copper indium gallium selenide (CIGS) all have limitations when ordered in mass. While silicon is the second-most abundant element in the Earth's crust, it requires enormous amounts of energy to convert into a usable crystalline form. This is a fundamental thermodynamic barrier that will keep silicon costs comparatively high.

2.6.4 Skills

There is a lack of suitably qualified personnel both in general technical skills and also more specialist skills, including: Science, Technology, Engineering and Mathematics, Communication, Leadership, IT and Management. Emerging skills identified by industry include those in: energy efficiency, full product life-cycle analysis, carbon auditing, carbon trading and resource efficiency.[73] However, two reports confirm that there is no reliable information on the skill needs (and hence deficits) of this emerging sector.[74] [75] This is because there is a lack of 'visible' demand for such skills from employers and as a direct consequence a 'latent' demand for low carbon skills.[76] Surveys of firms in the traditional environmental industries sector suggest almost one in three have skills gaps, particularly in renewable and low carbon energy generation.[76] [77] This stems from the low business priority given to the need to move to a low carbon economy, downsizing in the 1980s and an ageing workforce. Future job prospects in low carbon markets will depend on the approach taken.[37]

As part of the UK's strategy:

- The Higher Education blueprint 'Higher Ambitions', published in November 2009,sets out how government will support the higher education sector and employers to work together to address skills needs in the low carbon sector;[78]
- The Government also published a national skills strategy in November 2009 entitled 'Skills for Growth', which outlines its approach to skills policy;[79]
- Sector Skills Councils (SSCs) and the UK Commission for Employment and Skills (UKCES) are to process and deploy intelligence on skills needs in key sectors and markets and produce a national strategic skills assessment every year;
- The Skills Funding Agency[80] and the Higher Education Funding Council for England (HEFCE)[81] will have the ability to make funds available to move the skills system in the required strategic direction;
- In 'New Industry, New Jobs',[37] the Government is committed to ensuring that regulators and regulatory frameworks all make a full contribution to raising skill levels.
- Additionally, a new skills consultation was launched on 31 March 2010 to help UK businesses to take advantage of opportunities in the emerging low carbon economy. The consultation outlines the UK's skills priorities. At the same time co-funding was announced for up to 2,500 wind energy apprentices.[82]

Some progress towards skill standards has been made, for example:

- The development of National Occupational Standards for Microgeneration;[83]
- Energy & Utility Skills (EU Skills),[84] has already begun to work with other SSCs to develop a skills strategy for renewable energy;
- The Office for Renewable Energy Deployment ORED[85] will support a comprehensive review of the renewables sector skills across the UK;
- ORED is working with EU Skills to assist the electricity sector to develop the National Skills Academy for Power.[86]

The UK has announced plans to create at least 100,000 UK jobs in renewable energy schemes to ease unemployment during the recession[87] [88] but developing the skilled workers to fill these jobs is a major challenge as the average lead time, through apprenticeship or degree course, is several years. An added complication is that a high proportion of the 2020 workforce is already in work, meaning that much of the higher-level skills delivery will need to take place at work.[38] The deployment of low-skilled, inexperienced workers raises safety and health issues.

2.6.5 Rare earth metals

In the next few years, demand for rare earth metals will likely outstrip supply by about 40,000 tons. Most of the world's rare-earth metals come from China, but China is starting to use more and more of its supply whilst exporting less to the rest of the world, e.g. Neodymium (used in wind turbines and hybrid motors) and Lanthanum (used in nickel metal hydride (NiMH) batteries). Mines in Canada and California, previously uneconomical owing to China's dominance in the market, are now likely to re-open or expand for the production of these rare-earth metals.[89]

2.7 OUTLOOK FOR THE ENERGY MIX

A report by Ofgem[90] casts doubt over whether the current energy arrangements will deliver secure and sustainable energy supplies. This is due to a combination of factors including: the global financial crisis, tough environmental targets, increasing gas import dependency and the closure of ageing power stations As a result energy bills could rise by up between 14 and 25 per cent by 2020. Energy bills have already doubled since 2003 and the winter energy bill for an average household has increased by 20 per cent in the last 12 months, from £512 to £616.

The report goes on to say that leaving the future of the country's energy supplies to current market arrangements will fail to deliver the £200bn needed to overhaul the system. This implies that government intervention (and money) is needed to secure UK energy supplies. It further concludes that:

- In order to meet the 2020 renewables targets, the rate of wind deployment will need to be at least double the current rates by 2019. Based on a 5-year lead time, committed projects will need to double over the next four years.

- Gas storage, supply is likely to fall below 25 per cent of winter demand in 2015. Assuming a minimum lead time of 3 years for new storage projects, projects will need to be committed by the beginning of 2012 at the latest.

- Gas imports are likely to make up over 50 per cent of peak day demand from 2016, highlighting the energy security risk. Assuming a three year lead time to get a gas ballasting facility operational, a decision would need to be made by the beginning of 2013 should a facility be required by 2016.

- 12GW of plant must close by the end of 2015, although some plant may close earlier than this date. Replacement decisions would need to be made by early 2013.

- 7GW of existing nuclear plant is also likely to have closed by 2015. Assuming an eight-year lead time for the first plant, the project would need to be committed by early 2012.

- It is uncertain whether CCS will be a technically and commercially proven technology in order to provide the scale of capacity needed to replace closing unabated thermal plant.

The time scales mentioned in the report imply that decisions need to be taken very quickly to ensure the UK's energy supply.

Transition to renewable energy generation requires a number of technical, economic, institutional and social constraints to be overcome. These barriers are exacerbated by the subsidies that are given to the fossil fuel and nuclear industries.[91] Unsurprisingly, green lobby groups are eager to point out that without a commitment to funding from the Government, Britain could be left having to use more gas or even coal plants.[92] [93] And the Environment Agency has said, for example, that it would prefer to limit investment in low carbon sources that have an unwanted impact on the natural environment.[94]

Further, investment in renewable generation capacity will largely be in addition to the investment in fossil fuel and nuclear plant required to replace the power stations scheduled for closure by 2020. The scale and urgency of the investment required is formidable, as is the cost.[31] There is no evidence that advances in storage technology would become available in time to affect the UK's generating requirements materially up to 2020.[95] [96]

Currently the UK is behind target as the renewable electricity supply is only forecast to reach about 10% by 2010. Wind power, both on and off-shore, is presently the only emerging energy technology that can be upscaled to deliver the majority of the required growth in renewable energy to meet the 2010 target. It is also likely that Wind will continue to be the dominant renewable technology until 2020.[97] [98] The best options amongst other renewable sources of generation are tidal barrage and biomass but the scope for an increase in dependable supplies from renewable sources, particularly hydroelectric, domestic biomass and solar appears limited.[31] Tidal barrage and wave are still at an early stage of development in Britain, whilst hydropower is already near the limit of its potential. The most reliable low-carbon alternative to renewable energy is nuclear power (together with conventional fossil fuel generation with carbon capture and storage, if and when that becomes available).[99]

An indication of the likely future energy mix in the UK will help HSE prepare to meet the health and safety issues raised by emerging energy technologies and to plan for appropriate resourcing and training of its workforce. The next Chapter of this report considers a range of possible future energy scenarios taken from some of the many published reports available.

The limitations of using scenarios in this way are discussed in Chapter 3, but it is worth noting here that many of the scenarios (with the notable exception of the Shell scenarios) are based on different ways of meeting the various emissions targets. Thus, failure to meet the targets will introduce further variability into the various scenarios. Recently the Committee on Climate Change has questioned the likelihood of the UK reaching its targets for 2020 by following the plans set out in the Low Carbon Transition Plan. Its October 2009 report says that progress so far is slower than we need to meet the targets and that 'a step change' in progress is needed. Current reduced demand for energy is a consequence of the recession rather than of any fundamental changes. The Institution of Mechanical Engineers concurs in its 2009 report 'Climate Change: have we lost the battle?' and calls for a more significant contribution from geo-engineering as a solution. These views need to be taken into account while considering the contents of Chapter 3.

3 ENERGY SCENARIOS

3.1 INTRODUCTION

A key output from this study is information on the likely energy mix in 2020 and 2050. Many reports have been published which include future energy scenarios derived in a number of ways. A list of some of these reports is in Appendix 4.

3.2 SCENARIOS

First it will be helpful to clarify what is meant by the term ‘scenario’. In futures studies scenarios are short stories or descriptions of possible alternative futures. The scenarios are derived by selecting key uncertainties, which will affect the nature of alternative futures. Scenarios are not predictions, but represent a range of futures, none of which will necessarily materialise in its entirety. They can be used as an aid to strategic planning. For example, they can be used to stimulate thinking about the future, or they can be used to test policy proposals.

The ‘scenarios’ described in many of the energy reports can in principle be used in the same way, but they are derived in a different manner. They are produced by complex mathematical models using a range of variables and are based on a range of assumptions about underlying conditions. For example, they may describe possible energy mixes necessary to reach a given emissions target, so the process in which these ‘models’ are used might be more accurately be described as ‘backcasting’. Most government reports use this approach.

The Shell scenarios,[100] however, are derived from behavioural variables, along with data from models incorporating views of supply, demand and technology deployment, which allow quantitative assumptions to be applied to qualitative storylines. In the Scramble scenario, governments adopt a reactive response to energy crises, concentrating on security of supply. In the Blueprints scenario, a more planned, longer term approach is adopted.

A useful review of the various types of scenario and model and their application to energy studies has been published by the UKERC and EON.UK/EPSRC Transition Pathways Project.[101] A review of published futures work on energy has been prepared by the government’s Foresight Directorate.[102] A comprehensive list of scenario reports, particularly those concerning renewables and covering global, European and individual national contexts has been produced by Eric Martinot.[103]

Given the number of reports available, and the number of scenarios included (one report alone contains twenty-five scenarios), it has been necessary to restrict detailed study to relatively few reports – those issued most recently and those focusing on the UK perspective, rather than global models. But even within these constraints there is a large quantity and considerable diversity of material from which to choose.

To produce figures for ‘likely’ energy mixes in 2020 and 2050 is no simple task. There are many different models, relying on a vast range of parameters, so picking any one as likely over any other is impossible and not very helpful. The best that can be achieved is to give a range of possibilities. Given the many dozens of models, only a small fraction of those available can be considered here.

Scenarios or models may break down the component energy sources in different ways, for example merging renewables and waste figures, so in order to compare two sets of figures it can be necessary to aggregate some figures.

There are different ways of looking at the energy mix. ‘Primary energy demand’ describes the energy used in terms of its source and therefore excludes electricity (other than imported electricity, and some tables refer to the nuclear contribution as ‘nuclear electricity’). Final energy demand describes energy at the point of use, i.e. electricity is included, with a corresponding reduction when compared to primary demand, in those primary sources that are used to generate electricity. Some models consider electricity generation in some detail. Other models give a detailed breakdown of the renewables contribution. Some models give forecasts broken down by industry sector.

Some models give separate figures for coal with and without carbon capture. Some separate out international aviation while others do not say whether or not this is included. This affects the oil figure.

Many reports give a lot of detail on emissions rather than energy mix and the underlying energy mix data may not be readily available from the original researchers.

Some models give a year-by-year progression up to about 2020 and beyond in some cases. Some models give data for only particular years. There seems not to be a lot of data for primary demand for 2020, quite a lot for 2035 and much for 2050.

In summary it seems that apart from scenarios produced by Shell there are no single sets of data that compare primary energy demand in the same scenarios in both 2020 and 2050.

What information will be of most use to the EET project? Information on major areas of change is likely to be the most useful. Primary energy demand will give an indication of the major contributors, although most models forecast an ongoing major contribution from coal and gas. With gas, storage and LNG imports will be an issue, but the models do not generally subdivide the gas figure. Any indication of the extent of CCS will be useful.

Models based on the achievement of a particular emissions target may be of limited use if the target is not achieved. The Shell models, for example, cover a range of outcomes in both of which the global emissions targets will be missed.

The following sections present examples from the wide range of scenarios and models available that give a flavour of the range of possibilities under consideration.

3.3 MODELS

A range of models is used in the reports listed in Appendix 4. The model most widely used and that used primarily in reports produced recently for the Government, is the MARKAL (MARKet Allocation) model. In the 2003 White Paper the MARKAL M (M-M) version was used. In more recent studies, for example the CCC report, the UKERC Energy 2050 paper and the Low Carbon Transition Plan the MARKAL Elastic Demand Model (MED) was used. This can take into account variability in parameters such as fuel prices, technology development etc. A detailed description of the nature of the MARKAL model is beyond the scope of this report, but further information can be found in other reports. [104]

Other Models include:

- Global E3MG[105] used by the Intergovernmental Panel on Climate Change (IPCC)
- Other Sectoral Models

-WASP (Wien Automatic System Planning Package) – electricity systems[106]
-CGEN – combined gas and electricity networks[107]
-UK Domestic Carbon Models (UKDCM)[108]
-UK Non-domestic Carbon Models (UKNDCM)[109]
-UK Transport and Carbon Model (UKTCM)[110]

3.4 SUMMARY OBSERVATIONS FROM THE SCENARIOS

A range of scenarios is presented and discussed below. The key points that emerge from them are as follows.

The scenarios for 2020 show relatively little difference across scenarios, which reflects the closeness of 2020 in terms of our ability to make significant changes in the energy mix. Coal and gas are still the major sources of energy, although the contribution from renewables, particularly wind and biomass, is increasing. This is clear from the electricity generation models. Carbon capture is yet to make a significant appearance. Overall demand shows a small drop. Electricity demand is fairly constant to 2020.

In the 2050 scenarios selected there is, unsurprisingly, greater variation between the models, although overall demand is fairly consistent, showing a considerable drop from the current position. In all primary demand scenarios coal and gas are still significant players, although mostly subject to CCS by this time, and renewables, including biomass are increasingly evident. Oil use has dropped and nuclear energy's contribution has increased. Hydrogen has appeared on the charts (although this is an energy carrier, not an energy source).

The above observations are consistent with, for example the views of the Committee on Climate Change in its 2008 report 'Building a low-carbon economy – The UK's contribution to tackling climate change', which considers two scenarios – for 80% and 90% carbon reduction by 2050.[22] The Committee concludes that:

- Decarbonisation of electricity generation and increased efficiency in the use of electricity are key elements in carbon reduction. In both scenarios decarbonisation of electricity brings most dramatic early abatement. The residential sector is important in terms of improved efficiency in appliances.
- From the 2020s decarbonised electricity plays a greater part in car and light van sectors and in domestic heating.
- Overall electricity demand increases, supplied by a combination of nuclear, renewables (predominantly wind) and fossil fuel with CCS.
- Significant investment in low carbon generation is needed – early action is called for.
- In the 90% model earlier action is needed and non-CCS gas features less.

It is evident from the above that modelling of such a complex system can do no more than give only a very rough indication of what the future will hold. This is generally true of futures studies. They do not attempt to predict the future, but rather they consider uncertainties and the range of possible futures, allowing us to ask questions such as 'What could the future be like?' or 'What if the future was like this?'

As far as realistic medium-term planning for HSE is concerned, then the key areas to consider must be the ones that we know are changing now. So in the short term CCS, wind and biomass are the areas in which we should be focusing our efforts, as indeed we are. Next in line are wave and further down the road, solar. One source, albeit with a vested interest, claims that solar energy could match fossil fuels on price by 2016.

Hydrogen too is something that we cannot ignore, although it does not feature heavily in the scenarios considered in this report. Hydrogen buses have been piloted in London[111] and a fleet of hydrogen-powered vehicles will support the London Olympics in 2012.[112] Leased hydrogen cars with a refuelling network provided by BOC are planned for the UK in 2013[113] and a Sheffield company has developed domestic hydrogen CHP system.[114] While some commentators think that mass-produced hydrogen vehicles are a long way off, the proposed construction of a hydrogen refuelling network within four years must be of interest to HSE.

In addition to large scale projects, it is worth noting the fuel cell market has developed to the stage where a number of gas supply companies have started to advertise small fuel cell installations suitable as CHP units for domestic and small commercial premises. In similar vein it is quite likely we will see early use of hydrogen generation as a distributed way of absorbing excess renewable generation in periods of low demand or excessive generation from renewable sources.

3.5 2020 SCENARIOS

Selected examples from the wide range of scenarios available are shown below. As explained above, scenarios are not predictions of what will happen, but rather they represent a range of possibilities. Given the wide range of variables likely to affect the future energy mix, prediction with any sort of accuracy is impossible. However, these scenarios give an idea of what the outcomes could be. In each case the results are shown in terms of energy units, to convey an idea of overall demand, and in percentage terms to give an indication of the contribution from each source. The original data for each chart and an explanation of the units of measurement cited are given in Appendix 5.

3.5.1 Primary energy demand scenarios 2020

Primary demand refers to the energy used in terms of its original source. The Government's Low Carbon Transition Plan (LCTP)[27] refers to a range of models whose variables are Fuel Price, Policy Impact and Growth. Each variable can be rated Low, Central or High, although not all combinations are used. In addition there is a Baseline Scenario, which takes the Central assumptions on prices and growth, but excludes the policy measure included in the LCTP. Comparisons of the primary demand energy mix in 2020 across a range of scenarios were not found in government reports, but the Shell scenarios compare two outcomes below. Details for the Central scenario in the LCTP (each variable taking a central path) are given in Figures 3 and 4, which show the predicted trend in terms of total energy and percentage share respectively for the Central Scenario. Figure 3 shows a drop in overall energy demand up to 2020 as a result of improved efficiency and management of demand. Figure 4 shows relatively increased use of renewables displacing natural gas.

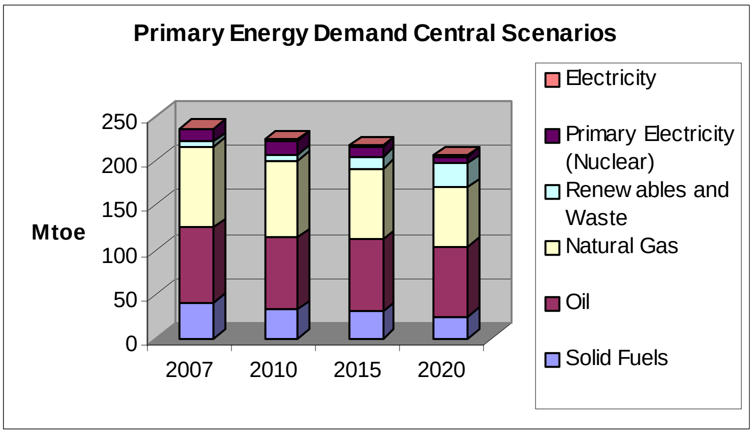


Figure 3 Primary energy demand central scenarios (Mtoe)**

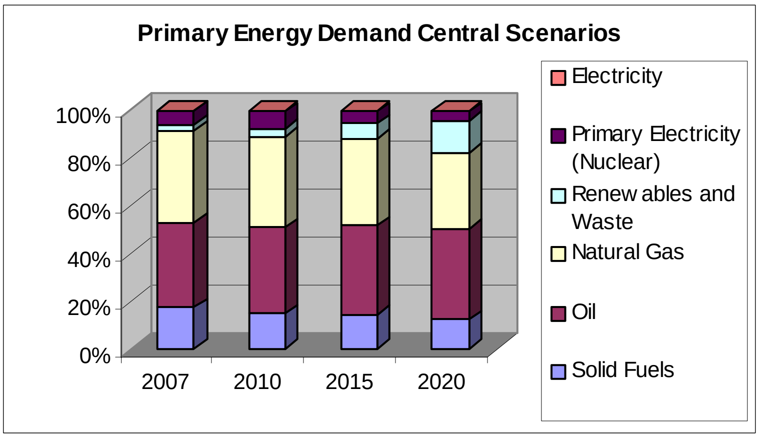


Figure 4 Primary energy demand central scenarios (%)

Figures 5 and 6 show the Shell scenarios in terms of energy units and percentage contribution respectively. The Blueprints scenario shows a greater contribution from renewables and less reliance on coal, although in both scenarios still rely heavily on fossil fuels.

** Source: DECC, Low Carbon Transition Plan, 2009[27]

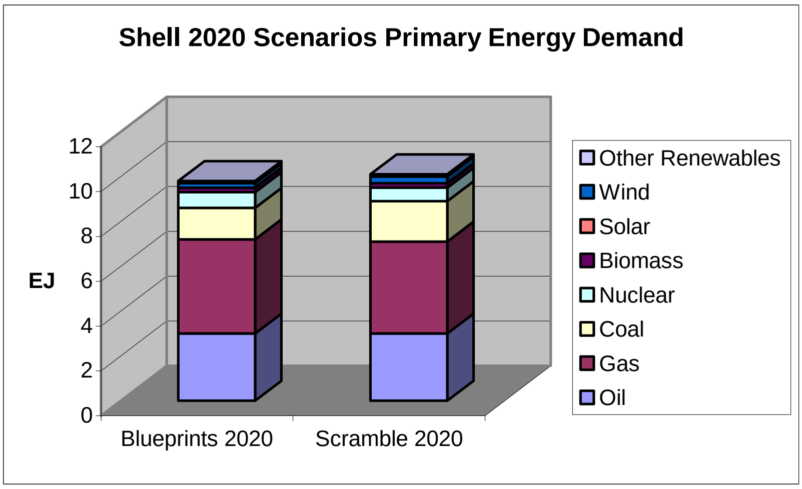


Figure 5 Shell scenarios, primary energy demand 2020 (EJ)[††]

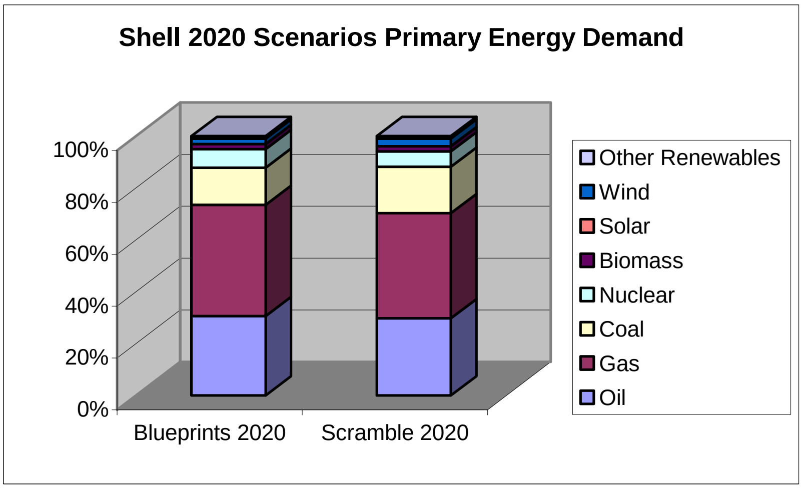


Figure 6 Shell scenarios, primary energy demand 2020 (%)[‡‡]

Figure 7 compares the LCTP Central scenario with the shell scenarios, showing significant differences between the LCTP scenario and Shell in all areas. The LCTP scenario anticipates a greater contribution from renewables than either Shell scenario. The data for Figures 5 to 7 are in Appendix 5.

[††] Source: Shell, UK data by private communication.
[‡‡] Source: Shell, UK data by private communication.

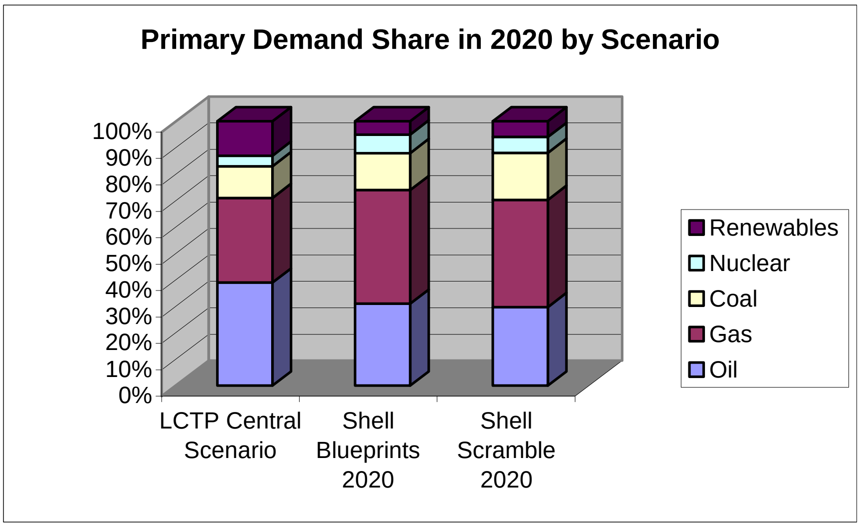


Figure 7 Comparison of LCTP and Shell primary energy demand scenarios for 2020

3.5.2 Final energy demand scenarios 2020

Final demand refers to energy in terms of the form in which it is used, i.e. electricity has its own figure and solid or manufactured fuels (i.e. mainly coal) are all but absent. Figures 8 and 9 show forecast final demand in the LCTP Central scenario in terms of energy units and percentage respectively. Figure 8 shows a drop in overall demand over the period 2007 to 2020 while figure 9 shows the increasing contribution from renewables.

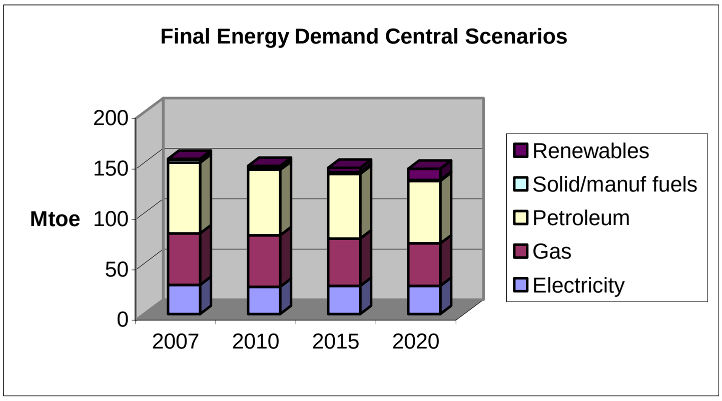


Figure 8 Final energy demand central scenarios (Mtoe)[§§]

[§§] Source: DECC Low Carbon Transition Plan 2009

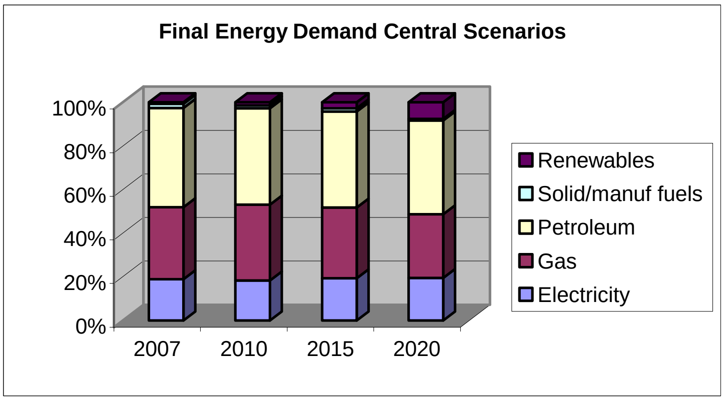


Figure 9 Final energy demand central scenarios (%)

Figures 10 and 11 show final demand across a range of scenarios. These are taken from the July 2009 update to the Energy and Emissions Predictions produced for the LCTP. The Baseline scenario shows little difference from 2007, while the others show slight variation in demand. However, Figure 11 shows little difference between the scenarios in terms of percentage contributions.

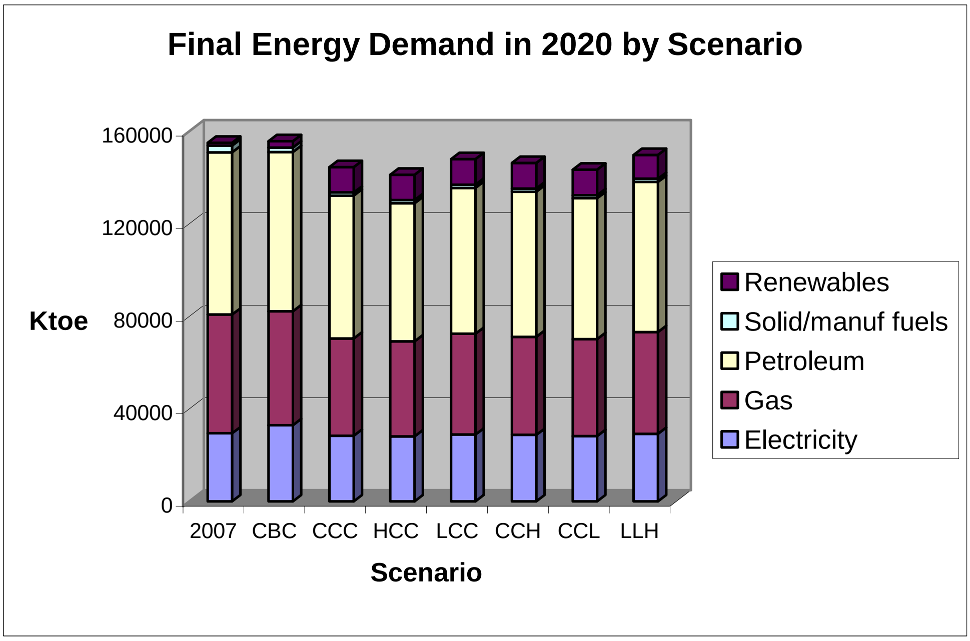


Figure 10 LCTP scenarios, final energy demand 2020 (Ktoe)

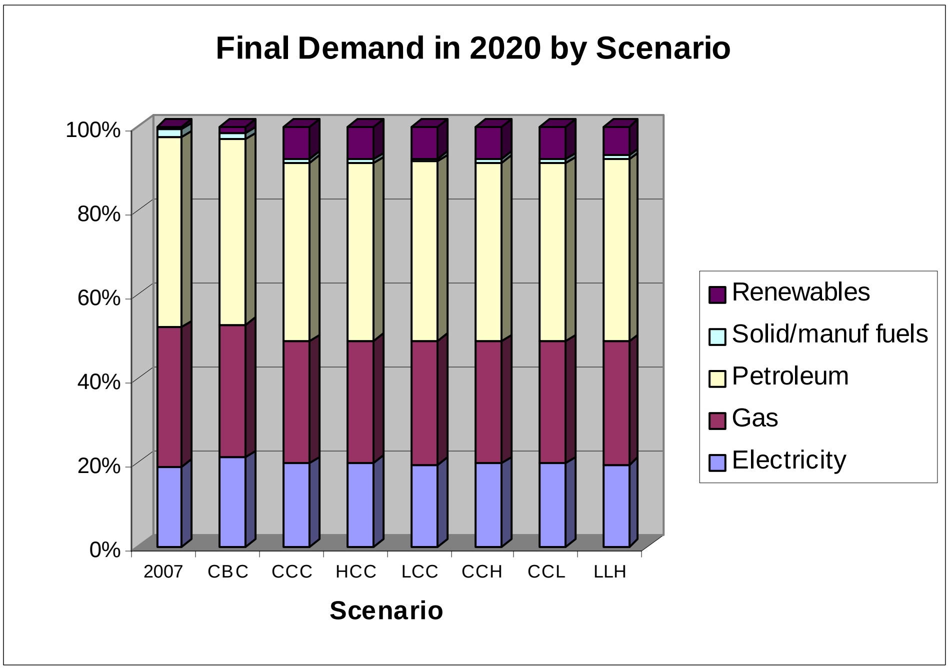


Figure 11 LCTP scenarios, final energy demand 2020 (%)

3.5.3 Electricity generation scenarios 2020

Electricity generation scenarios show the mix of fuels used to produce electricity. Figures 12 and 13 show the change in the LCTP Central scenario to 2020. The renewable contribution increases dramatically as gas and oil contributions drop. CCS coal makes its first appearance in 2015. Nuclear shows a decline as old power stations are run down in advance of new build.

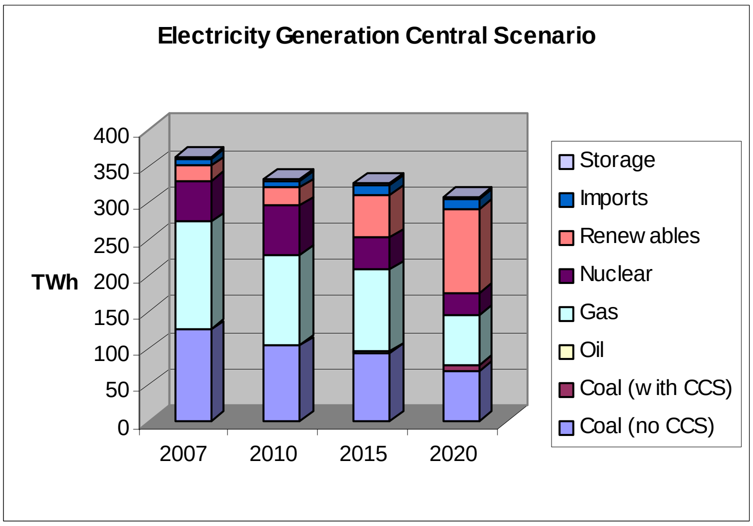


Figure 12 Electricity generation central scenario (TWh)

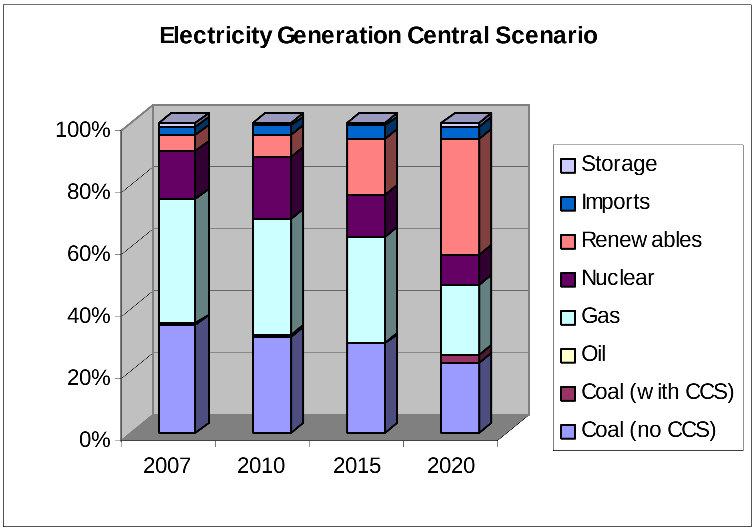


Figure 13 Electricity generation central scenario (TWh)

3.5.4 Renewable energy scenarios 2020

Figure 14 shows contributions to renewable energy in 2020 from the National Grid scenario.[68] The difference between this scenario and the 2008 position shown in Chapter 1, Figure 2, is dramatic. Most renewables have increased in absolute terms, but as a proportion of total renewables, wind has increased from 7% to 37%, while biomass as a proportion has dropped from 81% to 37% and hydro from 7% to 2%. The other sources were not separately identified in the 2008 chart.

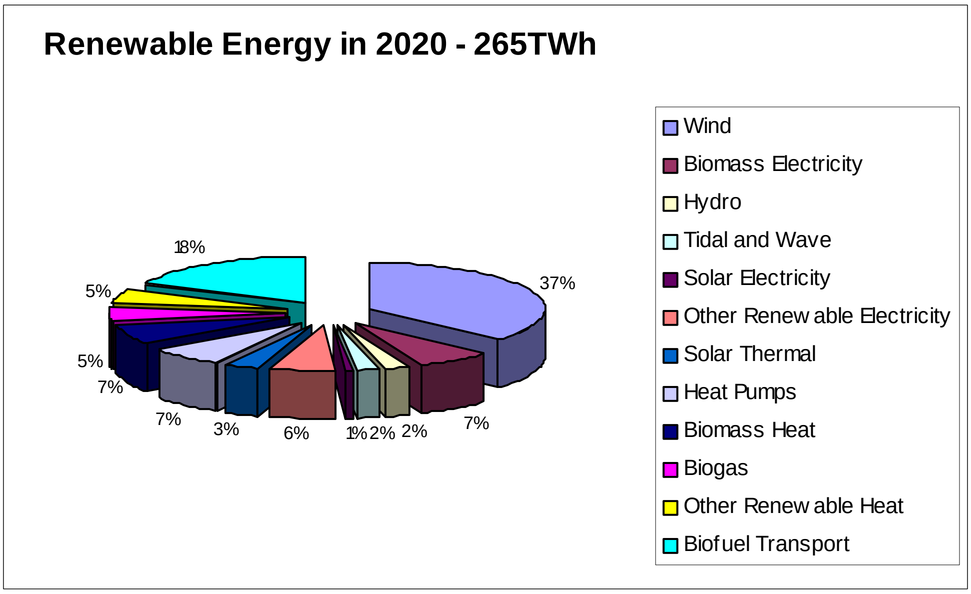


Figure 14 Contributions to renewable energy 2020

3.6 2050 SCENARIOS

3.6.1 Primary energy demand scenarios 205*0*

Figures 15 and 16 show primary energy demand across a range of scenarios taken from the 2008 UKERC report Pathways to a Low Carbon Economy: Energy Systems Modelling,[115] produced as part of the UKERC Energy 2050 programme.

The scenarios are all 80% carbon reduction scenarios as follows:

CAM – carbon ambition - 26% reduction by 2020, 80% by 2050
CEA – early action – 32% reduction by 2020, 80% by 2050
CCP – least cost path - 80% reduction post 2050
CCSP – socially optimal least cost path – 80% reduction post 2050.

Figure 15 shows in all scenarios a considerable drop in overall demand from the 2000 level, but with significant variation in contributions form the various sources.

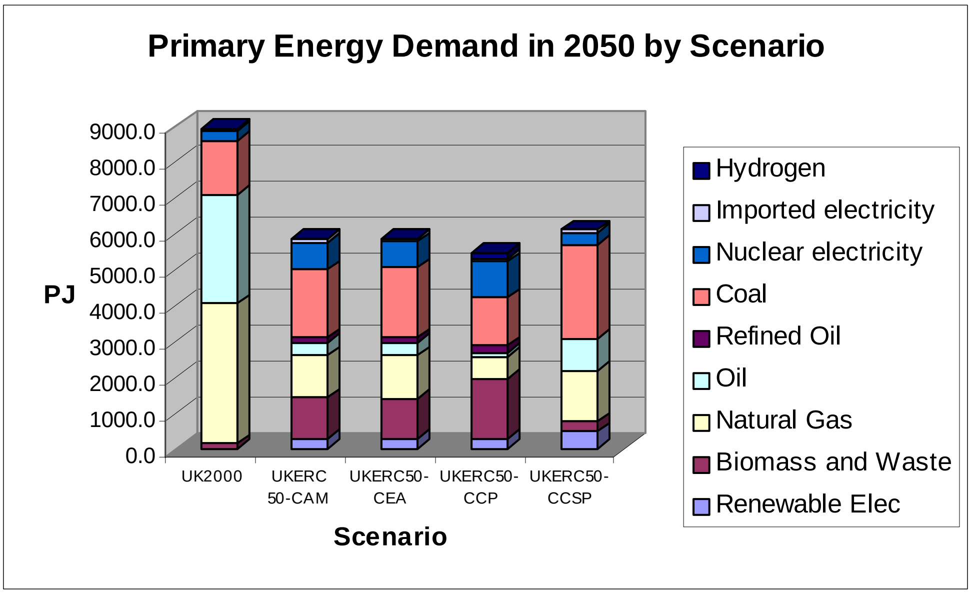


Figure 15 UKERC scenarios, primary energy demand 2050 (PJ)

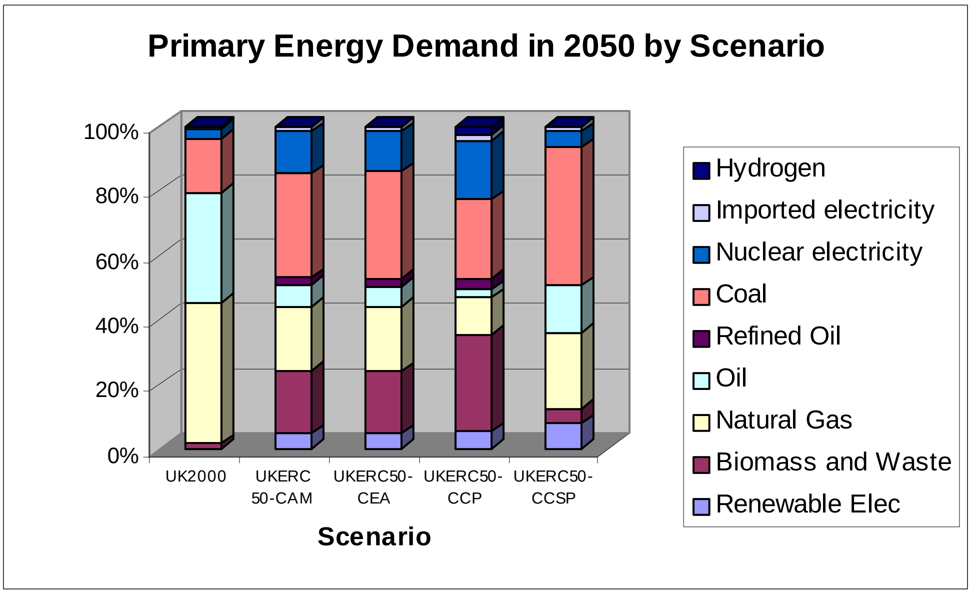


Figure 16 UKERC scenarios, primary energy demand 2050 (%)

The Shell scenarios in Figure 17 show greater overall demand in the Scramble scenario, while the percentage shares in Figure 18 show a much greater contribution from wind, with less from biomass in the Blueprints scenario, compared to the Scramble scenario.

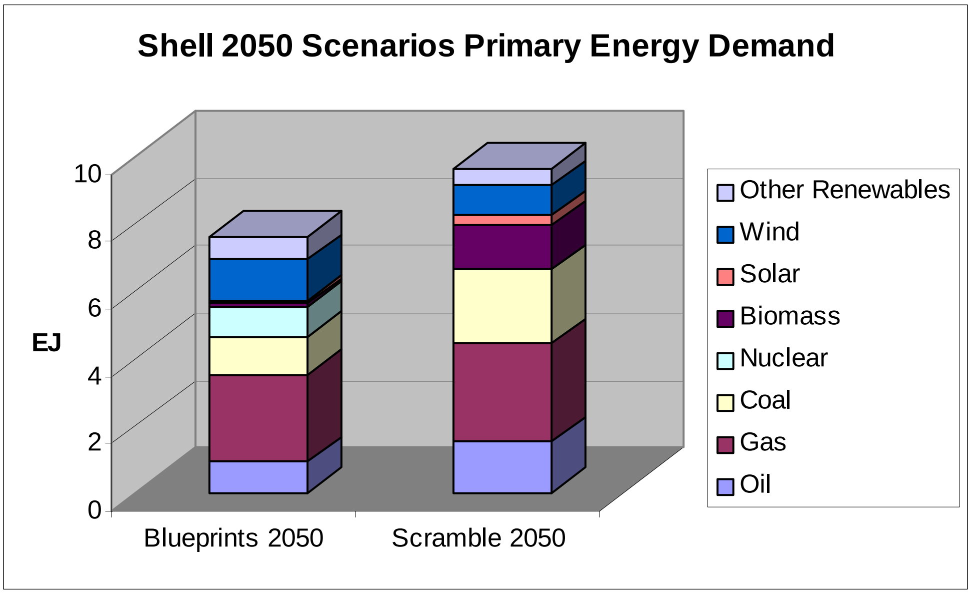


Figure 17 Shell scenarios, primary energy demand 2050 (PJ)

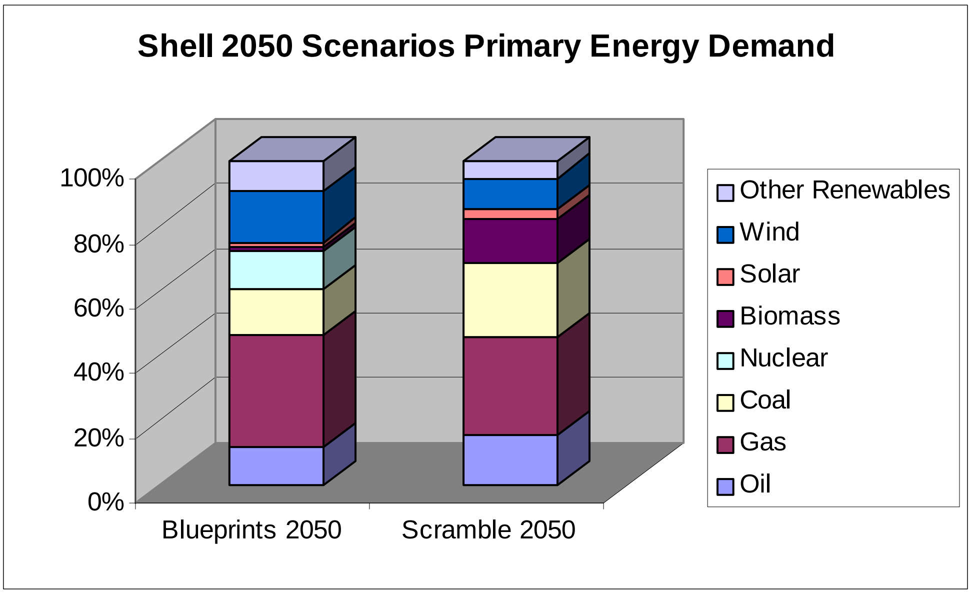


Figure 18 Shell scenarios, primary energy demand 2050 (%)

Figures 19 to 22 show the 2020 and 2050 Shell scenarios in sequence alongside 2005 in absolute and percentage terms.

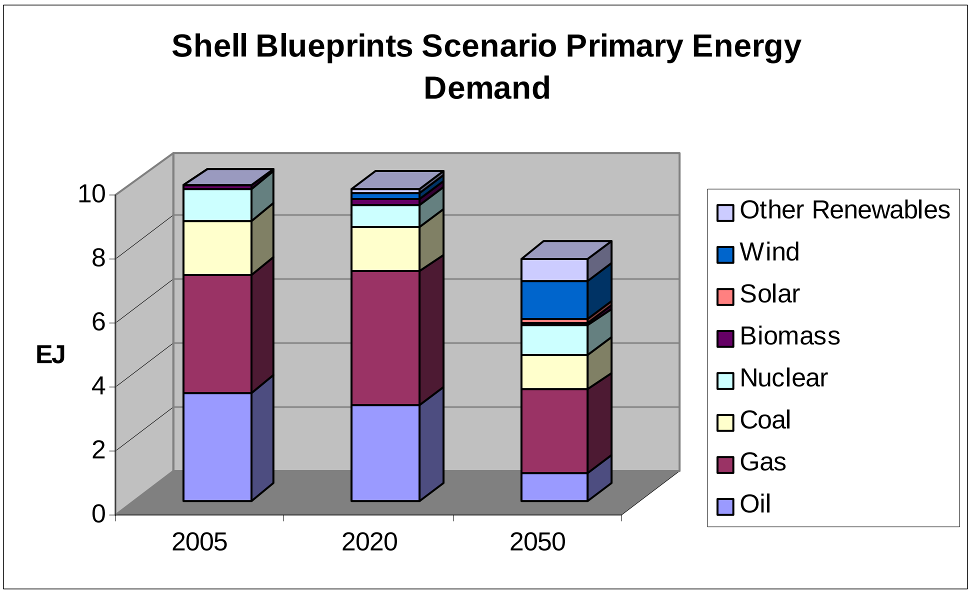


Figure 19 Shell Blueprints scenarios, primary energy demand 2020 and 2050 (EJ)

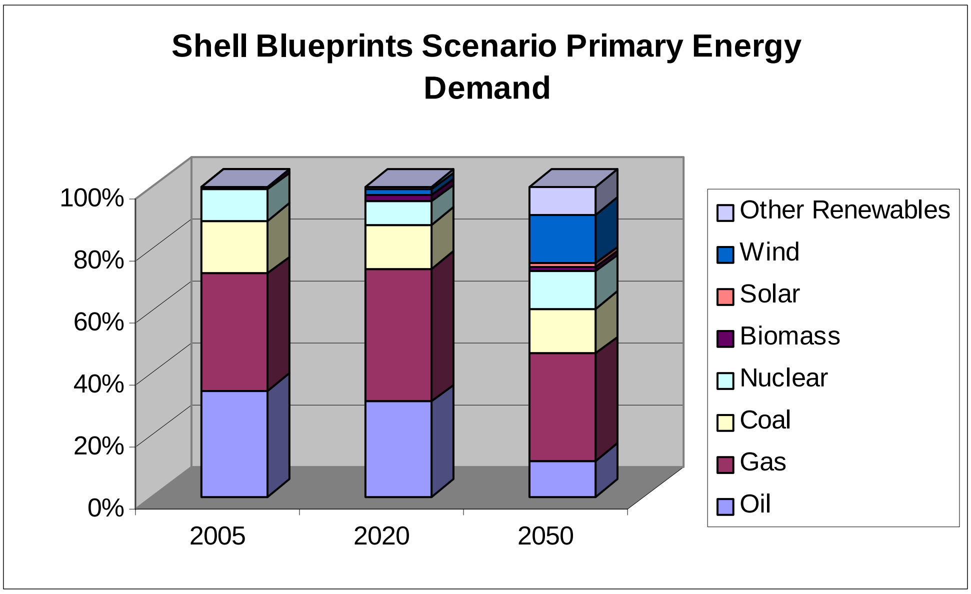


Figure 20 Shell Blueprints scenarios, primary energy demand 2020 and 2050 (%)

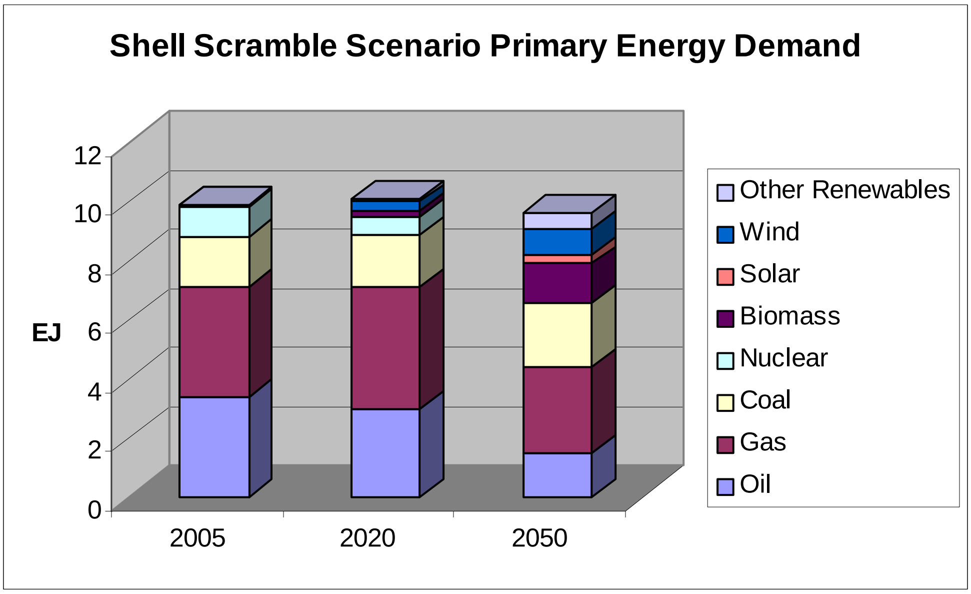


Figure 21 Shell Scramble scenarios, primary energy demand 2020 and 2050 (EJ)

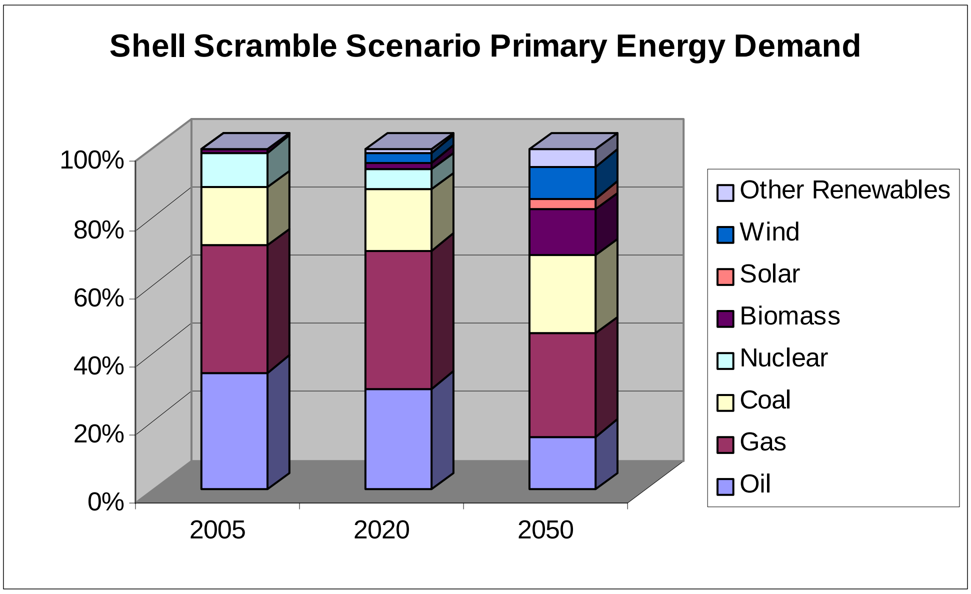


Figure 22 Shell Scramble scenarios, primary energy demand 2020 and 2050 (%)

3.6.2 Final energy demand scenarios 2050

Figures 23 and 24 show Final Energy demand in 2050 across the range of UKERC scenarios defined above in section 3.6.1.

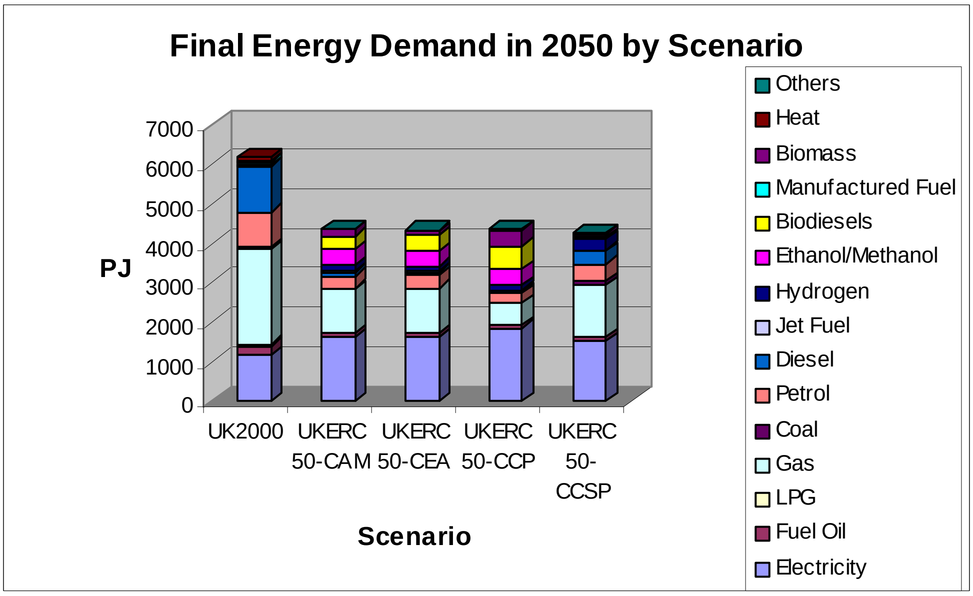


Figure 23 UKERC scenarios, final energy demand 2050 (PJ)

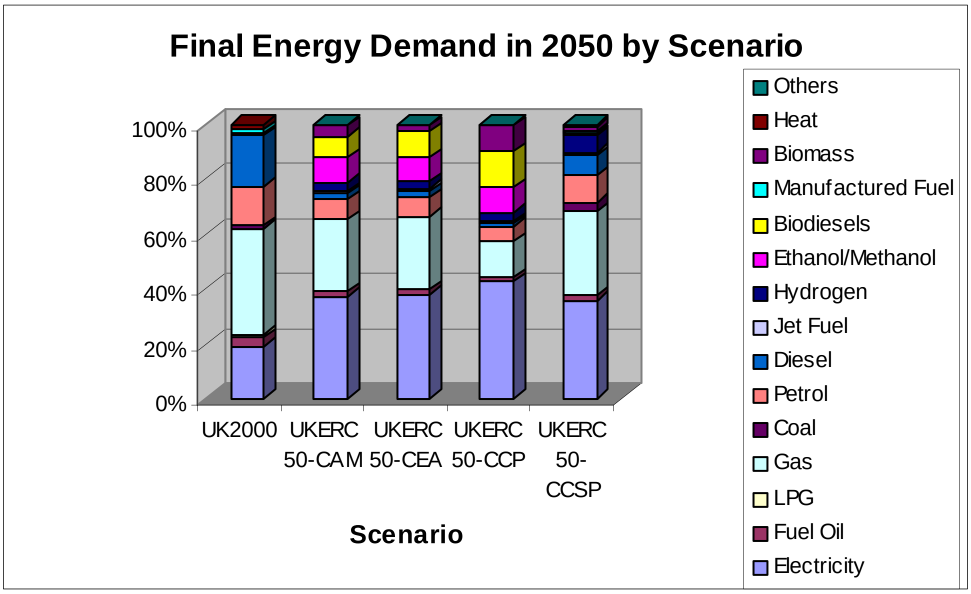


Figure 24 UKERC scenarios, final energy demand 2050 (%)

3.6.3 Electricity generation scenarios 2050

Figures 25 and 26 show electricity generation across the range of UKERC scenarios reported in Sections 3.6.1 and 3.6.2. Figure 25 shows a significant increase in overall electricity generation compared to 2000, which is consistent with the prevailing view that electricity demand will increase as electricity replaces fossil fuels in heating and transport.

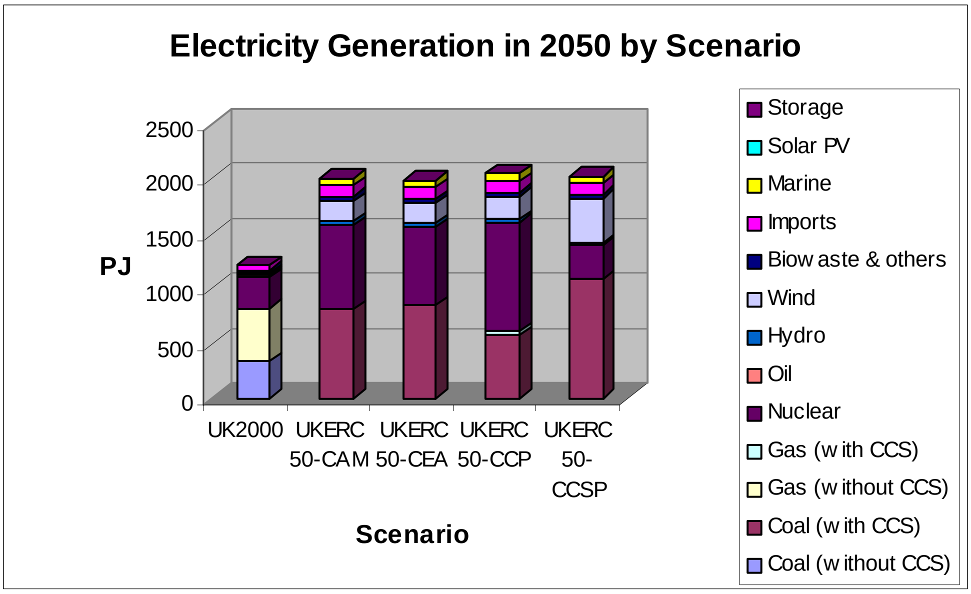


Figure 25 UKERC scenarios, electricity generation 2050 (PJ)

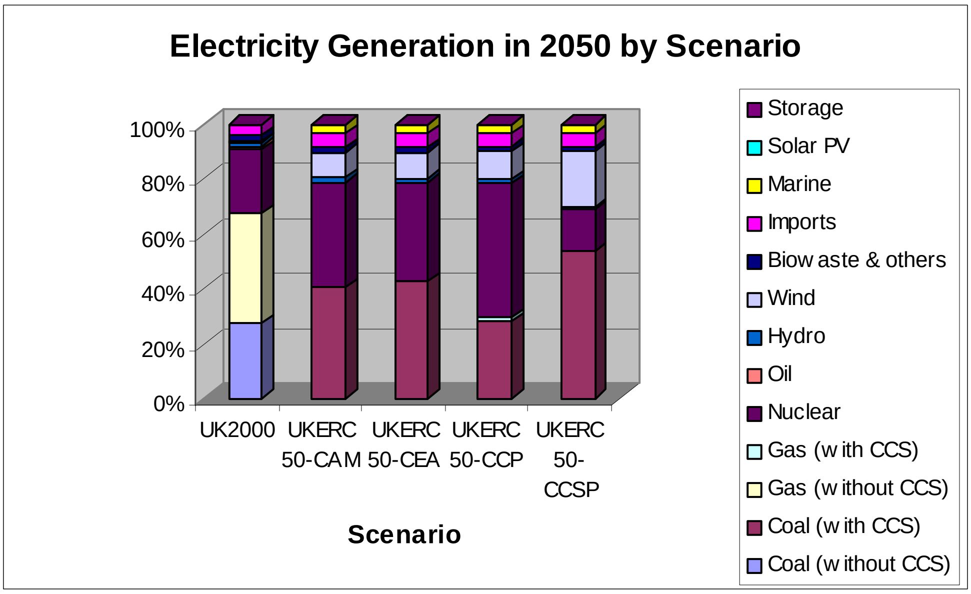


Figure 26 UKERC scenarios, electricity generation 2050 (%)

3.6.4 Renewables scenarios 2050

Recent dedicated scenarios for renewables in 2050 comparable with that shown for 2020 in Figure 14 were not found. However, a report from the Institution of Mechanical Engineers in September 2009 put forward *proposals* in terms of capacity rather than quantity of electricity generated to meet an electricity output of 127 GW, from which the following breakdown of the renewable contribution was extracted.[116] The main points are the increase in wind, wave and solar contributions compared to that from biomass.

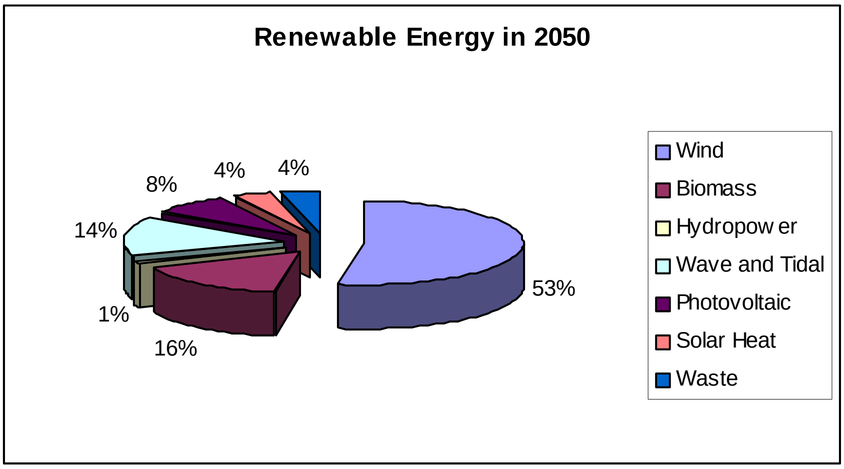


Figure 27 Contributions to renewable energy in 2050

4 TECHNOLOGY WORK STREAMS

4.1 INTRODUCTION

The work streams for the EET Programme derive from the technical areas identified in the Government's Energy Review of 2006. These are:

- Carbon capture and storage;
- Natural gas storage and LNG;
- Renewable technologies;
- Distributed generation (electricity storage is included here in this report);
- Clean coal technologies (other than CCS).

This section contains for each of these work streams, a brief introduction to the technology, the present state of the technology, developments under way or planned, and dependencies and barriers. Potential health and safety implications of the technology are considered.

In addition to the work streams described above, a summary of infrastructure issues is included.

4.2 CARBON CAPTURE AND STORAGE

4.2.1 Scope

Carbon Dioxide Capture, Transport and Storage.

4.2.2 Description

Carbon Capture and Storage (CCS) can be described as capturing carbon dioxide (CO_2) from sources such as fossil fuel power stations and transporting it to a deep underground geological formation where it can be stored securely.[117]

There are three stages of CCS: CO_2 capture, transport and storage.[118]

Capture

At full sized plants there are three main ways to capture CO_2:

- *Post-combustion*: CO_2 from the burnt fuel is captured chemically by an amine or ammonia solvent.
- *Pre-combustion*: gasified coal or natural gas is chemically split to form hydrogen and CO_2.
- *Oxy-fuel combustion*: the fuel is burnt in almost pure oxygen producing large amounts of water vapour that needs removing before CO_2 capture can take place.

Transport

Captured and purified CO_2 will then require transportation to its storage location by pipelines (although large ocean tankers have also been considered). Such large amounts of CO_2 are produced that it would be economically impractical to move it as a gas so it would be converted into 'dense or supercritical fluid' by applying high pressure so that it can be pumped like a liquid.

Storage

Geological storage is considered the most viable and economically sound option, however other methods such as storage in the deep ocean or as a solid carbonate deposit have been suggested. There are three main types of geological storage locations:

- Depleted oil and gas fields, or those with dwindling and/or uneconomic reserves;
- Deep saline aquifers (salt water underground within porous and permeable rock);
- Coal seams that cannot be mined. The technology is at an earlier stage although the Intergovernmental Panel on Climate Change (IPCC) reports that the global potential for coal seam storage is in the order of 200GTe[119].

4.2.3 Current usage

Each of the stages of CCS has been performed successfully in other applications. For example, CO_2 has been injected at large-scale into depleted oil reserves to enhance oil recovery for several decades and there is around 15 years experience with small-scale CO_2/H_2S storage in geological formations and more than 10 years experience of using saline formations to store CO_2. There is similar experience (in the USA) of large diameter pipelines transport of CO_2. Therefore, significant operational experience should be transferable, although generally there is little quality measurement data readily available. Marine shipping of CO_2 is also possible; the food industry already carries this out at small-scale.[120] However CCS has never been demonstrated at full scale as a complete process on a power plant. There are however a number of demonstration projects in progress, looking to integrate capture, transport, storage and monitoring into a power plant.

UK

The UK's first pilot scale oxyfuel CCS project was opened on 24 July 2009 in Renfrew, near Glasgow. The project is using a 40MW test rig and will run for two and a half years.[121] Scottish Power turned on a prototype carbon capture unit on 29 May 2009, which will process 1000m^3 of CO_2 an hour from Longannet coal-fired power station in Scotland.[122]

Worldwide

A pilot 30 MW oxyfuel CCS plant was opened by Vattenfall near the 1600MW Schwarze Pumpe power plant in Germany in September 2008.[123] E.ON switched on a 1MW pilot CCS plant near Hanaum, Germany in September 2009, designed to be retrofitted onto existing coal plants.[124] France's first pilot oxyfuel CCS plant at Lacq was inaugurated by Total in January 2010. It will inject CO_2 into a depleted gas field, aiming to store 120,000 tonnes of CO_2 over 2 years.[125] Norway, where two offshore projects are operating, has the greatest experience of CCS. One, the Statoil Sleipner project, currently separates 1M tonnes of CO_2 a year from natural gas and stores it in a saline aquifer beneath the seabed. Additionally geological storage of CO_2 has been occurring for a while at projects at In-Salah in Algeria, Weyburn in Canada and Snohvit, Norway.[126]

4.2.4 Planned developments

UK

The UK's CCS competition was launched in 2007 to publicly fund one CCS commercial scale demonstration project and attracted a number of bidders of whom two progressed in 2010 to the front end engineering and design (FEED) stage. They are E.On (proposing to use the Kingsnorth, Kent site in S England), and a consortium led by Scottish Power with Shell and National Grid (proposing to retrofit the Longannet, Fife facility in E Scotland).[127] [128] The project aims to demonstrate post-combustion CCS (which has the greatest potential for retrofitting to existing thermal power plants) on a coal-fired power station with the CO_2 stored offshore. The objective is to demonstrate capturing CO_2 from 300MW net of the power station's capacity (90% of carbon emissions) by 2014. Three further projects will be launched in 2010. The projects must include pre-combustion technology.[129] [130] Commercially significant CCS sites planned or operational in the UK are shown in Table 3.

The UK oil and gas fields in the North Sea have large potential for storage of CO_2,[131] mostly located offshore, over 60% in brine (saline) formations, with potentially 24 billion tonnes/CO_2 capacity (UK emissions from power plants are 170 million tonnes/CO_2 a year). However, further technical work is required to fully gauge our storage capacity for CO_2. Studies into the shape of future CO_2 hubs in the UK have been and are being done. There is a requirement to design a major infrastructure for the collection and distribution of CO_2.[120]

World

An offshore CO_2 pipeline is planned around Rotterdam by 2012 that could be a hub for EU CO_2 transport. There are other CCS projects planned in Europe in Norway, Bulgaria, Czech Republic, Denmark, Finland, France, Germany, Italy, Netherlands, Poland and Spain.[127] Early CCS projects and research and development are also taking place in other countries including Australia, Brazil, China, India, South Africa and Abu Dhabi.[120]

At the European Union Spring Council in 2007 an agreement was made, based mainly on recommendations from the European Technology Platform for Zero Emission Fossil Fuel

Power Plants (ZEP), to create the necessary technical, economic and regulatory framework to bring CCS to market, by 2020 if possible, including up to 12 demonstration projects by 2015 and 80-120 by 2030.[132] The EU recently awarded funding of €180 million for Powerfuel's Hatfield planned CCS demonstrator in Yorkshire, which was excluded from the DECC CCS competition.[133] In the USA 12 projects are being sponsored; each one will store up to 1Mt CO_2 over the coming 12 months. The Australian Government recently set up the Global Carbon Capture Storage Institute of which the UK is a foundation member. Also sited in Australia is the approved Gorgon project, which will capture and store some 4.5 MT of CO_2 per year from large deepwater gas fields when fully operational. In the UK on the 13 October 2009, twenty-two member countries of the Carbon Sequestration Leadership Forum met and agreed (amongst other things) to form a Capacity Building Programme to share knowledge and experience to allow members to develop capacity to successfully deploy CCS.[134, 135]

4.2.5 Dependencies

Government

In July 2009 the Government proposed a new regulatory requirement for any new power station to be built in England or Wales to show CCS on at least 300MW net of its capacity. This is alongside a regulation requiring power stations to be built CCS-compatible from April 2009. Additionally there is a proposal for new coal power stations to retrofit CCS at full capacity within five years of CCS being judged to be technically and economically proven by an independent review.[134] Further information on proposed government plans for the introduction of CCS in the UK is outlined in the Department of Energy and Climate Change (DECC) paper: "A framework for the development of clean coal: consultation document".

On 17 March 2010 DECC published its "CCS Industrial Strategy" coupled with the report "A study to explore the potential for CCS business clusters in the UK". Together they outline the Government's plans to develop CCS in the UK beyond the demonstration programme, the manufacturing skills and supply chain needed for CCS projects. As part of this the recently formed Office of Carbon Capture and Storage (OCCS) within DECC will produce a UK CCS roadmap to 2030. OCCS will be responsible for delivery of the CCS demonstration projects and formulating the longer term regulatory framework and strategy for CCS expansion in the UK. The Government also announced its first Low Carbon Economic Area (LCEA) for CCS, in the Yorkshire and Humber and its support for a capture demonstration project led by Scottish and Southern Energy (SSE) at Ferrybridge power station in Yorkshire. Other examples of CCS LCEAs in the future may include Teesside, Merseyside and the Thames Estuary.[136]

Funding

The future DECC CCS competition demonstration plants (i.e. competitions 2 – 4, to be launched in 2010) will be funded by a planned levy on electricity bills. Further funding for CCS will come from CO_2 emission allowances under the EU Emission Trading System (ETS) and the European Energy Programme for Recovery.

4.2.6 Barriers

A huge amount of money is required to help CCS reach commercial reality and beyond. This may prove difficult and could hinder this technology given the continuing grim economic outlook, as raising this money depends on taxpayers and customers. Little work has been done on the public perception of CCS. However one study by the Tyndall Centre found that people who had some knowledge of CCS showed slight support for it, but that this support was dependant the accompanying requirement for cutting carbon emissions and CCS being part of a suite of renewable energy technologies. There are public uncertainties over the risks of CCS particularly the risks of leakage, accidents or human health impacts.[137] Opposition in Europe to CCS appears greater where CO_2 is stored under the mainland (the UK intends CO_2 to be stored in offshore formations). For example, recently the Vattenfall's Schwarze Pump CCS project failed to obtain a permit to inject CO_2 in the depleted Altmark gas field 350 km away due to local resident opposition. As a result some of the CO_2 is now vented into the atmosphere and at least some of the CO_2 is trucked off for use in industrial applications, and there are concerns that public opposition could affect other projects.[138] Individuals may also not be supportive of CCS if large pipes containing liquid CO_2 pass near to their houses. Additionally customers will not welcome a significant rise in their electricity bills to fund CCS, as well as a rapid increase in renewable energy.

Other key determinants on the rate of commercial deployment of CCS include: technological readiness, appropriate financial and market framework, the regulatory environment, development timescales, development of an on and offshore transport network and capacity and skills of the industry to build demonstration plants then scale up to full-size plants.

The timescale for conception to operation of a CCS power plant is thought to be around 5-6 years. However the time taken to obtain permission for storage sites and constructing the pipelines could take 5-8 years.[120]

Government estimates put the market value for CCS in the UK at £2-4 billion by 2030 with 30-60,000 associated jobs.[134]

4.2.7 Hazards

The health and safety risks from CCS are health hazards: from carbon capture solvents, the release of gaseous CO_2, major pressure losses e.g. pipe rupture (potential impact injuries, burns from a release of supercritical CO_2 at low temperature and asphyxiation). The health risks and other occupational hygiene hazards (noise, vibration etc) will be controlled under existing HSE legislation and regulations.[24] However, current understanding of the engineering hazards associated with CCS is incomplete as there is limited experience both in the UK and internationally in handling supercritical CO_2. Additionally there is no best practice to address the design, construction, operational and maintenance issues of CCS plants. In response to these issues other initiatives are in development by industry stakeholders working in partnership and with government agencies.[139] There are also potential safety issues due to the high population density in the areas of likely CO_2 pipelines,[120] and in the potential use of existing hydrocarbon pipelines to carry supercritical CO_2. There may be additional hazards associated with CCS that have not yet been considered, for example Dr Christian Klose, (a geohazards researcher at the Colombia Lamount-Doherty Earth Observatory) has estimated that 25% of the UK's recorded seismic events were caused by human activity. He worries that CO_2 storage in deposits underground could generate earthquakes that would be close to heavily populated areas (coal power stations are closer to cities).[140] This will not of course be a consideration in the foreseeable future as CO_2 storage will be under the sea.

There is a need to consider the adequacy of current regulations to control the risks associated with CCS, in particular consideration of the classification of dense phase CO_2 as a dangerous substance under the Control of Major Accident Hazards regulations, given the limits in current understanding. These issues are considered in more detail in: 'Interim guidance on conveying CO_2 in pipelines in connection with carbon capture, storage and sequestration projects.[139]

Table 3 Commercially significant CCS sites planned or operational in the UK[141]

Name	*Location*	*Company*	*Status*	*Operational*	*Technology*	*Injection CO_2*
Kingsnorth	Kingsnorth power plant Kent	E.ON	In Planning	2014	Post Combustion	2 million tonnes/yr
Tilbury	Thames Estuary	RWE nPower	In Planning	2016	Post Combustion	Not currently known
Aberthaw	South Wales	RWE nPower	In Planning	2010	-	Not currently known
Drymn	Onllwyn South Wales	Progressive Energy, BGS CO2STORE	In Planning	None	Pre-Combustion	1-2 million tonnes/yr
Killingholme	Killingholme power plant Humberside	E.ON Powergen	In Planning	2016	Pre-Combustion	2.5 million tonnes/yr
Scunthorpe	Scunthorpe	CORUS	In Planning	None	Post Combustion	Not currently known
Ferrybridge	Ferrybridge West Yorks	Scottish and Southern Energy	In Planning	2015	Post Combustion	1.7 million tonnes/yr
Hatfield IGCC Project	Hatfield South Yorks	Shell Powerfuel GE Energy	In Engineering	2013	Pre Combustion	4.5 million tonnes/yr
Teeside Power Station	Tees Valley NE England	Coastal Energy (Centrica) Progressive Energy	In Planning	2013	Pre Combustion	5 million tonnes/yr
Blyth Power Station	Northumber-land Coast NE England	RWE nPower	In Planning	2014	-	Not stated
DECC CCS Competition	Site not yet decided	DECC	In Planning	2014	Post Combustion	Not currently known
Cockenzie	Cockenzie and Port Seaton Scotland	Scottish Power	In Planning	None	Post Combustion	Not currently known
Longannet	Fife Scotland	Scottish Power	Pilot	2014	Post Combustion	2.5 million tonnes/yr
Hunterston	North Ayershire Scotland	Clydeport	In Planning	2016	-	Not currently known
Oxycoal™2 Project	Renfrew Scotland	Dooson Babcock Scottish and Southern Energy DECC Drax DONG EDF E.ON Scottish Power Air Products	Pilot	2018	Oxy-fuel Combustion	Not currently known

4.3 NATURAL GAS STORAGE AND LIQUEFIED NATURAL GAS IMPORTS

4.3.1 Introduction

Oil and gas in the UK currently provide three-quarters of our primary energy needs. Supplies of natural gas in the North Sea are being rapidly depleted and the UK is now a net importer of gas. It is estimated that the UK will import between 45% and 55% of its gas by 2020. So in the near future the UK will become increasingly dependant on gas imports and storage.[142] [143]

4.3.2 Natural gas storage

Natural gas storage describes the replacement of current gas reserves with imported gas, which is then stored underground in:

- Manmade salt cavities: these are formed from the use of water to leach out the salt creating dome-shaped cavities, which are gas-tight.
- Depleted underground reservoirs: these are generally depleted oil and gas reservoirs. Gas is injected underground into porous rock formations.

Gas can also be stored offshore: either in depleted or partly depleted hydrocarbon fields under the sea floor, or in other geological features like salt cavities.

Storing natural gas in underground salt caverns has been carried out for many years in the UK and is common around the world. The Saltholme brine field in Teeside was first used in 1959 to store gases such as ethylene, ethane and naphtha. A single borehole, similar to those used in offshore gas and oil wells, is used to charge and discharge the salt caverns with gas.

UK gas storage facilities are shown in Table 4, while facilities under development are shown in Table 5. Storage projects at various stages in the planning and development process are shown in Tables 5, 6, 8 and 9.

Gas import projects existing, under development and proposed are shown in Tables 7 and 10.

4.3.3 Liquefied natural gas (LNG)

This is a liquid form of the gas supplied to the domestic and business market. Very low temperatures (-161°C) keep the gas in liquid form, at ambient temperature the liquid quickly reverts to a gas. In this liquid form it can be imported, stored and re-gasified. LNG provides a useful and flexible method to transport gas between areas without the use of pipelines. By liquefying natural gas its volume is reduced to 1/600th of its gaseous state. LNG is transported by special tankers and shipped worldwide. Special terminals that receive LNG store it in huge cryogenic tanks, when required it can be re-gasified by warming and be piped into the national gas grid.

LNG can be imported and regasified in the following ways:

- Onshore: LNG from ships is transferred in import terminals to storage or re-gasification onshore.
- Offshore: These are offshore terminals with a fixed or floating platform. Here the LNG is re-gasified and then piped to shore or to offshore storage.
- Ships in Ports: At import terminals re-gasification is carried out on board tankers in port. The natural gas is then piped into the national gas grid.
- On Ships Offshore: Here LNG tankers dock with an offshore pipeline and re-gasification takes place on board the ship and the resulting gas is pumped directly into the pipeline. These tankers may remain connected to the offshore pipeline for a number

of months for use as an unloading and gasification facility by other LNG tankers. Currently the UK can import LNG at three sites: The Isle of Grain, Teeside and two terminals at Milford Haven.

Britain has imported gas for many years from a number of countries, which include the Netherlands, Norway, Qatar and Algeria through pipelines from Norway (Vesterled and Langeled pipelines), the Netherlands (BBL pipeline) and Belgium (IUK pipeline).[144]

Table 4 Current UK gas storage capacity[68 145 146]

Project	***Location***	***Operator***	***Capacity (~BCM)***	***Type***
Rough	Offshore Easington	Centrica Storage Ltd	3.3	Depleted Reservoir
Humbley Grove	Hampshire	Star Energy	0.3	Depleted Reservoir
Hornsea	Yorkshire	Scottish & Southern Energy	0.3	Salt Cavern
Avonmouth, Dynevor, Glenmavid, Partington	Various	National Grid LNG Storage	0.3	LNG Peak Storage
Hatfield Moor	Yorkshire	Scottish Power	0.1	Depleted Reservoir
Hole House Farm	Cheshire	EdF	0.04	Salt Cavern
Aldborough	East Yorkshire	SSE/Statoil	0.06	Salt Cavern

BCM (Billion Cubic Metres)

Table 5 Gas storage projects under development[68]

Project	***Location***	***Developer***	***Capacity (BCM)***	***Gas Year***
Aldbrough II	East Yorkshire	SSE/Statoil	0.4	2011/12
Holford	Cheshire	E.ON	0.2	2011/12
Caythorpe	East Yorkshire	Centrica	0.2	2011/12
Stublach	Cheshire	Storengy UK Ltd	0.4	2013/14

Table 6 Storage projects with planning consent[68]

Project	***Location***	***Developer***	***Capacity*** *(~BCM)*	***Planning Granted***
Aldbrough II	East Yorkshire	SSE/Statoil	0.4	5/2007
Portland	Dorset	Portland Gas Ltd	1.0	7/2007
Whitehill Farm	Yorkshire	E.ON	0.4	10/2007
Gateway	Offshore Barrow	Stag Energy	1.5	11/2008
Holehouse Farm	Cheshire	EDFT Storage	0.3	3/2009
Bains	Offshore Barrow	Centrica Storage	0.6	6/2009

Final Investment Decision not yet taken for all projects.

Table 7 Gas import projects existing and near completed[68]

Import Project	*Developer/Operator*	*Location*	*Type*	*Capacity (BCM/yr)*
Interconnector	IUK	Bacton	Pipeline	25.5
Langeled	Gassco	Easington	Pipeline	25
BBL Pipeline	BBL	Bacton	Pipeline	*~15*
Isle of Grain Phase I and II	National Grid LNG	Isle of Grain	LNG	13.5
Vesterled	Gassco	St Fergus	Pipeline	13
South Hook 1	QP/ExxonMobil	Milford Haven	LNG	10.5
Tampen	Gassco	St Fergus	Pipeline	10
Dragon	BG/Petronas	Milford Haven	LNG	6
GasPort	Excelerate	Teeside	LNG	*~4*

Currently the UK can store 4% of its annual consumption, compared to France and Germany, which can store 24% and 21% of their annual consumption respectively. The UK strategy is to store a minimum of 10% of expected annual gas demand by 2020/21. Prior to the May General Election it was planned to publish a commentary on the UK's ability to cope with large demand and gas supply shocks to 2025 during 2010.[27]

4.3.4 Dependencies and barriers

Government incentives to increase gas and LNG imports and storage include reforming planning consent procedures in the 2008 Planning Act to speed up onshore gas storage projects. Offshore storage and unloading sites are now licensed under the 2008 Energy Act. There is also a new tax relief for 'cushion gas' (gas injected to maintain an operating pressure).[27]

The main barrier to new gas storage and import projects is the declining availability of bank finance and some projects are facing financial difficulties, e.g. Portland, Gateway and Esmond Gordon.[147] Additionally although planning is getting easier it can be difficult to obtain planning consents due to environmental, visual impact and community opposition (there were thousands of objections to the initial proposal from Cannatx for the Preesall project).[148] There is likely to be further public opposition to onshore underground gas storage projects. Some projects have also encountered technical challenges such as operating an LNG plant offshore or storage of gas in shallow onshore salt cavities.[149]

4.3.5 Health and safety risks and implications

Natural gas is explosive with a source of ignition and is highly flammable at 5-15% concentrations. With underground gas storage a positive gas pressure is maintained to prevent large amounts of air entering, to stop explosions occurring. However it is possible for natural gas to escape from underground storage, therefore the operator has to demonstrate to HSE and the Hazardous Substances Authority that there is no unacceptable risk of gas release. As large quantities of gas are stored at these sites they are classified as a major hazard under the Control of Major Hazards Regulations (COMAH) under HSE. Operators must also consider the risks of a gas release from earth tremors and earthquakes. Certain developments cannot be placed close to gas storage sites due to safety risks under land use planning controls.[142]

Underground gas storage both on and offshore has major hazard potential. There have been instances of gas releases from underground storage in mainland Europe and North America, mostly due to incorrect drilling practices or poor regulation. Gas storage schemes have encountered safety and planning problems for example a proposal at Preesall, West Lancashire.[142] Additionally, LNG re-gasification plants have a major hazard potential.

COMAH guidance has been altered recently to give sufficient regulatory coverage to salt cavities and depleted reservoirs onshore. Offshore gas safety regulations are licensed under the Energy Act 2008, not the Petroleum Act, so current gas safety regulations do not apply. Therefore HSE is currently reviewing its offshore regulation, as initial offshore gas licenses have been granted since November 2009 (the first of these is the Gateway storage facility, offshore from Barrow. Additionally HSE has no regulatory coverage in ports where re-gasification may be carried out near to homes. Therefore HSE will need to work with the Maritime and Coastguard Agency to ensure adequate regulatory cover.

Table 8 Gas storage projects yet to receive planning consent (as of July 2009)[68]

Project	*Location*	*Developer*	*Capacity (~BCM)*	*Date Applied*
King Street	Cheshire	NPL	0.2	10/2007
Saltfleetby	Lincolnshire	Wingas	0.7	10/2008
Fleetwood	Lancashire	Canatxx	1.0	02/2009

Table 9 Gas storage projects yet to seek planning consent (as of July 2009)[68]

Project	*Location*	*Developer*	*Capacity* (~BCM)
Albury I	Surrey	Star Energy	0.2
Albury II	Surrey	Star Energy	0.4
Baird	Offshore Bacton	Centrica	1.7
Hewett	Offshore Bacton	ENI	4.0
Gateway II	Offshore Barrow	Stag Energy	1.5
Hatfield West	Yorkshire	Scottish Power	0.1

Table 10 Gas import projects under construction and proposed (as of July 2009)[68]

Import Project	*Developer*	*Location*	*Type*	*Capacity (BCM/yr)*	*Due*	*Status*
South Hook 2	QP/ ExxonMobil	Milford Haven	LNG	10.5	2009/10	Under construction
ConocoPhillips	Partners	Teeside	LNG	7+	2013+	Planning Received
Isle of Grain 3	National Grid LNG	Isle of Grain	LNG	7	2010	Under Construction
Dragon 2	BG/Petronas	Milford Haven	LNG	6	2013+	Planning Received
Canvey LNG	Partners	Canvey Island	LNG	5.4+	2013+	Planning Rejected may resubmit
Port Meridian	Hoegh LNG	Barrow	LNG	4	2013	Planning Granted
BBL Expansion	BBL	Bacton	Pipe	*~3*	2010+	Investment decided
Other LNG	Various	N/A	LNG		2013+	Conceptual

4.4 RENEWABLE ENERGY SOURCES

4.4.1 Introduction

Renewable energy refers to electricity supplied from renewable energy sources, such as wind and solar power, geothermal, hydropower and various forms of biomass, they are considered renewable because their fuel sources are replenished continuously.

UK Renewable energy utilisation in 2008

Hydro (Large scale) 6.7%
Wind 10.3%
Biomass 81.1% comprising:
Landfill gas 26.7%
Sewage gas 4.1%
Domestic wood 6.1%
Industrial wood 1.8%
Co-firing 9.0% *(2)*
Waste combustion 9.1%
Animal biomass 5.0% *(3)*
Plant biomass 5.3% *(4)*
Liquid biofuels 14.0%
Other 1.8% comprising:
Geothermal and active solar heating 1.0%
Small scale hydro 0.8%

Total renewables used= 5.90 million tonnes of oil equivalent

(1) Excludes all passive use of solar energy and all (0.46 mtoe) non-biodegradable wastes. In this Chart renewables are measured in primary input terms – see paragraph 7.15.
(2) Biomass co-fired with fossil fuels in power stations; imported 7.1% of total renewables, home produced 1.9%
(3) 'Animal biomass' includes farm waste, poultry litter, and meat and bone combustion.
(4) 'Plant biomass' includes straw and energy crops.

4.4.2 The Renewables Obligation

The Renewables Obligation is the main policy measure to increase renewable electricity.[150] It is an obligation on electricity suppliers to source an annually increasing amount of their power from renewable sources or pay a penalty fee. Ofgem (the electricity and gas regulator) issue a Renewable Obligation Certificates (ROCs) to generators for each Megawatt hour (MWh) of electricity generated from renewable sources. The generators sell the ROCs on to suppliers who purchase renewable electricity from them. Suppliers show that they have fulfilled their obligation at the end of the obligation period by giving their ROCs to Ofgem, or paying a penalty fee. These fees are then distributed to the suppliers who provided ROCs, providing an incentive to present ROCs. Technologies are banded as below (under consultation until early 2010), in order to give increased support to technologies furthest away from commercial deployment.

ROC values per MW [151]

0.25 ROC	Landfill gas
0.5 ROC	Sewage gas, co-firing of biomass

1.0 ROC Onshore wind, hydroelectric, energy from waste with Combined Heat and Power (CHP), co-firing of energy crops, co-firing biomass with CHP1.5 ROC Offshore wind, Dedicated biomass plants, co-firing of energy crops with CHP

2.0 ROC Wave, tidal stream, tidal barrage (not including the Severn Tidal Barrage, incentives yet to be decided),[152] tidal lagoon, solar photovoltaics, micro-hydroelectric, dedicated energy crops, dedicated biomass with CHP, anaerobic digestion

3.0 ROS (Scottish ROC equivalent) Tidal power
5.0 ROS Wave power

4.4.3 Wind Energy

Wind energy can be described as the harnessing of moving air by wind turbines to produce electricity. The UK has the best wind resource in Europe and has excellent prospects for wind energy with offshore wind power having the potential to provide a third of the UK's current demand for electricity in the short to medium term.[153] The UK is now the world's largest generator of offshore wind energy. Developments in wind turbine design are allowing the production of ever-larger wind turbines up from an average of 3MW to planned offshore 7.5MW designs and maybe beyond.[154]

Current Usage and Planned/Proposed

There are currently 236 wind energy projects operational in the UK with a total of 2572 wind turbines. This comprises around 228 onshore and 8 offshore projects. Together these generate approximately 3.7GW of electricity a year. There are also 38 projects under construction onshore with a further 7 projects offshore.[155] [156] A total of 130 wind turbine sites are planned around the UK.[157] The largest projects under construction are:

- Greater Gabbard: 140 turbines, 504MW, Thames Estuary

And approved:

- London Array: 341 turbines, 1GW, Thames Estuary
- Gwynt y Mor: 250 turbines, 750MW, 13-25km off North Wales
- West of Duddon Sands: 160 turbines, 500MW, N Irish Sea

Recently the world's largest onshore wind farm was completed at Whitelee near Glasgow.

A complete list of wind energy projects current, planned, operational and sites awarded can be found on the British Wind Energy Association website.[155]

Development rights for nine marine zones around the UK have recently been awarded by the Crown Estate for Round 3 of the leasing programme for 25GW of development (on top of an existing 8GW currently planned).[158] Additionally the Crown Estate is also offering development rights to 10 potential sites in the Scottish Territorial Waters, with potentially 6.4GW of wind electricity exploitable, the awards are dependant the outcome of an SEA by the Scottish government in 2010.[159] The BWEA estimate that over 55,000 jobs could be created over the next ten years in planning, construction and maintenance. Additionally, Scottish Enterprise recently identified 11 sites that could be potential sites for offshore wind turbines, under Phase one of its National Renewables Infrastructure Plan.[160]

The UK Renewable Energy Strategy published recently also outlined an offshore transmission regime for delivery of grid connections required for this rise in offshore wind energy, requiring up to £15 billion investment. The Government is also providing support and funding for a new testing facility as part of a £120 million investment package for offshore wind.[39] July 2009 saw a new offshore regulatory regime announced to connect up to 39GW of offshore wind energy to the UK electricity grid and competitive tenders have begun.

A five-year European project called *Upwind* is looking at the future of wind power, specifically the design of very large wind turbines (8-10MW). UpWind is a European project funded under the EU's Sixth Framework Programme (FP6). The project looks towards the wind power of tomorrow, more precisely towards the design of very large wind turbines (8-10MW), both onshore and offshore. The project should be completed in 2010.[161]

Dependencies and barriers

- Hold-ups in the planning process or long delays in getting connection to the National Grid.[162]
- Investment for the planned huge expansion in wind energy and grid upgrades is not raised.
- The National Grid network will require upgrading to allow for the speedy connection of new wind farms.
- Wind generation is intermittent and unpredictable (wind turbines are only active 70-85%).[163] Therefore a back-up supply will be needed at short notice, such as power plants spun up in reserve to cope when the wind is not blowing. There will also be a need for the use of energy storing systems or development of a ‘smart grid’ (a grid able to take power from multiple sources and distribute it according to demand).[164]
- Other issues currently holding up wind farm applications are, public opposition, concerns from aviation, MOD concerns (potential effects on radar) other users of the sea (ships etc) and about impacts on wildlife).[165]

Health and safety implications and hazards

The hazards in this industry include working from height, slips and trips, contact with moving machinery, possible risks of electrocution and construction in very windy conditions. Offshore construction is even more hazardous including risks from large waves, diving activities, siting the turbines using very large jack-up boats and constructing the turbines at sea. Wind turbines also require regular access for maintenance; therefore workers will be exposed to these risks often. There are also the associated risks from piloting boats and helicopters in a harsh environment. Although it is a rare occurrence, wind turbine blades have failed and these or fragments have been shown to travel over appreciable distances; blades can also throw ice.[166] Additionally, structural failures can occur (HSE investigated two turbine collapses late in 2007) and the collapse of a jack-up barge used to attach turbines to the sea floor. Additionally turbines may be prone to being struck by lightning, which could cause damage and fire. A recent HSL report has examined the risks associated with construction and maintenance of offshore wind turbines.

4.4.4 Marine renewables

Marine renewable energy can be described as the conversion of the energy of waves, tides or currents into electricity.

Wave

Devices that capture the energy in the motion of waves and convert it to electricity, using a variety of techniques. These can be sited on the shoreline, near-shore and far-shore and consist of 3 main types:

- *Buoys*: move along with waves, connected to an anchored structure below the surface;[167]
- *Segmented devices*: snake-like connected segments move in the waves;[168]
- *Oscillating water columns*: wave movement pushes air through a column to power a turbine.[169] [170]

Tidal

Technology that converts the energy in the tides to electricity; there are 2 types:

- *Range* type: use the change in height of water due to tides; and
- *Current*: which use the flow of water due to tides.

Tidal lagoons, which store water at high tide, which can be released later to drive electricity generation also exist.

Ocean

- *Current*: generates electricity from the flow of water in ocean currents;[171]
- *Thermal*: known as Ocean Thermal Energy Conversion (OTEC) generates electricity from the temperature difference between shallow and deep water (which would be largest in the tropics).[172]

The Atlantic edge of the British Isles has some of the strongest waves and tidal currents in the world.[173] Estimates from the Carbon Trust state that the UK's exploitable resource could be around 20GW of electricity from wave power and about 6GW from tidal power (assuming a 33% capacity factor). This relates to up to 20% of UK electricity.[174]

Current and planned/proposed

There is currently around 1GW of installed marine renewable electricity capacity in the UK.[169] The following marine renewables technologies were deployed in the UK in 2008: Limpet at Islay (500kW), MCT Seagen at Strangford Lough (1.2MW), European Marine Energy Centre (EMEC) Open hydro (250kW), EMEC TGL (500kW), EMEC Aquamarine Oyster (300kW), EMEC OPT PowerBuoy (150kW), Pulse Tidal in the Humber (100kW) and Trident Energy (confidential).[175]

Tidal barrages are a proven technology however there are only a few in the world, including the Rance barrage, which has operated for 40 years in France. There are more than 80 marine renewables concepts currently, all at different stages of development.[169]

Planned and proposed marine renewable devices

Severn Estuary tidal power scheme: 5 projects short listed, including Severn barrage plan 8GW or 5% of UK energy needs by 2023. A feasibility study is being carried out by DECC and a decision is due sometime in 2010, after a second public consultation.[176] It could provide up to 18,000 jobs for more than 7 years.[177]
SeaGen: a marine turbine farm is planned off the Anglesey coast, initially rated 10.5MW by 2011, but could eventually be up to 350MW.[178]

Pelamis: 4 segmented devices to be placed off the Orkney coast and potentially 7 off the North Cornwall coast, each rated 750kW.[179] [180]
Open Hydro: giant fan devices with blades connected to a rotor, being trialled in Channel Islands; if successful a full-scale project could generate 3GW of electricity.[31]
Scottish Power intends to develop two sites: Pentland Firth and the Sound of Islay. This project could be the largest of its kind in the world and 5-20 turbines will be installed at each site. The combined electrical generation capacity is up to 60MW.
Thetis Energy: (a consortium of B9 Energy Offshore Developments, Deepblue Renewables and Statkraft UK) recently announced plans for a £300m tidal power plant near Torr Head, Co Antrim.[181]

On 16 March 2010 the Crown Estate announced Round 1 lease agreements for up to 1,200 MW of electricity for six wave project development sites and four tidal ones, with potential capacity split equally between wave and tidal (Table 11).[182]

Table 11 Crown Estate Round 1 lease agreements[183]

Site name	***Owners or tenant***	***Rating (MW)***
Costa Head	SSE Renewables Developments (UK) Limited	200
Westray South	SSE Renewables Developments (UK) Limited	200
Brough Head	Aquamarine Power Limited & SSE Renewables Holdings (UK) Ltd	200
Marwick Head	Scottish Power Renewables UK Ltd	50
West Orkney Middle South	E.ON Climate & Renewables UK Ltd	50
West Orkney South	E.ON Climate & Renewables UK Ltd	50
Cantick Head	SSE Renewables Holdings (UK) Ltd & Open Hydro Site Development Ltd	200
Brough Ness	Marine Current Turbines Ltd	100
Ness of Duncansby	Scottish Power Renewables UK Ltd	100
Armadale	Pelamis Wave Power Ltd	50

A shoreline oscillating water column device called the Limpet on Islay is the only wave device consistently supplying wave energy to the grid in the UK. It was expected to produce approximately 200 kW a year, but is producing around a tenth of that due a lower seabed than predicted. MCT's SeaGen tidal device is should start supplying consistent energy to the grid soon. The commercial facilities operating by 2010 are not expected to amount to more than around 25 MW of capacity.

Improved tidal turbines are also in development, such as the *Thawt* rotor device, which could be in use as multiple unit farms in 2013.[184] There are also testing facilities for marine devices at the New and Renewable Energy Centre (NaREC) in Northumberland, EMEC in the Orkneys and Wavehub in Cornwall. Other facilities exist in Ireland and Denmark with planned developments in Spain, France, Portugal and Canada.[169]

The UK Energy Research Centre (UKERC) Marine Renewable Energy Technology Roadmap has a target of achieving 2 gigawatts (GW) of installed capacity in the UK by 2020, taking into account to assumptions such as an attractive market being in place and it also aims to be competitive with other sources of energy by this time.[185] This agrees with the Energy Technologies Institute (ETI) target for marine renewables, they also have a target of 30GW by 2050.[169]

The majority of marine renewable energy technology is being developed in the UK and Ireland by the following companies: Marine Current Turbines (MCT) and Pelamis Wave Power (PWP), SeaGen and Open Hydro (Ireland). The infrastructure includes the Engineering and Physical Sciences Research Council's (EPSRC) SuperGen Marine Energy Research Consortium, UKERC and the Carbon Trust's Marine Energy Accelerator to advance the commercialisation and reduce the high costs of marine energy.[186]

Barriers and dependencies

Currently marine renewables are not cost competitive in the UK and are unlikely to be until more than one hundred megawatts capacity is reached, according to the Carbon Trust.[174] Factors that may slow the introduction or growth of marine renewables in the UK include: high initial costs, lack of investment (exacerbated by the current recession), planning delays, grid access delays, environmental and public opposition and that some technologies may not scale-up or prove robust enough in the open sea. Additionally, although tide patterns are known and wave behaviour can be predicted fairly accurately several days in advance, its supply is variable.[169]

Government support

Recently, as part of the UK's Renewable Energy Strategy and Low Carbon Industries Strategy £60 million of funding has been given to the marine renewables industry. The Government had intended to work with the sector to produce a Marine Action Plan by spring 2010.[187] A Marine Renewables Proving Fund (MRPF) of £22 million was also to be launched by the Government for testing and demonstrating marine renewable devices in 2010, with a further intention for the Marine Renewables Deployment Plan (MRDF) to be extended to 2014.[188] There is also a Marine Renewables Deployment Fund. Additionally, the UK's first Low Carbon Economic Area in the South West will concentrate on marine renewables demonstration, servicing and manufacture.[27] In Northern Ireland, the Department of Enterprise Trade and Investment published a Strategic Action Plan for offshore wind and marine renewables in December 2009, where it set a target of producing at least 300MW of electricity from Northern Irish waters by 2020.[189] In the period after the May election it is anticipated that all funding priorities are to be reviewed.

Other sources of funding include the Scottish Wave and Tidal Energy Scheme, the Energy Technologies Institute, the research councils. The Carbon Trust is providing up to £3.5 million to fund the commercialisation of marine renewables.[186]

Once marine renewable technologies are proven commercially, there could potentially be a large rollout of marine renewable units around the UK coastline over the next 10-15 years. Already the Severn Estuary scheme, which is the UK's largest renewable energy project, is under consultation by DECC.

Health and safety implications and hazards

Health and safety considerations include risks during construction and installation of large marine energy devices in a harsh marine environment using a variety of specialised boats. There are additional hazards such as anchoring devices to the seabed, which is challenging, associated diving activities and the laying of cables to connect to the electricity grid. Maintenance of these units is also difficult and currently regularly requires the device being returned to shore.[169] There are also potentially risks during the manufacture of marine devices, a large amount of which will take place in the UK. Potential external risks to marine energy operations could also come from boats and shipping.

4.4.5 Biomass

Biomass is biological material derived from living, or recently living organisms. In the context of biomass for energy this is often used to mean plant based material, but biomass can equally apply to both animal and vegetable derived material. Biomass can be converted into heat, electricity, fuel and feedstock for the chemical industry.[190]

Methods

There are various methods to convert biomass into electricity, heat, fuels and chemical feedstock these include:

- *Direct Combustion*: heating water or to generate steam to drive a turbine for electricity generation (Large biomass power stations are appearing and are planned).[191] Additionally existing large coal-fired power stations can sometimes burn biomass along with coal, this process is known as 'co-firing'.[192] This has been trialled using small amounts of biomass at Drax power station, which aims to use 10% rising to potentially 20% biomass co-fired with coal.[193]
- *Gasification*: solid biomass converted by heat into a combustible gas
- *Pyrolysis*: heating biomass without oxygen, producing a combustible gas or liquid
- *Fermentation/Distillation* processes: e.g. sugar/biomass conversion to bioethanol (e.g. British Sugar: is producing bioethanol up to 70 million litres/yr)[194] and there are other proposals in the pipeline, including for butanol production.
- *Esterification/Transesterification processes:* vegetable oil conversion to biodiesel (there are a number of different-sized producers in the UK).[195]
- *Anaerobic Digestion*: the bacterial breakdown of organic waste into CO_2 and methane (biogas). "The implementation of food waste biomass conversion in Bruichladdiach whisky distillery on Islay led a manufacturer of anaerobic digesters to cite that there are 5,000 similar UK small food manufacturers with product wastes who could adopt this technology.[196]
- *Sewage* and *Landfill* gas can also be burnt as an energy source.
- *Converting biomass to feedstock for the chemical industry*: as an alternative to using oil
- *Conversion of Algal biomass to transport fuels*: there are a number of start-up companies around the world, including Cellena (part-owned by Shell) attempting to commercialise this sustainable technology.[197] On 23 October 2008 the UK Carbon Trust put out a call for proposals for the Algal Biofuels Challenge. This was set up to support the development and commercialisation of algae biofuel technologies in the UK by 2020, with potential funding up to £26 million.[198]

In May 2007 the UK Government published its UK Biomass Strategy coupled with the Government's Energy White Paper. This strategy states that the Government wants to realise a major expansion in the use and supply of biomass. In order to meet these goals there is a requirement for a major increase in UK biomass production. The UK Biomass Strategy states that this could be done by:

- Sourcing an additional 1 million dry tonnes of wood per annum;
- Increasing the amounts of perennial energy crops in the UK to up to 17% of total UK arable land (1 million hectares);
- Increased supply from organic waste materials (e.g. manures).[199]

It is thought that at least 300,000 jobs related to biomass fuel production could be created in Europe by 2020.[200]

Barriers and dependencies

The UK Renewable Strategy published in 2009, considers using biomass to generate electricity and heat to be a significant cost-effective contributor to UK renewable energy targets to 2020. Potentially 30% of that target could be from biomass. Analysis has confirmed large potential for non-domestic biomass heat and biomethane injection into the gas grid. Additionally heat pumps could play an important role.[39]

A barrier to development of a biomass heat sector in the UK is the high costs to set up an infrastructure, compared to other systems. As such the Renewable Heat Incentive (RHI) is being set up as a financial support mechanism, which aims to begin in April 2011. Further consultation on this occurred in late 2009.[201]

The Forestry Commission's Wood fuel Strategy plans to supply a further 2 million tonnes of wood fuel a year by 2020 to provide around 2% of our 2020 renewable energy target. The UK's Energy Crops Scheme, with £47 million of support has had low take-up, but increases in grants may be considered.

In Budget 2009 the UK announced £25 million to help to fund at least 10 exemplar schemes of community heating infrastructure; biomass and anaerobic digestion technologies are being considered.[27] The Biomass Energy Centre is working with the sector providing information and guidance on biomass installation and a biomass training course.[202] Additionally the SUPERGEN Biomass and Bioenergy Consortium funds research in these areas.[203]

Current and planned/proposed

Total current UK biomass capacity is over 300 MW. Of this 96 MW is mostly clean biomass wood fuels, about 120 MW is mainly fired by agricultural residues and a little more than 100 MW is largely fired by industrial and commercial wastes.[204] Stephen's Croft biomass plant was recently opened in Scotland by E.ON, it has a rating of 44MW and uses forestry co-products and willow.[205]

Local Authorities currently generate 6 terrawatt-hours (TWh) of heat and power from biomass municipal solid waste and around 18 TWh from landfill gas. Analysis for the UK's Waste Strategy for England 2007 states that 42 TWh or around 18% of the 2020 renewable energy target could be generated if all food and wood waste sent to landfill were used for energy.[206] Landfill tax and further increases in the 2009 Budget should help stimulate the use of large amounts of waste for heat and energy in the near future.

Biomethane

Syngas (gasification of biomass) will not be a big growth area in the UK up to 2020 with only a few small plants in the UK being built, due to high costs. Several demonstration plants currently operate in Europe though.[39] Businesses have shown considerable interest in injecting biomethane (cleaned and upgraded syngas or biogas) into the UK's gas grid. Financial support for this could come through the RHI and there have been consultations in 2010 on giving biomethane producers exemption from holding a Gas Transporters Licence by 2011 when the RHI is introduced.[***]

[***] HSE with DECC is to consider whether certain statutory requirements for the quality of gas in the grid could be adjusted to allow safe biomethane injection.

Co-firing

Existing coal-fired power stations co-fire clean biomass products with coal to generate energy e.g. Drax, where approximately 2.5% of the supplied fuel is biomass and Didcot which accepts around 20 kilo-tonnes a year of bio-energy crops.[207] Comments upon the upper level of biomass useable in co-firing without major challenges vary but are put at 10-25%.

Biodiesel

Around 320 million litres (Ml) of biodiesel were produced in the UK in 2008, compared to 485Ml in 2007. Figures from the HMRC show that 886Ml of biodiesel were consumed in 2008, up from 347Ml in 2007. Approximately 572 million litres of biodiesel were imported in 2007. If all the planned biodiesel plants become operational and the existing plants run at full capacity the total annual capacity for biodiesel production in the UK is estimated to reach 540Ml a year in 2010, equivalent to around 2.2% of the UK's 2008 diesel consumption.[31]

Bioethanol

In 2008, 206 Ml of bioethanol was consumed in the UK, continuing a trend of increasing bioethanol use from 85 million litres in 2005. Just one UK bioethanol plant was in production in 2008, therefore most bioethanol was imported. UK bioethanol production capacity would reach 505Ml by 2011 (2.2% of 2008's UK petrol use) increasing to potentially 1660Ml beyond 2012 if all planned plants meet their timescales.

Significant planned biomass plants

The first large biomass-fired plant is under construction in Port Talbot. With a generating capacity of 350 MW, it could provide electricity for half the homes in Wales by 2010.[39] MCT Power recently obtained consent to build a 295MW woodchip-burning biomass plant, one of the largest in the world, scheduled to start operating in 2012 at Teesport, Teeside.[208] They also have plans for a second woodchip-burning plant at the Port of Tyne, also 295MW, targeted to operate from 2014.[209] Other companies have proposed similar-sized biomass plants around the UK, including Drax who are planning three 300MW wood-burning biomass plants, two in Hull the other in Immingham.[210] Recently Tilbury Green Power received government permission to build a 60MW biomass plant in Tilbury docks, Essex.[211] Additionally E.ON have approval for a 25MW plant in Sheffield, burning recycled wood, which is expected to start operating in 2011.[212] Most of the wood for these plants will be imported. A number of other large biomass plants are in planning or construction around the UK.[213] There are proposals for 2 power plants: at Portbury Docks Bristol and Tilbury, Essex, also for a biofuel plant at Tunstall, near Stoke.[157]

UK plans

There are plans to increase the use and deployment of anaerobic digestion to make biogas under the Anaerobic Digestion Task Group and by establishing a Biomass Sustainability Working Group, which the EET might consider joining.[214] Other plans include the Anaerobic Digestion Demonstration Programme for up to £10 million to build cutting-edge anaerobic digestion demonstrators by March 2011, on top of £10 million from 2008. Additionally the Feed in Tariff (FIT) rate for anaerobic digestion announced by DECC recently should stimulate the market from April 2010.[225] The technical potential for biogas heat and power generation in the UK is estimated to be 10-20TWh or greater.[215]

The Scottish Biomass Support Scheme has resulted in 60 projects of 20MW total thermal capacity and is currently rolling out its £3.3 million Biomass Heat Scheme. The Welsh Assembly is currently consulting on its Bioenergy Action Plan for 5TWh of electricity and

2.5TWh of heat energy from biomass by 2020. European standards for the sampling and testing of solid biomass fuels have been drafted by the European Committee for Standardisation (CEN) and full standards are expected by the middle of 2010.[39]

Health and safety implications and hazards

The processes described are well-understood therefore current HSE regulation and strategy should be adequate to cope with a rise in biomass use. However there could be a number of implications for health and safety from an increase in the use of biomass at both small and large scale installations in the UK over the coming decade. These include:

- Increased collection of wood from managed and unmanaged woodland. Forestry occupations already have a very high injury and fatal accident rate.[216]
- High temperatures and sometimes high pressures are used in pyrolysis (350-550°C) and gasification (over 700°C). There is a potential issue with increased variability of gas constitution from biomass compared to fossil fuels.
- Increased collection and distribution of biomass. The recycling sector has one of the highest injury and fatal accident rates.
- There is some evidence that biomass can present a potential fire or explosion risk. If the biomass is not stored well it could constitute a microbiological or chemical health risk.[24] Biomass has also been known to self-heat and combust. Recycling of laminates and chipboard may present a dust explosion risk due to their high resin content and brittle nature. Increasing use of land for crops (Agriculture) e.g. elephant grass may mean farmers switching to growing energy crops with limited or no experience. Other potential issues could be use of ageing equipment, equipment sharing or training issues. There could also be respiratory health effects from exposure to new or existing crop material.
- Huge amounts of biomass, primarily wood will be imported into the UK for electricity and heat generation over the coming decades. There will be associated risks from the transportation and storage of this biomass.
- There may be potential land use planning issues from the use of biogas e.g. landfill generators. Use of biogas boilers commercially and in schools is set to increase under government plans. Potential risks could include gas leaks or explosions although this does not mean to say the risks of leaks or explosions will be higher than the systems they replace.
- Since June 2007 there is no need to register, submit returns or pay duty if biodiesel production is less than 2500 litres/year.[217] Therefore there is the potential for a large increase in domestic production (there are number of home biodiesel kits available)[218] and on-farm production. There are significant health and safety concerns as the process involves a number of hazardous chemicals that have toxic or corrosive effects or pose a fire and explosion risk. HSE has produced some guidance on the domestic production of biodiesel.[219]
- Increased collection, transport and use of large amounts of slurries and manures for energy production. Potential risks include: falls into slurries/manures, fume exposure, microbiological risks and biogas explosions.

4.4.6 Solar energy

Two types of technology are in common use for the exploitation of solar energy:

- *Solar photovoltaic* (PV): use the sun's energy to generate electricity. A solar cell consists of 1 or 2 layers of semi-conducting material, often silicon. Light hitting the cells causes an electric field across the layers, with more light giving a stronger electric field.[220]

- *Solar thermal power* (STP): use the sun's energy to heat air or water.

Current and Planned/Proposed

Large-scale electricity generation in 'solar farms' such as are found in for example the US and Australia is not appropriate for the UK. However solar energy can make a useful contribution of the UK's energy needs, despite the diffuse and intermittent nature of our sunlight. Building integrated PV could significantly contribute to electricity production in the UK. For example if $10m^2$ of 20% efficient PV was installed on 3 million homes then 1.5% of UK electricity at 2006 levels would be generated. Additionally STP could replace a significant amount of fossil fuels in domestic water heating and space heating/cooling in the future.[221]

The solar industry is growing by 30% a year and world PV capacity is predicted to rise from 100MW to 40000MW by 2020. There have been recent rises in the installation of solar PV systems on new and existing domestic and commercial buildings in the UK, e.g. Manchester's CIS tower, which is one of the largest PV facades in the world.[222] Over 100,000 solar thermal systems are installed in the UK, with about 10,000 more being installed each year.[223]

The Department for Business Innovation and Skills (BIS) states that the UK has a small but established market for solar thermal energy,[223] but there are signs of growth evidenced by a major double-glazing provider now offering solar thermal heating installation.[224] It is likely that the DECC's 'feed in tariff' (FIT) for solar energy in April 2010 (retro-fitted solar PV has the highest payment level)[225] will cause an expansion in home installations this will result in a significant number of jobs in solar being created.[226]

UK solar manufacturing companies include Sharp making PV panels in Wales and G24 Innovations who have expanded production. The UK also has the largest building integrated PV line in Europe. Other new solar companies spun out of UK universities include QuantaSol, SolarStructure and Whitfield Solar.

Barriers and dependencies

The challenges of solar energy in the UK include the seasonal/diurnal variation of sunlight and energy storage issues of the electricity generated. Other issues include the current high costs and long payback time, relatively low efficiency, material shortages (silicon) and some use of rare materials.[221]

Subsidies for solar energy under the recent Department of Energy and Climate Change (DECC) Low Carbon Buildings Programme have proved very popular, and the grants were quickly oversubscribed. From April 2009 DECC planned to allow householders to claim double the financial support through the Renewables Obligation, followed by guaranteed cash payments the year after, via feed in tariffs.[227, 225] The market for solar energy has been shown to increase with feed-in-tariff support; such a scheme has been successful in Germany.[228] A FIT for solar is also available in the UK with energy producer Scottish and Southern.[229]

Efficiency of PV ranges from 8-20%; concentrator cell prototypes have reached 26.8-40.7%, but are very expensive. The future will bring greater efficiencies at cheaper cost;[230] it is thought that next (3rd) generation systems will reach 60% efficiency. There is an active research environment focused on next generation solar technologies in the UK including the Sustainable Power Generation and Supply Initiative (SUPERGEN), and the New and Renewable Energy Centre.[223] Additionally in late 2007 the Carbon Trust launched a £5 million research and development programme which aims to produce 1GW of thin organic PV that can be sited on a variety of different surfaces by 2017.[231]

Health and safety implications and hazards

The heath and safety risks associated with solar energy will be from the installation of, maintenance and manufacture of solar devices. There are an increasing number of STP and PV installers in the UK[232] and with the rise in solar installations there may be training and competency issues for the sector, for example working at height. This may be particularly relevant with STP where plumbing skills and 'Gas safe' registration (from 1 April 2009) may be required to allow integration with gas central heating. There may be potential domestic electrical safety issues associated with PV panel installation, integration with the National Grid and maintenance.

The next generation of highly efficient solar PV is being developed in the UK, and use chemicals such as cadmium telluride, copper indium diselenide and copper indium gallium selenide in their manufacture, which are known to be highly toxic.[221] [222] Additionally new and emerging chemicals and processes will be used in future solar panels, which may well also be harmful to human health.[233] There is a potential health risk from exposure to these chemicals during the manufacture of solar panels and also from their disposal and recycling. There may also be hazards associated with the transportation of these chemicals. Additionally there may be land use planning issues associated with the establishment of PV panel manufacturing sites, which will be classed as hazardous installations if large amounts of toxic chemicals are stored onsite.

Although recent market research states that the world solar demand growth will stay roughly flat in 2009 and 2010,[234] over the longer term, with increasing energy prices solar power will likely play a significant role in the UK's future energy mix. According to BIS estimates solar PV could be cost competitive with other forms of electricity production between 2020 and 2030.[227] Solar energy take-up will be increased in the future by the UK's FIT and their commitment to a low carbon economy. Additionally, a UK ambition that all new homes to be carbon neutral by 2016 may further stimulate the solar energy market.[222]

4.4.7 Hydroelectricity

Hydroelectricity is created by converting the water flow kinetic energy into mechanical energy to rotate turbines that drive an electricity generator. The amount of electricity generated is dependent on water flow and the vertical distance the water falls (known as 'head').

There are three types of hydroelectricity:

- *Run of river schemes:* Uses the natural flow of a river, possibly enhanced by a weir. The water is typically channelled from the river to a powerhouse, containing the turbine and generator.
- *Storage scheme:* A water reservoir feeds a turbine (usually within the dam), but may be channelled to a remote powerhouse.
- *Pumped storage:* Consists of two reservoirs, where water is pumped from a lower basin to an upper basin at times of low demand and then used to peak shave loads at high demand.

Current and Planned/Proposed

Currently UK capacity is 4,244 MW (this includes 2,788 MW of pumped storage capacity).[235] This is equivalent to 1.3% of the UK electricity, largely generated from large-scale plants in the Scottish highlands. Hydro plants are classed as:

- Large-scale capacity if the hydro plant produces more than 20 MW.
- Small-scale capacity if the hydro plant produces less than 20 MW.
- Micro-scale capacity if the hydro plant produces less than 50 KW.

DECC state that 3% of the total electricity needs, can be generated by hydro electric if all potential sources are utilised.[235] Hydroelectricity is a proven technology (over 150 years) with modern plants giving efficiency of modern plants of 90%+ and rarely below 80%. However, there have been few large hydro schemes since the 1980s and Opportunities to use technology on a large scale are limited, both for environmental and financial reasons. The untapped potential lies with micro and small scale schemes, which DECC is hoping to exploit with its FIT incentives.[225]

4.4.8 Geothermal

Geothermal energy can be described as the thermal energy stored in the earth. The heat within the earth can be used to generate electricity or heat.

<u>Enhanced Geothermal Systems (EGS)</u>

Boreholes are drilled to 5km or more into hot rocks underground. Water is injected, which is turned into steam and travels up another borehole to the surface to drive steam turbines or heat exchangers to generate electricity.

<u>Ground source heat</u>

Uses the generally constant, lower temperature heat (around 10-20°C) close to the earth's surface. This heat is used by heat pumps to generate hot water (around 40-50°C) for heating e.g. radiators. These heat pumps use some electricity and can be used on a medium or large scale and in reverse for cooling purposes.

Geothermal power plants can use EGS or hot water from deep geothermal reservoirs to power generators and generate electricity. The resulting cooled water can then be recycled down the reservoir to be re-heated.[236] Additionally 'Wet rock' technology consist of drilling into deep pockets of steam, which are renewed by underground streams, to drive steam turbines and generate electricity at the surface.

Current and Planned/Proposed

Geothermal Plants: There is currently one geothermal power plant is operating in the UK in Southampton where heating, cooling and electricity is supplied to local homes and businesses. It has been operating since 1986.[237]

Significant geothermal resource has been identified in Cornwall from studies in the 1970's and 80's. Engineered Geothermal Systems have selected a site and developed a plan for a pilot plant to exploit a geothermal reservoir here. Subject to adequate financing, planning permission and technical considerations the plant could be ready by 2012 and generate electricity for close to 5000 homes and supply heat to local buildings.[238] [239]
The is one EGS plant operated commercially in Landau, Germany since 2007, which has a capacity of 3-3.8MW of electricity and enough heating for 200-300 homes. A research project in Soultz-sous-Forèts, Eastern France started in 1998, which generates 1.8MW but has not been operated commercially. [240]

The largest group of geothermal plants is in the Mayacamas Mountains, 72 miles north of San Francisco. These use steam field reservoirs deep underground and generate 750MW of electricity from 15 plants.[241] Geothermal energy is used in a number of countries with over 500 EGS plants worldwide in 30 countries (United States, Philippines, Mexico, Italy, Indonesia and Iceland) and about 10GW of generating capacity worldwide. [242]

EGS systems are being developed in Germany, Japan, Switzerland, Australia and the US, where AltaRock Energy are well advanced in creating a demonstration ETS plant.[243] The biggest project planned is in Cooper Basin Australia with a 5000 to 10000MW of electricity generation potential.[244]

Heat Pumps: Currently there are about 5000 ground source heat pumps installed a year in the UK, every year 2000 more are installed. Estimates state that there are potentially 1550 large industrial sites where large scale heat pump systems could be used. Grants are available under the Low Carbon Buildings Programme. The Government had expected ground source heat to make a significant contribution to the UK's 2020 EU renewables target.[245]

UK Plans

As part of the UK LCTP £6 million of capital grant funding as a challenge fund (part of the Low Carbon Investment Fund, LCIP) was made available, to explore the potential for deep geothermal energy in the UK. The money, available over 2 years will assist in exploratory work required to locate viable geothermal sites. Three projects have been awarded first round grants: EGS Energy (see above) exploratory borehole at the Eden Centre, Cornwall, Geothermal Engineering Ltd exploratory borehole at Redruth, Cornwall and Newcastle University for boreholes for Eastgate a proposed 'eco-village' in County Durham. Projects are expected to produce at least 2MW of electricity or $5MW_{th}$ of heat generation within 5 years.[246]

Health and safety risks and implications

Although geothermal energy has been proven commercially, there is limited geothermal construction, planning and operational experience in the UK. Geothermal power has only been deployed once in the UK previously and the planned Cornish pilot plant is a different technology. Health and safety risks could be associated with borehole drilling, piping steam or hot water and construction and operational activities of novel plants. There may also be potential earthquake risks from drilling and pumping water deep underground.

4.5 DISTRIBUTED GENERATION (INCLUDING ELECTRICITY STORAGE AND HYDROGEN)

The term ‘distributed generation’ (DG) describes decentralized, grid-connected or off-grid, low carbon or renewable electricity or heat systems located in or near the place where energy is used. ‘Microgeneration’ comes under the banner of DG and refers to the generation of electricity or heat at the *domestic* level.[247] Energy security and climate change targets are providing powerful drivers for an increased DG energy system in the UK. A range of DG technology exists, but it is not widely used in Britain.[248]

4.5.1 Technologies

DG technologies include combined heat and power (CHP), air and ground source heat pumps, wind power, use of biomass and biofuels, photovoltaic solar, fuel cells, micro hydroelectric and energy storage e.g. supercapacitors and batteries. Descriptions of wind power, biomass, solar photovoltaic and hydroelectric power can be found in the Renewables section of this report above. The other methods are described below.

Combined heat and power is the generation of usable heat and power (usually electricity) in a single process. There are a number of different CHP Systems using a range of fuels and technologies. A simple version will use a gas turbine, engine or steam turbine driving an alternator to produce electricity for use on-site (mostly) or for distribution. Heat is recovered by a heat recovery boiler, which can be used to produce steam, or to generate hot water for heating. With appropriate equipment it can even be used for cooling. CHP system efficiencies can reach over 70%, compared to 48% for a gas-fired power station. Generation on-site helps avoid losses during electricity transmission from plant to customer.[249]

Ground source heat pumps use the generally constant heat (around 10-20°C) close to the earth’s surface. This heat is used by heat pumps to generate hot water (around 40-50°C) for heating e.g. radiators. These heat pumps use some electricity and can be used on a medium or large scale and in reverse for cooling purposes.

Air source heat pumps can absorb heat from the outside air, which can be used for heating water for heating systems or warming the air inside, using the same technology as a fridge for removing heat from its interior.[250]

Fuel cells are electrochemical devices that combine oxygen and hydrogen to generate electricity, with water and heat as by-products. The waste heat can be used for heating or to produce hot water. Fuel cells are efficient (around two or three times more efficient than burning fuel), produce low or zero emissions and can use multiple fuels. They are also durable, reliable and can be easily scaled up.[251]

4.5.2 Energy Storage *(relevant to distributed generation – larger scale storage is considered elsewhere)*

- *Batteries* are electrochemical devices that store electrical charge; they can store a lot of energy but release it slowly.
- *Capacitors* provide very high power, but can only store small amounts of energy.
- *Supercapacitors* on the other hand, provide much higher power than batteries and store much more charge than capacitors. As supercapacitors have a larger capacity they are suitable for supporting renewable energy generation, by storing excess energy until it is needed.[252]

4.5.3 Current and Planned

In 2007 less than 10% of UK energy was produced by DG.[253] Levels of electricity generation from DG have grown to over 12GW in 2008.

Countries such as Sweden and the Netherlands have high amounts of DG. In the UK Woking Borough Council has been a good case study in the effective use of DG.[254]

There were an estimated 100,000 micro generation installations in the UK in 2008, up from 82,000 at the end of 2004, ranging from solar energy to geothermal technology. Currently there are no statutory targets for microgeneration.[255] A study by the Energy Saving Trust (EST) estimates that by 2050 30-40% of UK electricity needs could be supplied by microgeneration.[256]

4.5.4 Dependencies

Government Support

The Government has stated that increasing use of distributed generation is part of its plan to meet the EU's renewable energy targets. There are a number of government support mechanisms to help facilitate this:

- The £131m *Low Carbon Buildings Programme* (LCBP), CERT (Carbon Emissions Reductions Target), permitted planning, highest level of reward under the reformed Renewables Obligation (RO) from April 2009.
- The *Renewables Obligation*, under the Energy Bill support for microgeneration has been increased from 1 to 2 Renewable Obligation Certificates (ROCs), it is set to continue until at least 2037.
- Low Carbon Buildings Programme Phase 2 programme provides grants for public sector, community groups and charities, up to 50% of installation costs. A further £45 million was made available in the April 2009 budget.[257]
- Ongoing support will be through FITs from April 2010[225] –to support small scale generation up to 5MW – and the *Renewable Heat Incentive* is set to provide similar incentives to install renewable heat technologies of all sizes from April 2011.[39] The Government considers that there is greater potential for small-scale heat generation compared to micro-electricity.[258]
- *Reduced VAT*: small-scale onsite low carbon and renewable energy technology installations pay 5 percent VAT (this does not apply to DIY installations).
- The *Microgeneration Certification Scheme* (MCS) is a UKAS accredited certification scheme for installers and products, offering consumers protection. MCS, or an equivalent mark for installers is already mandatory for access to LCBP grants, and will apply to all products from 1 January 2010. Based on European and international standards, MCS integrates a robust consumer code of practice.[259] Additionally the National Occupational Standards for Environmental Technologies provide standard competencies for microgeneration technologies.[201]
- As part of the *Microgeneration Strategy*, the Government announced permitted planning for most onsite low carbon and renewable energy technologies in April 2008. Permitted development means that generally householders do not require individual applications for planning permission if the development will not negatively affect the amenity of others.[260]

- Proposed changes to the planning regime, such as the extension of permitted development status to domestic microgeneration installations.
- No tax is paid on any income from sale of excess electricity back to the grid or from ROCs by microgenerators.[83]
- In 2006 the Government announced that all new homes will be zero carbon by 2016. In the 2008 Budget announcements were made that all new public sector buildings will be zero carbon by 2018 and all other new non-domestic buildings will be zero carbon by 2019. Earlier announcements were for all new schools to be zero carbon by 2016.[83]
- There is an Energy Efficiency Loan Scheme for SMEs; this gives interest-free loans ranging from £5000 to £200,000 to energy efficiency projects.[199]
- Exemptions from the Climate Change Levy and business rates can be obtained for good quality CHP plants. Additionally there are increased capital allowances for equipment and plant.
- Ofgem is attempting to remove barriers to DG more widely.[261]

Export tariffs are now also available from the six main energy suppliers and others for excess electricity sold back to the grid.[83] Households producing electricity from microgeneration can now connect to a local network, without having to obtain permission from the distribution network operator.[262]

4.5.5 Barriers

Reasons given for constraining microgeneration in the UK include:

- Installation costs can be high.
- There is a lack of good quality information/awareness of microgeneration options.
- There are technical issues - installation is more complex than standard installations (e.g. a boiler).
- It is challenging to access incentives for generating electricity, due to a lack of information/awareness and lack of familiarity with new approval processes.
- Planning policy and building regulations.
- A lack of an accreditation scheme for installers and suppliers dissuades people from installing untried technologies.[253]

4.5.6 Challenges

Electricity distribution companies have encountered three main technical challenges in relation to whether the grid can cope with an increase in microgenerators exporting electricity:

- Managing power flows (so thermal ratings of circuits aren't exceeded).
- Voltage control (keep within statutory limits).
- System fault levels (remain within equipment rating).

The Institution of Engineering and Technology (IET) thinks that with the many different DG technologies being developed that it is possible that a large proportion of this generation could be connected to the grid at every voltage level. The size and direction of power flows in networks will also be less easy to predict with increased DG use than in the current centralised model. This would be a significant challenge to the national grid.[247] The Government and regulator have established the Distribution Working Group of the Electricity Networks Strategy Group to look at issues surrounding this and Ofgem have created the Registered Power Zone concept to research novel approaches to these challenges.[248]

'Accommodating Distributed Generation' written along with the UK's 2006 Energy Review stated that the network and market systems could easily cope with an 18% domestic penetration of microgeneration, as long as this happened gradually so networks could be upgraded in time.[263] However this does not appear to include community or SME DG. There may also be concerns if microgeneration occurs more quickly than this.

4.5.7 Predictions

In the medium to long term there are some groups who believe that DG will be the dominant role in electricity generation in the UK. Indeed the European Smartgrids Technology Platform sees DG having a significant role in its future networks vision.[264] UK incentives in the form of FITs from April 2010 and RHI from April 2011 are likely to stimulate the DG market in the UK (FIT levels are listed on DECC's Website).[225]

The view of the IET is that growth of DG in the UK will be driven mainly by the economics of competing energy generation technologies, with a number of scenarios possible. At one end DG technologies may be successful enough to start mass production and therefore their costs will drop dramatically, resulting in mass adoption. Alternatively DG technologies may not perform well enough or may remain too expensive for mass adoption. Then renewable generation could rapidly increase in scale (offshore wind) requiring connection to the national grid; this could stunt or diminish growth in DG.[247]

4.5.8 Health and safety risks and implications

These are well understood for the majority of renewable technologies (see renewables report – Section 4.4). The primary concern for distributed generation will be electrical safety in households, communities and small and medium-sized enterprises (SMEs), which will be generating electricity. Health and safety risks could be from inexperienced individuals or tradesmen installing, maintaining or operating DG technologies that export electricity into the National Grid or use the electricity locally. There may be issues around isolating these individuals from the electricity being generated on-site. As such there are potential issues around, skills, competence, accreditation, particularly in relation to electrical safety, but also in relation to other DG technologies such as ground source heat and biomass. For example, there have been incidents involving biomass boilers exploding.

4.5.9 Energy Storage

Large-scale storage of electricity enables power generated at low demand to be stored for use when demand is high. It is becoming much more important given the huge increases in UK wind energy planned because they do not generate electricity at a constant level. As such the levels of reserve and backup energy will need to increase.

Technologies Current and Planned

<u>Hydrogen (see below)</u>

<u>Battery Storage Technologies</u>
These include lead-acid, sodium-sulphur and related "Zebra" (high temperature), sodium-nickel-chloride and lithium-ion batteries. Currently a 34MW sodium-sulphur battery is being installed in at a wind farm in Japan. Smaller scale batteries such as lithium ion may become useful alongside microgeneration technologies. There are a number of lead acid battery storage

plants over 1MW operating in America and Germany. Lithium ion batteries have a good power density, but their cost and performance are not likely to be appropriate for very large battery storage. They may well be better suited to microgeneration technologies unless a step-change in their technology is achieved.[265 268]

Electric vehicles

Battery powered electric vehicles, which consume electricity from the grid, could also be used for the temporary storage of electricity. The electric vehicles could then be used as providers of standby energy. When required, this electricity could be made available again to the grid.[266]

In late February 2010 the UK announced a new project called "Plugged-In Places" led by the Office for Low Emission Vehicles (OLEV), which provides £30 million of funding for a network of electric vehicle hubs starting with London, Milton Keynes and the North East. Over the next 3 years more than 11,000 vehicle recharging points will be installed. A plug-In car grant was also announced, of up to £5000 towards the cost of purchasing a new electric vehicle from January 2011.[267]

Given this early government support for electric vehicles there is the potential for electric vehicles to be used as providers of standby energy for the National Grid in the UK in the near to medium future.

Flow-cell battery electricity storage consists of two salt solutions, which are charged and discharged. Flow cells have a few advantages over conventional batteries, as they are easily expandable and can be fully charged and discharged without problems. Although they have drawbacks compared to conventional batteries in that they have a lower efficiency and lower energy densities.[268] Most work has been done on vanadium-vanadium technology, which has been demonstrated at 4MW at a Japanese wind farm since 2005.[269] A 2MW vanadium flow battery for a wind farm in Ireland has been proposed but this project has fallen through.

Flywheels

Use of a rotating flywheel to take electricity from the grid and store it. Energy is released when needed by using the motor driving the flywheel as a generator, power is returned to the grid as the flywheel continues to rotate. TGT Energy has a flywheel system, which has been used by rail operators to control high currents on power networks.[270] Beacon Energy has installed a number of significant flywheel storage systems in the USA.

Supercapacitors

These store energy by using a supercapacitor to polarise an electrolytic solution so energy to store energy eletrostatically. They are low energy and high power storage systems and can be discharged very quickly and charged and discharged hundreds of thousands of times. Although they have low storage potential, so their use at transmission level is limited.[271] However, there is a substantial amount of research being done on supercapacitors in the UK under the Supergen Energy Storage consortium, including in relation to grid implementation and materials, so this may change in the near to medium future.[272]

Geological Storage Technologies

Compressed Air Energy Storage (CAES) uses energy to compress air, which is stored at high pressure underground in airtight underground caverns. This energy can be subsequently released and used to drive electricity generators or in prove the efficiency of gas-powered generators. Currently 110MW to 270MW installations exist worldwide. In March 2009 Gaeletric announced a plan to construct what is believed to be the UK's first CAES plant to store energy from wind turbines in caverns under County Antrim; construction will take 3 years.[273] However geographical locations for large-scale CAES are limited in the UK as most suitable sites are allocated for gas storage. Micro CAES systems are being researched and in the medium future could be widely used to support distributed generation power networks.[265]

Pumped Hydroelectricity

These are large scale, high energy and power systems, where two reservoirs of water are apart by a large difference in height. When demand is low and electricity is cheap water is pumped to the higher reservoir from the lower. Water is allowed to flow down through turbines when demand is high to generate electricity. There are installations in the UK with around 2800MW of pumped storage capacity the biggest is Dinorwig plant in Wales with 1728MW capacity. New large-scale construction is unlikely in the UK due to limits on their location because of geographical limit where they can be built. Smaller scale plants for microgeneration hold more promise.[265 268]

Barriers and Challenges

Large storage units have high upfront costs so will take many years to pay back. The efficiency of storage devices also varies between technologies at 50-80%. Conventional batteries are costly to maintain, as they must be replaced after a limited number of charge cycles.[268] Large energy storage technologies will also have to compete with Open Gas Cycle Gas Turbines[†††] and in the future Demand Side Management (DSM) technologies.[‡‡‡] There has been little in the way of government funding for energy storage technologies and private investment is unattractive due to the high initial costs and long pay back period (over 10 years).

Predictions

Existing energy storage technologies that are technologically proven and are capable of commercial deployment at >5MW are considered to be pumped-hydro, flywheels, CAES, some flywheels and the following battery types: lead acid, nickel cadmium and sodium sulphur. Hydrogen coupled with fuel cells could also be used as a stationary energy storage system, but it is more likely to be used as an energy carrier.[265]

Most large energy storage systems are modular, easy to site, quick to build, small and produce no emissions. The majority of observers think that in the future with rising prices of fuel and carbon trading credits, fossil fuel energy reserve will become uncompetitive so energy storage will become more economically attractive. Mass-production will also decrease the initial costs. However, without incentives there would need to be a very big increase in fossil fuel prices for energy storage technologies become financially viable.[268]

[†††] OGGTs provide a standing electrical reserve for the national grid. They have lower set-up costs, but their costs are rising rapidly with the increasing price of gas.

[‡‡‡] DSM technologies match energy supply to demand and could be mated with smart metering and communication to check pricing and supply. New domestic appliances that turn on and off (for short periods) such as water heaters and fridges and a mass roll out of smart meters would be required. Start up costs will be lower than storage, but will be slow to implement nationwide and may not be popular domestically due to the lifestyle alterations required.

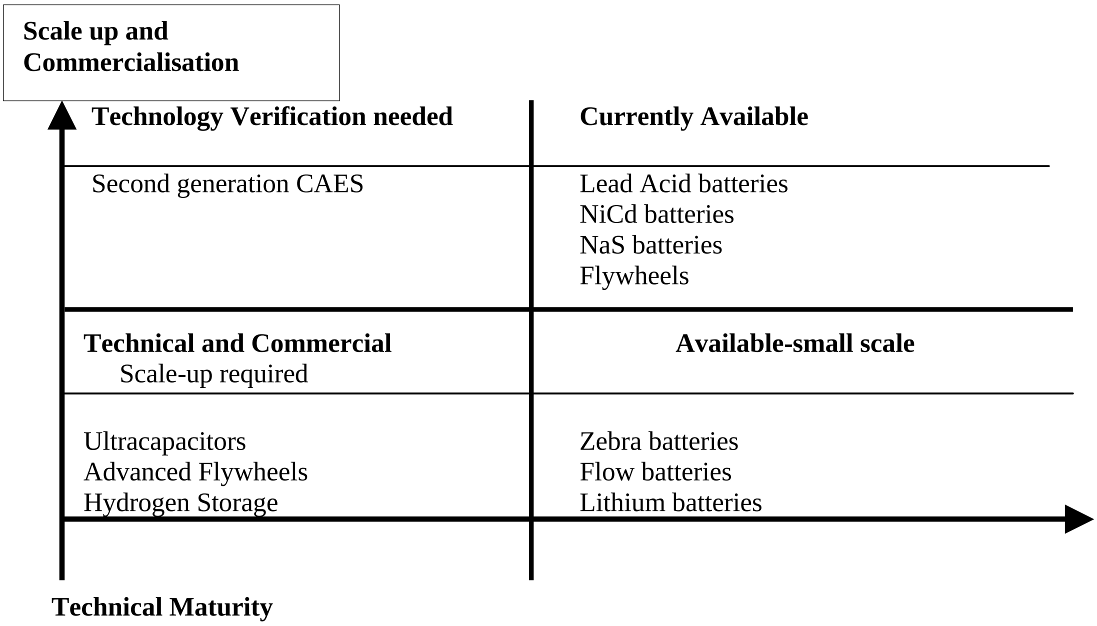


Figure 28 Scale-up, commercialisation and technical maturity of energy storage technologies[265]

Health and safety risks and implications

The primary concern with high voltage electrical storage technologies is electrocution risk. In the near to medium term there is likely to be increasing use of electrical storage technologies in the distributed generation and microgeneration areas. The concern will be electrical safety in households, communities and small and medium-sized businesses (SMEs), which will be generating electricity. Health and safety risks could be from inexperienced individuals or tradesmen installing, maintaining or operating electricity storage technologies that export electricity into the National Grid or for use locally. There may be issues isolating these individuals from the electricity being generated on-site for storage or to be exported to the grid. As such there are potential issues around, skills, competence, accreditation, particularly in relation to electrical safety. The estimated 48 million Smart meters to be installed in homes in the UK over the next 6 years will see an enormous increase in meter installers who will probably not all have electrical installer qualifications to the level of qualified domestic or light industry electricians and will therefore not be able to certify the connections between the householder system and the new meter. There are obvious areas of safety concern in blocks of flats sharing a common Smart meter, both in terms of access controls, and also the connection of a Smart meter to a number of different electrical installations with different maintenance contractors.

Other health and safety risks may come from the high temperature operation of sulphur and zebra batteries. CAES will have risks related to the integrity of pipelines and storage structures, and to the associated mechanical equipment. Flywheel technology may also have risks associated with rotating mechanical equipment.

Hydrogen

In its most likely future incarnation, the “Hydrogen Economy” is described in terms of a “Fuel Chain”, comprising the transformation of a primary energy source in order to generate hydrogen to feed Fuel Cells, which in turn provide power for a range of stationary or vehicle applications.[274]

A Hydrogen Fuel Cell (HFC) is an electrochemical device, which oxidises a hydrogen fuel releasing electricity. Most fuel cells use oxygen from the air and hydrogen from:

- cylinders of compressed gas,
- cryogenic liquid storage,
- metal hydride storage
- methanol
- reformed liquid petroleum gas (LPG)
- methane.[275]

The key stationary application foreseen for the hydrogen/fuel cell system is to provide Combined Heat and Power (CHP) for homes and businesses, either via centralised/distributed energy or through "microgeneration" of electricity (and heat) on site. The wide variety of primary energy sources, which include fossil fuels, solar, wind and wave power, nuclear and biomass make hydrogen very attractive as an "energy carrier" or "vector" in terms of enhancing the future security of energy supply.

Hydrogen can also be used to power vehicles by one of two methods: combustion in a modified internal combustion engine or by using a HFC stack to power an electric traction motor.

Current and Planned

Currently the gap between the state of hydrogen technologies and successful commercialisation is large. However there are a number of projects ongoing over the coming years, which may lead to an expansion in the hydrogen sector. Some examples include:

- The Cleaner Urban Transport for Europe trial (CUTE), which ran from December 2003 to January 2008; Transport for London (TfL) operated HFC powered buses in the centre of London. In 2010 five hydrogen buses will enter service in London, with potentially a further three buses, subject to EU funding.[276] There are plans to construct a hydrogen refuelling and maintenance facility in a First Group diesel bus depot in Waltham Forest London. The hydrogen, refuelling equipment and maintenance will be provided by Air Products.[277] Additionally a fleet of HFC London taxis will be rolled out by 2012, in association with Intelligent Energy.[278]
- Royal Mail are trialling a HFC post van for six months on the Isle of Lewis; designed and built by Microcab along with two hydrogen combustion vans. This project also involves post group PostEurop, FuelCellEurope and Cenex, who hope to use the trial to introduce a universal hydrogen post van design which will be presented to other European postal companies and then to vehicle manufacturers for consideration. It is hoped that this will stimulate mainstream construction of affordable hydrogen post vans.[279,280]
- ITM Power has a hydrogen-powered home in Sheffield, which is powered by an electrolyser (to produce hydrogen by splitting water) coupled with an internal combustion generator to produce electricity. This removes the need for a hydrogen pipeline infrastructure. In the short term ITM Power initially sees these electrolysers appearing at filling stations to power cars, before later domestic use.[281] The hydrogen can also be used in an internal combustion engine to power a modified Ford Focus car. If mass-produced the electrolyser could be available for a tenth of the current prototype cost of £20,000.[282]
- Intelligent Energy has a joint venture with Scottish and Southern energy to develop Combined Heat and Power HFCs for UK commercial and residential market.[283]

- Riversimple recently announced a HFC car (which uses ultracapacitors to store and release large amounts of energy quickly) that would be available on lease hopefully from 2013. In 2010 they aim to run 10 prototype cars in a UK city. BOC will supply the hydrogen filling stations and there are hopes that as cities adopt this technology, a nationwide network of stations will develop. The car designs are 'open source' to allow local manufacturing in small plants.[284]
- Major car manufacturers are trialling HFC vehicles. Mercedes is to lease 200 HFC cars in Europe and America from early 2010.[285] Suzuki have produced a HFC scooter called the Bergman, demonstrations will be rolled out soon, including the UK.[286] Honda has produced the FCX-Clarity, 10 of which were leased in Los Angeles in 2009. It plans to offer HFC cars at similar price to mid sized petrol cars by 2020.[287] Nissan is testing a new type of car fuel cell[288] and Hyundai are aiming to produce HFC cars by 2012.[289] BMW have loaned 100 Hydrogen 7 cars, which burn hydrogen in a combustion engine and some of these cars were used in London.[290] However BMW have, for now suspended plans for mass production of hydrogen cars.[291] Both Renault[292] and Ford[293] have stopped plans for hydrogen cars, concentrating instead on electric cars.
- A range of projects on hydrogen generation from various sources of biomass (plants, by-products and waste materials), are in progress at UK universities, including Glamorgan, who are running a number of pilot plants.[294] In October 2008 they opened the first hydrogen energy research centre in the UK, which uses solar PV for electrolytic hydrogen production, compression and storage and will soon be capable of hydrogen vehicle refuelling.[295]
- The University of Birmingham Fuel Cell Group has a number of pilot projects and demonstrations including a hydrogen filling station, a hydrogen-powered house, five Microcab vehicles to deliver university post, powered by HFCs and a HFC CHP device. They are also working on setting up a HFC supply chain in the UK.[296]
- Imperial College's Hydrogen and Fuel Cell Research Group who look primarily at the policy dimensions of fuel cell technologies.[297]
- The use of solar photovoltaic (PV) processes for the generation of hydrogen by electrolysis of water, as e.g. in the "Hydrogen Solar" company's "tandem cell" technology.[298]

Dependencies

Public incentives for hydrogen are limited. £7.2 million of funding for companies to develop hydrogen and fuel cell technologies has been previously supplied by DECC to the Low Carbon Knowledge Transfer Network.[299] But this is modest compared to the funding awarded to other alternative energy technologies.

Cenex has been set up with the help of BIS as the UK's Centre of Excellence for low carbon and fuel cell technologies. Its aims are to promote UK market development and competitiveness in low carbon and fuel cell technologies for transport applications. It runs a number of projects, including the Low Carbon Vehicle Procurement Programme and the Low Carbon Knowledge Transfer Network.[300]

The Policy Studies Institute has carried out horizon scanning activity on the Hydrogen Economy as part of its UK sustainable hydrogen energy consortium.[301]

Barriers and Challenges

The main problem with rolling out a national hydrogen network in the UK is the lack of an infrastructure for hydrogen. Companies are unwilling to invest in hydrogen cars and stationary equipment with no infrastructure in place and no indication of who will build it. Currently UK investment is modest and there has so far been less UK investment relating to hydrogen technology compared to other significant emerging energy sectors. Doubtless this will come to be reviewed along with other potential ‘green energy’ priorities. In any case, over the coming decade(s) the hydrogen outlook may change as petrol and other fossil fuels become increasingly expensive and domestic and EU carbon targets become harder to reach.

Health and safety risks and implications

There are implications for safety for aspects from all elements of the fuel chain from conversion of the primary energy source, through to possible transport, storage and delivery stages, to use of the hydrogen for electricity generation.

Hydrogen gas is flammable and easily forms an explosive mixture in air. There is a very wide range of hydrogen/air concentrations that will explode. Additionally, a very low ignition energy is needed to ignite a hydrogen/air mix. Methanol, which can be used directly by fuels cells, is highly flammable and toxic. LPG and methane, which can be converted into hydrogen using a high temperature catalytic reformer, often adjacent to the fuel cell, are also highly flammable.[275]

What is HSE doing?

Electrical hazards within fuel cell installations are from the 240 volts (v) mains supply and the electrical output of the fuel cell stack, this can be around 100-400v and 500 amps. The risks associated with the storage of hydrogen (under high pressure or cryogenically in liquid form) and its use in fuel cell applications, are well appreciated by HSE and work has been done on various aspects of the fire and explosion hazards at the Health and Safety Laboratory (HSL), for example comprehensive Guidance Notes: HSG 243 – “Fuel Cells, Understand the hazards, control the risks” and Research Report 715: “Installation Permitting Guidance for hydrogen and fuel cell stationary applications: UK version” have been issued.[302] HSL is also a member of “Hysafe” an EC funded Network of Excellence set up to facilitating the safe introduction of hydrogen technologies and applications and has contributed to their research.[303] International ISO standards for hydrogen car refuelling are being developed.

There may also be materials considerations of the pipelines and storage systems, relating to the use of cryogenic hydrogen, and gas permeability issues.[304] In the future it is possible that major infrastructure developments will be needed to distribute hydrogen either alone or mixed with natural gas (as “Hythane”), via existing or new pipeline networks and the risks and hazards associated with this approach will need to be considered.

The Future

Over the next 10 years or so the hydrogen sector in the UK is set to grow slightly given the number of hydrogen projects and demonstrations running or planned in the UK and Europe. There are likely to be only modest numbers of commercial HFC installations and vehicles in this time period.

4.6 CLEAN COAL TECHNOLOGIES

4.6.1 Background

Coal is the world's most important fossil fuel with about 6.5 billion tons used each year. This is expected to rise by more than 60 per cent by 2030. This has serious environmental implications because coal is highly polluting, generating more CO_2 per ton than any other major fossil fuel. There is, however, no ready alternative to coal, especially in power generation. When burnt, coal is the dirtiest of all fossil fuels but a range of methods, called clean coal technology (CCT), are being developed to reduce the environmental impact of coal-fired power stations. Carbon dioxide capture, described in Section 4.2 is a key clean coal technology and complements other clean coal technologies which aim to make coal burning more efficient, therefore reducing carbon dioxide output, and to reduce the quantities of other pollutants. These carbon abatement methods have proved technically feasible but have yet to be shown to be economically viable on a large scale.

The first CCT programs were set up in the late 1980s in response to concerns over acid rain. The programs focused on reducing emissions of sulphur dioxide (SO_2) and oxides of nitrogen (NOX), the primary causes of acid rain. Now the promise of "clean coal" technology is being used to promote coal as an energy source. "Clean coal" technologies are extremely expensive in terms of day-to-day running costs.[305] BP has claimed that CCS technology will not be commercial for at least ten years whereas gas offers the cheapest and quickest solution to cutting carbon emissions.[306]

Environmentalists believe that 'clean coal' is a contradiction in terms and focus on the environmental impact of coal extraction, the high cost to sequester carbon and the uncertainty of how to manage end result pollutants. Critics say that such power plants still release large amounts of pollutants compared to renewable energy sources, such as wind or solar power. Clean coal research could risk diverting investment away from renewable energy, which is available to reduce greenhouse gas emissions now. Greenpeace has been a major opponent, insisting such power stations would lock Britain into huge carbon emissions for decades and signal a surrender of Britain's long-term climate change targets. [306] [307] [308] Other green NGO's tend to be more pragmatic, recognising there is a global dependency on fossil fuels during the period to 2050 that world governments are unable to avoid.

4.6.2 Types of coal

There are many different types of coal, which determine different carbon-capture schemes and different technologies. Coal from certain areas of the world can contain twice the amount of energy as coal from other parts of the world. The amount of water, ash, carbon, and sulphur varies markedly in coal and all have an impact on the efficiency and economics of 'clean coal' plants than for more-conventional types of coal burning plants.[309] [310]

4.6.3 Coal production and energy security

The UK consumed 58.2 million tonnes of coal in 2008.[2] Imports of Russian coal amounted to about 38 per cent of the total burned in Britain with a further 20 per cent coming from Colombia, South Africa, Poland and Australia. In 2008 43m tonnes of coal were imported, mainly from Russia. Only 33 per cent of coal used in Britain is mined in Britain. There are in excess of 400 million tonnes of proven coal reserves identified, which at present extraction rates would last about 20 years.[311] British Coal presides over 90m tonnes of coal reserves yet is expected to close one of its four remaining sub-surface mines in 2010.[312] [313]

4.6.4 Clean coal technologies

'Clean coal technologies include, apart from carbon capture, chemically washing impurities from the coal, gasification, treating the flue gases with steam to remove sulphur dioxide, dewatering lower rank coals (brown coals) to improve the calorific quality and increasing efficiency of the conversion into electricity, coal bed methane and underground coal gasification.

Technologies currently in use or being developed include:

- **Supercritical Pulverised Coal Combustion (PCC):**[314] [315] [316] PCC is the most commonly used method in coal-fired power plants, and is based on many decades of experience. Units operate at close to atmospheric pressure, simplifying the passage of materials through the plant. Using high pressures and temperatures can increase the thermal efficiency of the plant from 35% to 45%, so reducing emissions, as less coal is used.

- **Fluidised Bed Coal Combustion (FBC):**[317] [318] allows coal combustion at relatively low temperatures, which reduces NOX formation. A sorbent is used to absorb sulphur.

- **Coal gasification:** coal is reacted with steam and air or oxygen under high temperatures and pressures to form Syngas (mostly carbon monoxide and hydrogen).[§§§] Syngas can be burnt to produce electricity or processed to produce fuels such as diesel oil. The first coal gasification electric power plants are now operating commercially in the United States and in other nations, and many experts predict that coal gasification will be at the heart of the future generations of clean coal technology. [319]

- **Integrated Gasification Fuel Cells (IGFC):**[319] a 'zero emission' technology under development that does away with the steam cycle. It uses hydrogen from coal gasification in a solid fuel cell to produce electricity.

- **Integrated Coal Gasification Combined Cycle (IGCC):**[320] [316] is the technology behind some experimental 'zero emission' projects. It is considered the most suitable technology for possible carbon capture and storage but less reliable than other options. In IGCC a gas turbine burns syngas to produce electricity. Exhaust heat from the turbine is used to produce steam to power a steam turbine. The Hatfield CCS project is based on IGCC.

4.6.5 Pollutants from coal burning

Burning coal produces a number of polluting emissions, which can be controlled, but then the resultant waste has to be disposed of. These include:

- **Particulate emissions**[321] [322] can be reduced by Electrostatic Precipitators (ESPs) and fabric filters. ESPs are most widely used. Flue gases are passed between collecting plates, which attract particles using an electrical charge.

[§§§] Syngas is primarily hydrogen and carbon monoxide, but can include other gaseous constituents the composition of which can vary depending upon the conditions in the gasifier and the type of fuel.

- **Nitrogen Oxide (NOX) emissions**[323] [324] can be reduced by Low-NOX Burners (LNB). These reduce the formation of NOX by controlling the flame temperature and the chemical environment in which the coal combusts. Selective Catalytic and Non-Catalytic Reduction (SCR/SNCR) are expensive and less widely used.

- **SO_2 emissions**[325] [326] [327] can be reduced by Flue Gas De-sulphurization (FGD). Wet FGD, or wet scrubbing, is most common and absorbs SO_2 using a sulphur-absorbing chemical (sorbent), such as lime.

- **Trace elements emissions**[328] [329] include mercury, cadmium and arsenic. Some emissions can be reduced by particulate controls, fluidised bed combustion and FGD equipment. Activated Carbon Injection is being trialled to remove mercury.

4.6.6 Clean coal in Britain

The Government has given the go-ahead for a new generation of coal-fired power plants but only if they can prove they can reduce carbon emissions.[330] Up to four new plants will be built if they are fitted with technology to trap and store CO_2 emissions underground. The technology is not yet proven and would only initially apply to 25 per cent of power stations' output. Green groups welcomed the move but said any new stations would still release more carbon than they stored. The 2009 Budget (see para 2.4.1) provided a new funding mechanism for at least two and up to four "demonstration" carbon capture and storage (CCS) projects. Subsequently it was indicated the UK funded demonstration projects will comprise the initial post combustion project and three others of which at least one will demonstrate pre-combustion technology. The terms of the three other demonstration projects are to be negotiated during 2010.

In January 2009, the first underground coal gasification licences were issued covering coalfields under the Firth of Forth.[331] [332] These reportedly cover more than 200 square miles and were previously unminable, lying 500 m or more below the surface. The aim is to use hydrogen gas produced by the underground gasification of the coal to feed fuel cells, and so generate electricity with water as the waste product. The extraction of hydrogen from the gas generated from the coal will allow the free capture of at least 99 per cent of the carbon dioxide also produced by the gasification process, which can then be stored.

Underground coal gasification is very simple in principle.[333] Coal is gasified in its seams underground, extracting just the gas and simultaneously extracting and processing the resource. This is done by drilling boreholes into the coal, and injecting mixtures of water and air or water and oxygen. The mixture plus the coal is ignited (through an ignition well) and the result is the burning of the coal, creating hydrogen-rich synthetic gas (syngas), which is extracted through a production well.

In practice, there are difficulties. These are associated with the leading-edge nature of the drilling and well completion technologies, with monitoring and therefore controlling the processes underground, and with handling contaminants of all kinds in the production stream. The drilling and production process, called Controlled Retractable Ignition Point (Crips),[334] uses the most recent long-reach and horizontal drilling and completion methods developed by the oil and natural-gas industry. The resulting syngas is separated into two streams by a process known as pressure swing absorption; one stream will be pure hydrogen, which will then feed the fuel cells, and the other stream will be pure carbon dioxide. In other applications, the syngas could also be used to directly fuel modified gas turbines, although it has only one-third of the calorific value of natural gas, or it could be turned into liquid fuels using Fischer-Tropsch processes.[332]

4.6.7 For the longer term future

BP is investing in a project to use bacteria that can turn coal into methane. The bacteria discovered a mile underground, are said to have unique enzymes that can break down coal producing methane. This could lead to an entirely new form of mining, where coal is infected with the bacteria, allowing methane to be harvested without digging up the coal. This discovery needs far more research and investment before it could be deployed on an industrial scale. If it works, however, the potential would be huge.[335] [336]

4.6.8 Is clean coal a myth?[337]

Many of the 'clean coal' technologies being promoted by the coal industry are still in the development stage and will need billions of dollars and many more years before they are commercially available. Only weeks after the Obama administration resurrected the clean coal Futuregen project,[338] two major power companies opted out. The demonstration coal plant was meant to work out the best way to capture and store carbon emissions using $1 billion of stimulus money. The project now faces an uncertain future with members moving on and lots of technical hurdles yet to be overcome.[339] The world's first clean coal power station prototype, based on gasification, is on target for 2012, with a 2017 date for a commercial version.[340] A 2007 report found that barriers to clean coal technology being embraced and pursued in Britain are not technical. The technology exists and has existed for some time. If the market is to genuinely embrace a competitive energy sector, which reduces CO_2 and maintains crucial base load energy provision, then it probably has to include clean coal.[341] This would be complementary to UK policy towards carbon capture and sequestration (see section 4.2) for both existing and new power plants.[330]

4.6.9 Implications for HSE

HSE is already aware of the health and safety implications of opening up new commercial mines and in the coal mining industry per se. The likelihood is also for increased coal imports, which would be transported to power stations by rail. New power plants would need to be sited close to rail centres or new rail track built specifically for new power plants. Some of the issues surrounding carbon capture and methane (hydrates) have already been raised in two Horizon scanning reports.[342] [343] The use of technology developed for the North Sea oil and gas industry for coal gasification raises other issues. The coalfields in question are deep and considered unminable either because they are under the sea,[****] far from the coast or not suitable for mining by conventional extraction methods. The technology surrounding underground gasification is also still emerging. There are developments in NE Australia (Queensland) but not yet on the potential scale and operational complexity of UK offshore deep coal seam developments[344] The extraction of syngas requires hydrogen transportation and storage, the issues relating to these have also been discussed on the HSE Horizon Scanning website 'Hydrogen Economy'.[345] Similarly the infrastructure for methane extraction, storage and transportation is not in place.

In terms of technology, the skills of the workforce to use this technology in this way may still be limited e.g. lack of experience of supercritical steam plants. Also the process safety hazards

[****] There have been a number of undersea coal mines near to the east coast in England and Scotland that were extensions of existing coal seams being worked from the land. The seams were evaluated using light drill ships (e.g. the Wimpey operated MV Geocore) but coal was not produced from off shore sites.

involved in adapting this technology to these new processes will need to be reviewed ands assessed. Neither is it certain as to how the Firth of Forth work[331] should be classified, onshore or offshore. Issues relating to offshore drilling and gas extraction are already known to HSE and may well be relevant for this emerging technology.

The pollutants (discussed above) from burning coal are already known to HSE. The ‘safe disposal’ of the waste products will be an issue for HSE to ensure environmental and public protection as well controlling exposure levels to the workforce.

4.7 INFRASTRUCTURE ISSUES

4.7.1 Introduction

Three Transmission Owners (National Grid in England and Wales and SP Transmission Limited and Scottish Hydro-Electric Transmission Limited in Scotland) and 14 Distribution Networks construct and operate the electricity grid under licence from Ofgem. This allows electricity to flow from where it is produced to where it is needed. National Grid also acts as 'system operator' ensuring the amount of electricity produced and consumed is balanced. Consumers then buy their electricity from electricity suppliers who are also private companies. The centralised power distribution system currently in place was developed alongside the large fossil fuel power plants, which supply 75 per cent of the UK's energy. It is unclear how it will operate with a renewable energy supply which is intermittent e.g. wind generation,[346] and which may be dispersed.

The trade body Renewables UK (originally the British Wind Energy Association, BWEA) estimates that in its present state, the UK electricity grid can only handle 1.5 GW of offshore wind power with a potential of a further 3 GW of offshore wind capacity by the end of the decade.[347] Improving the electricity grid to a sufficient state to be able to handle the UK's commitment to a 20% target by 2020 is estimated at £2.3 billion. The Renewables Innovation Review[348] sees grid upgrades as being on the critical path to delivering the 2010 targets. It states that 8-10 GW of new renewable transmission capacity will be needed by 2010, at a cost of £1,125 million. In addition, up to £601 million will need to be invested in distribution systems over the same period.

4.7.2 Wind power grid connections

The Government proposed, in 2009 new rules to revamp the way power plants are linked to the UK's power grid.[349] These are aimed at speeding up the process and helping renewable energy projects like wind farms to get realistic connection dates. Three options have been proposed to reform the previous system of projects getting a connection date on a first come, first served basis regardless of when they will start generating energy. The current system means that some wind farms are given grid connection dates years after they are due to start producing electricity. Some 17 gigawatts (GW) of generation capacity from renewable sources are currently waiting to be connected to the UK grid.

Three connect and manage models that look at different ways to manage the queue and to share the cost of connecting more plants to the system are proposed:

- Socialised: Costs will be shared between all users of the network.
- Hybrid: Targets some, but not all, of the additional constraint costs on new entrant power stations.
- Shared cost and commitment: Offers a choice to new and existing power stations to commit to the network in return for greater certainty over charges, or to opt out and be exposed to additional constraint costs.

Industry was given until November 2009 to comment on these proposals, which only applied currently to wind power. The industry's response came out in favour of the socialised model as most likely to contribute to the achievement of the UK's green energy targets.[350]

4.7.3 Wave and tidal grid connections

Grid connection remains a major challenge for offshore energy. 'The World Offshore Renewable Energy Report 2002-2008',[351] suggests that less than 3 per cent of marine energy is located in areas served by a strong grid. The UK networks have a finite capacity to transport electricity and particularly in Scotland and Wales, availability of connections are limited. This will require significant reinforcement of grid connections. The National Grid needs to invest heavily to bring about the amount of grid improvement needed for grid connection for wave or tidal device on the west coast of Scotland, the Pentland Firth and the Orkney islands, in order to reinforce the grid in remote areas of Scotland, which holds a large part of the UK's marine power potential. This investment is being driven by the needs of the wind industry, rather than the smaller wave and tidal sector. There are no major connections in the Pentland Firth, and National Grid's earliest offer of a connection is 2018.[352] If the schedule of planning and construction progresses well, the Grid will grant immediate advancement to earlier than 2015, if required. At present, National Grid has had few "contractual signals" that it needs to build additional transmission capacity for marine applications. Initially, marine power developers are required to pay an £80,000 application fee for a grid connection, followed by a security deposit during the construction phase of the development, which places a financial burden on smaller developers.[353] The Wave Hub tidal energy project off the coast of Cornwall has secured a £1m contract to have it connected to the national grid commencing in 2010.[354] The UK's Renewable Energy[39] and Low Carbon Industrial Strategies[38] provide for investment up to £60 million in UK marine energy infrastructure and technology. Subsea cabling can account for between 10-15% of project cost. The length of cable required each year will rise rapidly throughout the period, as a growing number of projects are increasingly large-scale and far offshore. As larger turbines are used, the spacing is increased and the cable length is greater. Available grid connections dictate the cable length to shore and in some cases several lower voltage cables will be used in place of a single large voltage one.[351]

4.7.4 Smart grids

In order to deal with the fluctuations in electricity generated from renewable sources as well as the fluctuations in electricity demand, more sophisticated control solutions, which make the UK networks even more 'smart' than they are today, are needed. Ofgem has set aside £500 million for a Low-Carbon Networks Fund to support large-scale trials of advanced technology, including smart grids. New commercial arrangements with customers have been included in Ofgem's initial proposals for the Fifth Distribution Price Control Review,[355] covering 2010-15. The fund is designed to help the networks to accommodate growth in local generation and other developments anticipated in a low-carbon economy. This will see annual bills increase by £4 per household to pay for the £6.5 billion needed to invest in the future power grid. Ofgem plan to start an overhaul of the ageing electricity grid to make it more localised using renewable forms of generation. Mini smart grids will be trialled in four "smart grid cities" in the UK that will be able to handle more unpredictable large volumes of power from intermittent/variable energy sources such as wind farms. The grids will also make it easier for households that have their own micro-generation, such as solar panels to supply electricity back to the grid. Smart Meters[††††] will be fitted in homes, which are better able to manage the demand from the unpredictable supply peaks resulting from renewable forms of energy generation.[356] [357] [358]

†††† Smart Meters are designed to improve information for electricity consumers in order to allow them to manage their energy use (and hence energy bills) more effectively and facilitate demand management, providing data to technologies in homes and buildings that can regulate electricity use (e.g. using electric devices when there is "surplus electricity" available on the system). See s. 4.5.9 above, subsection on 'H&S risks'

Many of the technologies to enable such capability are already available, e.g. communications but have not yet been integrated together in large-scale demonstrations. The actual mix that is deployed will depend on their feasibility.

4.7.5 HVDC grid connection

Offshore HVDC (High Voltage Direct Current)[359] [360] links provide an effective means of gathering remote offshore generation and, in the right circumstances, providing supplemental transmission capacity. However, they are normally point to point devices and have disadvantages compared to AC networks in their ability to harvest distributed generation, serve demand centres and to isolate faults without shutting down. In addition, HVDC links have very different availability characteristic compared to onshore transmission with cable fault repair times in the order of 3 to 6 months compared to normal return to service times for overhead lines of less than 24hours. They also have limited capacity compared to onshore 400kV overhead lines and are considerably more expensive on a £/MW basis. Consequently, offshore HVDC can be used in cases where particular circumstances justify its use, however it is less suitable to use as a general replacement for onshore AC transmission networks due to costs and maintenance.[361]

4.7.6 Connection with European grids

Inter connectivity allows for the import and export of electricity to offset peaks and troughs between the countries that are interconnected. The national grid system is already linked to France by a 2,000 (MW) HVDC interconnector. National Grid is to construct a new 260 kilometre (km), 1,000-megawatt electricity interconnector between the Netherlands and UK. The €600 million construction of the interconnector is expected to be commissioned by late 2010.[362]

The Scottish government is planning to establish an offshore grid network in the North Sea, as part of its aim to export electricity directly to Europe through an underground network of cables between itself, Norway, Sweden, Denmark, Germany and the Netherlands. The ‘super-grid' would potentially allow the easy transfer of renewable energy among northern European countries; however, plans for the proposed network preclude England.[363] The development of additional HVDC links (and possibly a European Grid) may materialize between 2020 and 2030 but the business case to support such an investment has yet to be established.[364] A Europe-wide electricity system would be able to balance variation in the renewable energy generated from solar in southern Spain, with wind, wave, and tidal resources from the north of Scotland.[365] [366] This would improve security of supply, decarbonise supply, provide protection from fossil fuel prices, and, given UK renewable energy export potential, optimise economic benefit.[367]

4.7.7 Influences on infrastructure development

National Grid estimates that, with a system combining wind and larger nuclear generating units that are currently connected to the transmission system, the UK’s Short Term Operating Reserve Requirement (STORR) would need to increase from 4GW to possibly 8GW(that is double), in order to meet the 2020 renewable energy target.[271] The existing and planned GB transmission system in terms of the electrical parameters of its components, its electrical and geographical structure and its planned development over the period to 2015/16 are described in ‘Operating the Electricity Transmission Networks in 2020’.[368] The proposed connection of a significant volume of new transmission contracted generation is in the Scottish Highlands area, substantially made up of wind farms. This depends on the completion of transmission reinforcements,[‡‡‡‡] including the proposed Beauly/Denny transmission reinforcement.[369] However, elements of this reinforcement are currently the subject of a Public Inquiry and, consequently, the final commissioning date may vary, which would impact on transmission system performance and capability. There remains a great deal of uncertainty over how electricity-operating margins (the difference between forecast demand and the available generation) will develop over the next decade.[370] This is due to uncertainty in underlying energy demand linked to economic activity, uncertainty over the growth rate of small-scale generation and uncertainty over the introduction and impact of energy efficiency measures. There is further uncertainty over the rate at which new generation can be constructed and how this can contribute once in operation. In order to assess future operating margins there will need to be a proposed working estimate of; the contribution of renewable generation flows across interconnectors, the required operating reserve and consumers' reaction to pricing.[371]

4.7.8 Gas infrastructure

Since the 1960's UK North Sea gas production provided self-sufficiency for the UK natural gas market with surpluses being exported. The decline of UK domestic gas production means the UK is now a net importer of gas.[372] Since 2006, the UK has received natural gas imports through new pipelines from Norway and the Netherlands.[373] [374] A relatively new development for the UK gas market is the volume import of natural gas in the form of Liquefied Natural Gas (LNG). A number of LNG import terminals are under construction, with two new large terminals in Wales[375] and further expansion at Isle of Grain near London.[376] Over time, LNG imports could account for 40-50 per cent of total UK supply. The composition of UK gas supply is therefore changing rapidly and import dependence will continue to grow. Currently gas imports from the Netherlands and Norway are largely sufficient to meet demand, however in the coming years reliance on LNG imports will increase. It is estimated that by 2020, 45-55% of UK gas will be imported. Qatar and Russia are the two biggest exporters of LNG. Two per cent of the UK's imported gas comes from Russia.[377] Algeria, Malaysia and Egypt also export to the UK. Over the ten-year forecast period, UK gas demand is projected to grow at a rate of just under 1% per annum. The main current key programme is the mains replacement programme, which requires all iron mains pipes to be replaced by 2030. There is still concern about an ageing infrastructure for gas transportation.[378]

4.7.9 Liquefied petroleum gas

Liquefied petroleum gas (LPG) is usually delivered to bulk distribution depots[376] and cylinder filling plants, by means of large bulk road tankers. From distribution depots, smaller delivery tankers carry out deliveries to domestic customers. One safety issue with LPG is that, unlike natural gas, it is heavier than air; therefore any leakage will result in the gas forming around the container instead of dispersing rapidly.

4.7.10 Hydrogen gas

The natural gas pipes to which most homes are now attached would need to be replaced by hydrogen pipes. These are about 50% wider, but otherwise the system is much the same. Based on current technology, the following generalizations can be made for hydrogen storage and transportation requirements: [379]

- Underground Storage - For large quantities of gas or long-term storage.

[‡‡‡‡] Sub Power stations, overhead cables etc.

- Liquid Hydrogen - For large quantities of gas, long-term storage, low electricity costs or applications requiring liquid hydrogen.
- Compressed Gas - For small quantities of gas, high cycle times or short storage times.
- Metal Hydrides - For small quantities of gas.
- Pipeline - For large quantities or long-distance power transmission.
- Liquid Hydrogen - For transport over long distances.
- Compressed Gas - For small quantities over short distances.
- Metal Hydride - For short distances.

4.7.11 Health and safety implications in distribution (see also s.4.5.9)

HSE is responsible for ensuring that those involved with the transmission, distribution and storage of natural gas comply with the relevant legislation. Though the numbers of major incidents have been low, there are potential hazards from these gas mains failures and HSE is working with Industry to mitigate the risks from these and major pipeline incidents. HSE has employed a rolling operational strategy to identify major gas safety issues and, where possible, improve existing standards.[378] The main issues surrounding gas infrastructure are already known by HSE, although HSE does not have additional resource capability to regulate sector expansion. The issues arising from the transportation and storage of LPG, LNG and hydrogen are still new but have been identified in two of HSE's Horizon Scanning reports.[343 345]

HSE is also familiar with the issues arising from the building of onshore plant, power cables, substations etc. The issue relating to wind farms on- and offshore marine renewables,[380] biomass,[381] and solar power[382] are discussed in the relevant HSE Horizon Scanning reports. One of the main issues for HSE will be the emergence of a newly skilled workforce who may have to operate in non-traditional environments e.g. offshore, coastal, remote areas, etc. not only for construction but also for repair and maintenance. Shift work and non-routine working practices are likely to be associated with these technologies, as they are with traditional power supply systems currently used.

5 CONCLUSIONS

This report provides a background to emerging energy technologies. This will be used primarily to inform the work of HSE's Emerging Energy Technologies programme, but may find wider application as an introduction to future energy technologies. The report has considered and summarised the drivers behind the emergence of new energy technologies, the political, legislative and social environment that encourages, enables and in some cases hinders progress towards a sustainable energy future.

It is clear that there is much work to be done before the UK can reach its emissions targets while at the same time meeting its energy needs. Some commentators doubt whether we can be successful in the timescales being set by the international community. This typifies the lack of consensus in the economy with regard to climate change issues. It is against a shifting background that HSE and others have to make decisions on, for example, future skills needs, guidance and resourcing.

HSE's role is to ensure that health and safety standards and regulation can be maintained in the energy sector as it evolves while at the same time avoiding imposing any unnecessary barriers to progress. It can best do this by anticipating possible energy futures and where possible preparing in advance for the emerging technologies. Therefore the energy scenarios examined in Chapter 3 will provide some assistance in this. Despite the difficulties that prevail in trying to predict the UK's energy mix over the coming decades, given the many uncertainties that exist, the scenarios give an idea of the range of possible outcomes.

Unsurprisingly, since 2020 is much closer, there is less variation between the 2020 various scenarios than between the 2050 scenarios. Nevertheless, there is no such thing as a typical 2020 scenario, but if a single example were required, then the LCTP Central scenario for primary demand of Figure 29. (This is a duplicate of Figure 4 from Chapter 3, reproduced here for convenience).

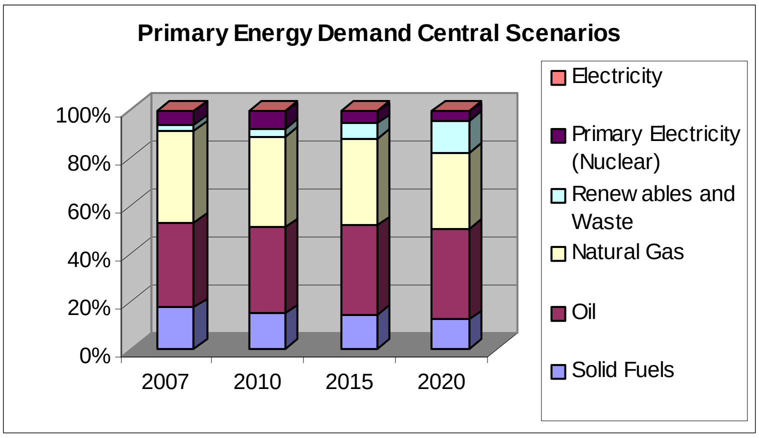


Figure 29 Primary energy demand central scenarios (%)

A range of possible primary energy mixes for 2050 is shown by the UKERC scenarios in Figure 30 (a duplicate of Figure 16 from Chapter 3, reproduced here for convenience).

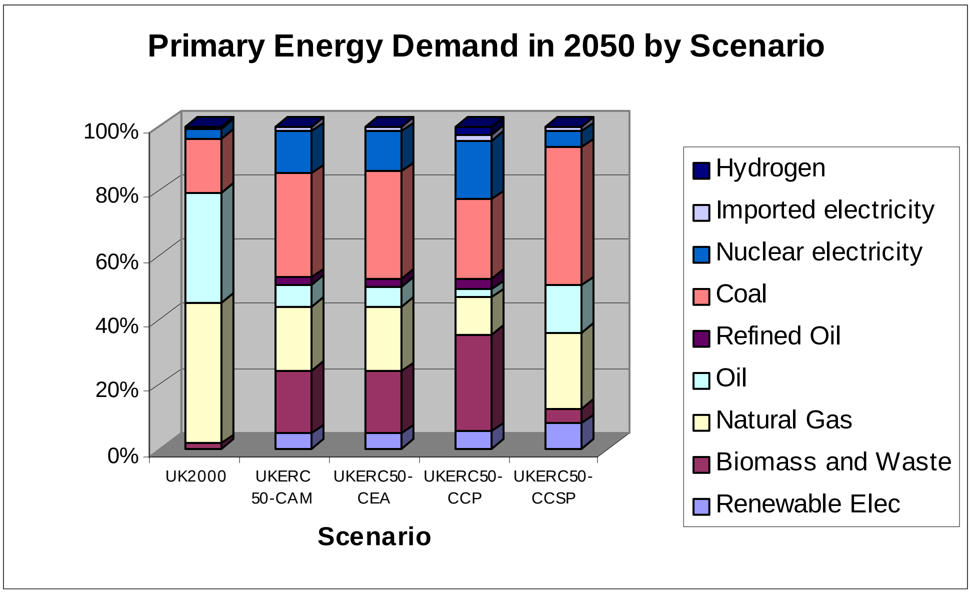


Figure 30 UKERC scenarios, primary energy demand 2050 (%)

The sections on the individual technologies presented in Chapter 4 give a brief description of the principles behind the technologies, their current usage and where available information on trends. In addition, brief descriptions of the potential health and safety hazards associated with the emerging technologies are given. Further work will be done on the technology areas by HSE specialists as the Emerging Energy Technologies programme progresses. They will examine health and safety issues in more detail, including the suitability of the existing regulatory regime and will identify where changes or enhancements need to be made.

APPENDIX 1 LEGISLATION AND POLICIES PROMOTING EMERGING ENERGY INITIATIVES

International

- The United Nations Framework Convention on Climate Change (UNFCCC)[4]
- Kyoto Protocol to the UN Framework Convention on Climate Change (1992)[5]
- The Kyoto Protocol, adopted in 1997[5]

European

- EU Emission Trading Scheme (EU ETS)[54]
- The Large Combustion Plant Directive (LCPD) (2001/80/E)[383]
- EU Green Paper " adaptation to climate change in Europe - options for EU action"[384]
- European Climate Change Programme[385]
- EU Sixth Environmental Action Programme (2002 - 2012)[13]
- EU Carbon Dioxide Storage Directive (2009/31/EC)[386]

United Kingdom

- Energy Review 2006[23]
- HSE Contribution to the Energy Review[24]
- Climate Change - The UK Programme 2006: Tomorrow's Climate Today's Challenge (HM Government, March 2006)[387]
- Policy Planning Statement 1 Delivering Sustainable Development (2005)
- UK Climate Projections (UK CIP '09)[388]
- UK Climate Change Committee (2008) 'Building a low-carbon economy – the UK's contribution to tackling climate change'[22]
- Health Effects of Climate Change in the UK 2008
- Climate Change Act 2008[25]
- Planning Act 2008[28]
- An update of the Department of Health Report 2001/2002[389]
- Environment Agency Climate Change Adaptation Strategy (2008-11)[390]
- Low Carbon Transition Plan 2009[27]
- Low Carbon Industrial Strategy 2009[38]
- Renewable Energy Strategy 2009[39]
- Road Transport Fuel Obligation

England

- Planning Policy Statement (PPS): Planning and Climate Change Supplement to PPS 1 (2007)[391]

Wales

- Wales Changing Climate: Challenging Choices: the Impact of Climate Changing in Wales 2020-2080[392]
- One Wales: A progressive agenda for Wales[393]
- Draft MIPPS on Climate Change (consultation 2007 and 2008)

- Environment Strategy for Wales[394]
- Climate Change Strategy (Consulted on - closed 22/2/09) [395]

Scotland

- Scottish Executive 'Changing Our Ways' Scotland's Climate Change Programme (2006)[396]
- Preparing for a Changing Climate: Second Consultation to Inform Scotland's Climate Change Adaptation Framework (2009)[397]
- Climate Change (Scotland) Bill[398]

Northern Ireland[§§§§]

- Preparing for Climate Change in Northern Ireland 2007[399]

[§§§§] Northern Ireland policy is included here as mainland Britain is a major exporter of energy to it.

APPENDIX 2 BODIES INVOLVED IN EMERGENT ENERGY TECHNOLOGY RESEARCH AND DEVELOPMENT

Technology Strategy Board

A business led non-departmental public body, which plays a cross-government leadership role in delivering a national technology strategy and advising on polices which relate to technology, innovation and knowledge transfer. It operates across various sectors of the UK economy to stimulate innovation in those areas, which offer the greatest scope for boosting Britain's growth and productivity. Website: http://www.innovateuk.org/

Energy Technologies Institute

A public-private partnership with leading international engineering and energy companies, investing in the development of low carbon energy technologies and solutions. It works by bringing more focus, ambition and collaboration to Britain's work in energy science. Website: http://www.energytechnologies.co.uk/Home.aspx

Carbon Trust

An independent company working to accelerate the move to a low carbon economy. As well as providing business and the public sector with support and expert advice, it works to cut future carbon emissions by developing new low carbon technologies through project funding and management, investment and collaboration and by identifying market barriers and practical ways to overcome them. Website: http://www.carbontrust.co.uk/Pages/Default.aspx

Research Councils

The public bodies which fund basic, strategic and applied research and related postgraduate training, mainly in the academic base, across the UK. These include:

- **The Engineering and Physical Sciences Research Council** (EPSRC) is the main UK government agency for funding research and training in engineering and the physical sciences, investing more than £800 million a year. Website: http://www.epsrc.ac.uk/default.htm

- **The Economic and Social Research Council** (ESRC) is the UK's leading agency for research funding and training in economic and social sciences. Website: http://www.esrc.ac.uk/ESRCInfoCentre/index.aspx

- **The Natural Environment Research Council** (NERC) delivers independent research; survey, training and knowledge transfer in the environmental sciences. Website: http://www.nerc.ac.uk/

Environmental Transformation Fund

Promotes business and public sector energy efficiency through investment in the development of low carbon energy technologies. It works through developing partnerships, funding, expert advice and large-scale demonstrations. The ETF is jointly administered by the Department for Food, Rural Affairs and the Environment and the Department for Business, Innovation & Skills (BIS). This fund invests in early stage research and development of low carbon technologies. The ETF is not open to direct funding requests, but schemes funded by the ETF are publicised when funding is available.
Website:
http://www.decc.gov.uk/en/content/cms/what_we_do/lc_uk/lc_business/env_trans_fund/env_trans_fund.aspx

Devolved Administrations and Regional Development Agencies

Promote regional economic development and growth, by investing in the capabilities of business and the knowledge base. Activities include supporting innovation through research and demonstration of new and emerging technologies and exploiting market and supply chain opportunities.
Websites:
http://www.direct.gov.uk/en/Governmentcitizensandrights/UKgovernment/Devolvedgovernment/index.htm; http://www.englandsrdas.com/

Sector Skills Councils (SSCs)

State-sponsored, employer-led organisations that cover specific economic sectors in the United Kingdom. Their remit is to: reduce skills gaps and shortages, improve productivity, boost the skills of their sector workforces and improve learning supply. Websites: http://www.sscalliance.org/

The UK Commission for Employment and Skills (UKCES)

Has a remit to raise UK prosperity and opportunity by helping to develop world-class employment and skills systems in all four UK nations. Website: http://www.ukces.org.uk/

The Skills Funding Agency

Replaces the Learning and Skills Councils and will be ultimately responsible for the allocation of funding to all post 19 educational institutions and employers, but not universities. Website: http://www.dius.gov.uk/~/media/publications/S/sfa_qa_for_employers

The Higher Education Funding Council for England (HEFCE)

Promotes and funds high-quality, cost-effective teaching and research, meeting the diverse needs of students, the economy and society. Website: http://www.hefce.ac.uk/

The Office of the Gas and Electricity Markets (Ofgem)

Promoting competition, wherever appropriate, and regulating the monopoly companies which run the gas and electricity networks.
Website: http://www.ofgem.gov.uk/Pages/OfgemHome.aspx

The Electricity Networks Strategy Group (ENSG)

Jointly chaired by the Department of Energy and Climate Change (DECC) and Office of Gas and Electricity Markets (Ofgem) and its broad aim is to identify, and co-ordinate work to help address key strategic issues that affect the transition of electricity networks to a low-carbon future. Website: http://www.ensg.gov.uk/

UK Innovation Investment Fund

Addresses the finance gap, which occurs before new technologies reach the marketplace, where companies have invested in research and development but where new revenue streams have yet to begin to be generated by sales. The Fund will invest in technology-based businesses with high growth potential, including in the low carbon area that require equity finance. Website: http://www.dius.gov.uk/innovation/ukiif

The BIOMASS Energy Centre (BEC)

Owned and managed by the UK Forestry Commission, to provide information, advice and guidance to UK individuals and organizations - signposting to other specialised sources of advice as necessary - on a wide range of biomass fuels and conversion technologies.
Website: http://www.dius.gov.uk/innovation/ukiif

The UK Business Council for Sustainable Energy brings together the key players in the energy sector to develop an effective dialogue with government that can help strengthen the UK's strategic agenda for sustainable energy. Website: http://www.bcse.org.uk/

The Clean Coal and Renewable Energy Programmes of the former Department of Trade & Industry DTI (now BIS).

The Department of Communities and Local Government (DCLG)
Website: http://www.communities.gov.uk/corporate/

The Department for Transport (DfT). Website: http://www.dft.gov.uk/

The Leverhulme Trust The Trust makes awards for the support of research and education emphasising individuals and encompassing all subject areas. Website: http://www.dft.gov.uk/

European Economic Community
http://www.direct.gov.uk/en/Governmentcitizensandrights/UKgovernment/TheUKandtheworld/DG_073417

European Research Fund for Coal and Steel (RFCS)
Supports research projects in coal and steel sectors. These projects cover: production processes; application, utilisation and conversion of resources; safety at work; environmental protection and reducing CO_2
emissions from coal use and steel production.
Website: http://ec.europa.eu/energy/research/coal_en.htm

The European Strategic Energy Technology Plan (SET-Plan) aims to contribute to the creation of the European Research Area in the domain of Energy.
Website: http://ec.europa.eu/energy/technology/set_plan/set_plan_en.htm

The FP7 Energy Work Programme focuses on research and demonstration actions that accelerate the development of cost-effective technologies for a more sustainable energy economy for Europe (and the rest of the world) and ensuring that European industry can compete successfully globally. Website: http://www.managenergy.net/fp.html

APPENDIX 3 TIMELINE TO 2020

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Power	Wind (onshore and offshore) produces over 4GW of power Government publishes a high level vision for a future smart grid Third round of leases for 25GW offshore wind sites awarded Shortlist of possible Severn Tidal schemes published Pay as you save pilots start	New planning regime under Infrastructure Planning Commission begins Anticipated first deployment of wave and tidal energy demonstration projects under the Marine Renewables Deployment Fund Reforms to the Renewables Obligation are introduced Government makes a decision on Severn Tidal scheme Government introduced new long-term grid access rules	Levy on electricity suppliers to fund CCS demonstration projects in place Commissioning of Wave Hub energy testing centre in Cornwall and first deployment of wave energy devices Expansion of wave and tidal energy testing sites in Northumbria and Orkney completed		The cap for the EU Emissions Trading System starts to be tightened every year from now The power sector starts paying for every tonne of carbon emitted by purchasing allowances in EU Emissions Trading System auctions Construction of first new nuclear power stations expected to be underway	First UK commercial scale carbon capture and storage demonstration intended to be operational Larger-scale wave and tidal energy generation (>10MW) starts to be deployed	The EU will have selected 12 carbon capture and storage demonstration projects for support across the EU			Plans show first new nuclear power station operational		**Around 30% of electricity is generated from renewable sources** Up to four carbon capture and storage demonstration projects operational in the UK
	2009	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
				4% of total energy (including power, heat and transport) to come from renewable sources		Over 5% of total energy from renewable sources		7.5% of total energy to come from renewable sources		Over 10% of total energy to come from renewable sources		15% of total energy to come from renewable sources
Workplaces and jobs	880,000 people work in the green sector Government provides £1.4 billion of targeted support for low carbon industries in the world. Central Government departments take on carbon budges for their own estate and operations.	Carbon Reduction Commitment introductory phase begins Central Government building will be 15% more efficient than in 1999/00	First sale of allowances for the Carbon Reduction Commitment for 2010 and 2011 in April New period for Climate Change Agreements begins		Emissions from large businesses and public sector become capped under the Carbon Reduction commitment Current Climate Change Agreements end		1.2m people could be working in the green sector Low carbon economy could be worth £150m a year in UK and £4.3bn a year globally The NHS expects to have reduced its carbon footprint by 10% compared to today	All new schools proposed to be zero carbon (subject to consultation and confirmation)	Climate Change Agreements extension to 2017 ends Carbon Reduction Commitment first capped Phase ends. Cap for second Phase set	New nuclear power stations could create or sustain up to 9000 jobs during the course of construction and operation (including supply chains) Carbon Reduction Commitment second capped phase starts Government ambition for all new public sector (non-domestic) buildings to be zero carbon (subject to further work)	Government ambition for all new non-domestic buildings to be zero carbon from this date (subject to consultation and confirmation)	

Source: Low Carbon Transition Plan, DECC 2009[27]

APPENDIX 4 ENERGY SCENARIO REPORTS

The following documents represent a range of energy reports that call on scenarios for their analysis of energy futures.

UKERC: Pathways to a Low Carbon Economy: Energy Systems Modelling Nov 2008
http://www.ukerc.ac.uk/Downloads/PDF/U/UKERCEnergy2050/281108UKERC2050PathwaysLowCarbonEconomy.pdf

Sinclair Knight Merz: Growth Scenarios for UK Renewables Generation and Implications for Future Developments and Operation of Electricity Networks BERR June 2008
http://www.berr.gov.uk/files/file46772.pdf

Are sustainable futures possible? Part III of a larger UN document
http://stone.undp.org/undpweb/seed/wea/pdfs/Chapter9.pdf

Bellona (Norway): How to Combat Global Warming: The Bellona Scenario
http://www.bellona.org/reports/How_to_Combat_Global_Warming

IEA: World Energy Outlook 2007 (Annual) Scenarios to 2030
http://www.worldenergyoutlook.org/2007.asp (600 pp)

Deloitte Touche: 2020 Vision 60pp 2007
http:/www.deloitte.com/dtt/article/0,1002,sid%3D2855%26cid%3D109003,00.html

Tyndall Centre: UK Electricity Scenarios for 2050 Nov 2003
http://www.tyndall.ac.uk/content/uk-electricity-scenarios-2050

Tyndall Centre: Decarbonising Modern Societies: Integrated Scenarios Processes and Workshops March 2006 http://www.tyndall.ac.uk/research/theme2/summary_t3_24.shtml

Tyndall Centre: Decarbonising the UK Energy for a Climate Conscious Future
http://www.**tyndall**.ac.**uk**/media/news/**tyndall_decarbonising_the_uk**.pdf

National Grid: Transporting Britain's Energy 2009: Development of Energy Scenarios
http://www.nationalgrid.com/uk/Gas/OperationalInfo/TBE/

World Energy Council: Deciding the Future: Energy Policy Scenarios to 2050 (2007)
http://www.worldenergy.org/documents/scenarios_study_online.pdf

DECC: Updated Energy and Carbon Emissions Projections 2008
http://www.berr.gov.uk/energy/environment/projections/recent/page26391.html

Millennium Project: 2020 Global Energy Scenarios http://www.millennium-project.org/millennium/scenarios/energy-scenarios.html

Foresight: Built Environment - Sustainable Energy
http://www.foresight.gov.uk/OurWork/ActiveProjects/SustainableEnergy/ProjectHome.asp

Foresight: Intelligent Infrastructure
http://www.foresight.gov.uk/OurWork/ActiveProjects/SustainableEnergy/ProjectHome.asp

Foresight: Energy for Tomorrow 2001
http://www.foresight.gov.uk/Energy/Energy_For_Tomorrow_Sep_2001.pdf

Foresight: Short Project How S&T could help us meet future energy challenges
http://www.foresight.gov.uk/Energy/Executive_Summary.pdf
Minienergy: project
http://www.foresight.gov.uk/OurWork/ActiveProjects/SustainableEnergy/Key%20Information/Energy.asp

Foresight: Review of Futures Studies by other Agencies
http://www.foresight.gov.uk/Energy/Review_of_Futures.pdf

APPENDIX 5 ENERGY SCENARIOS SUPPORTING DATA

The various scenario reports and other documents cited in this report use a variety of units of measurement:

Energy is quoted in this report in Joules (J), Watt hours (Wh) and tonnes of oil equivalent (toe)

The following prefixes can be used

kilo (k)	= 1,000	$= 10^3$
mega (M)	= 1,000,000	$= 10^6$
giga (G)	= 1,000,000,000	$= 10^9$
tera (T)	= 1,000,000,000,000	$= 10^{12}$
peta (P)	= 1,000,000,000,000,000	$= 10^{15}$
exa (E)	= 1,000,000,000,000,000,000	$= 10^{18}$

1 tonne of oil equivalent = 41.868 GJ or 11,630 kWh

1 GWh provides roughly the electricity for about 225 average UK houses for a year.

Table 1 Primary Energy Demand (Central Case) i.e. price, policy, growth all Central (Mtoe) from URN 09D/678 UK LCTP emissions projections (see Figure 3, main report)

	2007	***2010***	***2015***	***2020***
Solid Fuels	41	33	31	25
Oil	84	81	81	79
Natural Gas	91	86	79	66
Renewables and Waste	6	7	14	27
Primary Electricity (Nuclear)	14	16	11	8
Electricity	0	1	1	1
	236	224	217	205

Table 2 Shell scenarios primary demand in 2020 (EJ) (see Figure 5, main report)

	Blueprints 2020	***Scramble 2020***
Oil	3	3
Gas	4.2	4.1
Coal	1.4	1.8
Nuclear	0.7	0.6
Biomass	0.2	0.2
Solar	0	0
Wind	0.2	0.3
Other Renewables	0.1	0.1
	9.8	10

Table 3 Comparison of LCTP Central and Shell 2020 Scenarios for primary energy demand (%) (see Figure 7, main report)

	LCTP	Shell Blueprint	Shell Scramble
Solid Fuels	12.2	14.3	18
Oil	38.5	31	30
Natural Gas	32.2	43	41
Renewables and Waste	13.2	5	6
Primary Electricity (Nuclear)	3.9	7.1	6
Electricity	0.5		
	100.5	100.4	101

Table 4 Final Energy Demand (Central Case) Mtoe i.e. price, policy, growth all Central (Mtoe) from URN 09D/678 UK LCTP emissions projections (see Figure 8, main report)

	2007	2010	2015	2020
Electricity	29	27	28	28
Gas	51	51	47	42
Petroleum	70	65	64	62
Solid/manufactured fuels	3	2	2	1
Renewables	1	2	4	11
	155	147	145	145

Table 5 Comparison of final energy demand in 2020 from LCTP scenarios (Ktoe) (see Figure 10, main report)

	2007	CBC	CCC	HCC	LCC	CCH	CCL	LLH
Electricity	29402	32905	28384	28139	28840	28707	28247	29156
Gas	51370	49291	42048	41030	43632	42451	41884	44047
Petroleum	70083	68854	61718	59733	63044	62665	60891	64869
Solid/manuf fuels	2924	1920	1357	1360	1361	1396	1342	1399
Renewables	1228	2725	11040	10939	11102	11061	11022	10287
	155007	155696	144547	141201	147979	146279	143386	149757

Table 6 Electricity generation (Central Case) i.e. price, policy, growth all Central (TWh) from URN 09D/678 UK LCTP emissions projections (see Figure 12, main report)

	2007	2010	2015	2020
Coal (no CCS)	126	104	94	70
Coal (with CCS)	0	0	1	7
Oil	2	1	1	1
Gas	146	124	112	69
Nuclear	57	67	44	30
Renewables	20	25	60	115
Imports	9	9	13	13
Storage	4	3	3	3
	363	333	328	307

Table 7 Comparison of primary energy demand (PJ) in 2050 from UKERC scenarios (see Figure 15, main report)

	UK2000	*UKERC 50-CAM*	*UKERC50-CEA*	*UKERC50-CCP*	*UKERC50-CCSP*
Renewable Elec	20.0	284	281	299	488
Biomass and Waste	121.0	1142	1135	1648	279
Natural Gas	3907.0	1170	1181	613	1430
Oil	3039.0	386	364	134	894
Refined Oil	-298.0	128	138	188	0
Coal	1500.0	1888	1958	1343	2617
Nuclear electricity	282.0	764	719	997	308
Imported electricity	52.0	103	103	103	103
Hydrogen	0.0	0	0	139	0
	8623.0	5865	5879	5464	6119

Table 8 Shell scenarios primary demand in 2050 (EJ) (see Figure 17, main report)

	Blueprints 2050	*Scramble 2050*
Oil	0.9	1.5
Gas	2.6	2.9
Coal	1.1	2.2
Nuclear	0.9	0
Biomass	0.1	1.3
Solar	0.1	0.3
Wind	1.2	0.9
Other Renewables	0.7	0.5
	7.6	9.6

Table 9 Shell Blueprints scenario series for primary energy demand (EJ) (see Figure 19, main report)

	2005	*2020*	*2050*
Oil	3.4	3	0.9
Gas	3.7	4.2	2.6
Coal	1.7	1.4	1.1
Nuclear	1	0.7	0.9
Biomass	0.1	0.2	0.1
Solar	0	0	0.1
Wind	0	0.2	1.2
Other Renewables	0	0.1	0.7
	9.9	9.8	7.6

Table 10 Shell Scramble scenario series for primary energy demand (EJ) (see Figure 21, main report)

	2005	*2020*	*2050*
Oil	3.4	3	1.5
Gas	3.7	4.1	2.9
Coal	1.7	1.8	2.2
Nuclear	1	0.6	0
Biomass	0.1	0.2	1.3
Solar	0	0	0.3
Wind	0	0.3	0.9
Other Renewables	0	0.1	0.5
	9.9	10	9.6

Table 11 Comparison of final energy demand (PJ) in 2050 from UKERC scenarios (see Figure 15, main report)

	UK2000	*UKERC 50-CAM*	*UKERC50-CEA*	*UKERC50-CCP*	*UKERC50-CCSP*
Electricity	1176	1632	1640	1849	1528
Fuel Oil	220	78	78	74	82
LPG	52		0	0	0
Gas	2391	1148	1154	562	1317
Coal	75	2	2	2	131
Petrol	872	311	311	243	425
Diesel	1164	103	95	48	312
Jet Fuel	30	34	34	34	36
Hydrogen		138	114	136	279
Ethanol/Methanol		393	382	393	29
Biodiesels		338	403	582	12
Manufactured Fuel	75	3	3	3	3
Biomass	28	176	100	405	87
Heat	105	19	15	19	34
Others		0	0	0	0
	6188	4375	4331	4350	4275

Table 12 Comparison of electricity generation (PJ) in 2050 from UKERC scenarios (see Figure 25, main report)

	UK2000	*UKERC 50-CAM*	*UKERC50-CEA*	*UKERC50-CCP*	*UKERC50-CCSP*
Coal (without CCS)	336	0	0	0	0
Coal (with CCS)		816	846	576	1091
Gas (without CCS)	487	0	0	0	0
Gas (with CCS)		2	0	33	0
Nuclear	282	764	719	997	308
Oil	16	0	0	0	0
Hydro	17	31	31	31	16
Wind	3	189	186	205	407
Biowaste & others	26	38	38	38	38
Imports	52	103	103	103	103
Marine	0	64	64	64	64
Solar PV	0	0	0	0	0
Storage	0	0	0	0	0
	1219	2007	1987	2047	2027

GLOSSARY

AC	Alternating Current
BEC	Biomass Energy Centre
BIS	Department for Business, Innovation and Skills
BWEA	British Wind Energy Association
CAES	Compressed Air Energy Storage
CCC	Committee on Climate Change
CCL	Climate Change Levy
CCS	Carbon Capture and Storage (or Sequestration)
CCT	Clean Coal Technology
CDM	Clean Development Mechanism
CdTe	Cadmium telluride
CEN	European Committee for Standardisation
CERT	Carbon Emissions Reductions Target
CHP	Combined Heat and Power
CIGS	Copper Indium Gallium Selenide
COMAH	Control of Major Accident Hazards Regulations
DECC	Department for Energy and Climate Change
Defra	Department for the Environment, Food and Rural Affairs
DG	Distributed Generation
DSM	Demand Side Management
EC	European Community
EDF	Électricité de France
EEPR	European Energy Programme for Recovery
EET	Emerging Energy Technologies
EGS	Enhanced Geothermal Systems
EIB	European Investment Bank
ENSG	Energy Networks Strategy Group
EST	Energy Saving Trust
ETS	Emissions Trading System
EU	European Union
EU Skills	Energy and Utility Skills
FEED	Front End Engineering Design
Final Energy Demand	Energy usage in terms of the form in which it is used (e.g. electricity)
FIT	Feed In Tariff
FBC	Fluidised Bed Combustion
Fuel Poverty	Where a household cannot afford to keep adequately warm at reasonable cost. In the UK Fuel Poverty is said to occur when in order to heat its home to an adequate standard of warmth (21 degrees centigrade main living room, 18 degrees elsewhere in daylight hours, lower at night) a household needs to spend more than 10% of its income on total fuel use.
GDP	Gross Domestic Product
GHG	Green House Gas
GW	Gigawatt (see Appendix 5)
HE	Higher Education
HEFCE	Higher Education Funding Council for England
HVDC	High Voltage Direct Current
HSE	Health and Safety Executive
HSL	Health and Safety Laboratory
IET	Institution of Engineering and Technology
IGFC	Integrated Coal Gasification Combined cycle

IT	Information Technology
JI	Joint Implementation
KPMG	A global network of independent professional companies
KWh	Kilowatt hour (see Appendix 5)
LCBP	Low Carbon Buildings Programme
LCEA	Low Carbon Economic Area
LCTP	Low Carbon Transition Plan
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MARKAL	Market Allocation Model
MCS	Microgeneration Certification Scheme
MED	MARKAL Elastic Demand Model
MRPF	Marine Renewables Proving Fund
$MtCO_2e$	Metric tons carbon dioxide equivalent (see Appendix 5)
MW	Megawatt (see Appendix 5)
MWh	Megawatt Hour (see Appendix 5)
OCC	Office of Climate Change
Ofgem	Office of the Gas and Electricity Markets
ORED	Office for Renewable Energy Deployment
OTEC	Ocean Thermal Energy Conversion
Primary Energy Demand	Energy usage in terms of original source
PCC	Pulverised Coal Combustion
PVC	Photovoltaic Cell
RDA	Regional Development Agency
RHI	Renewable Heat Incentive
ROC	Renewables Obligation Certificate
SEA	Strategic Environmental Assessment
SP	Scottish Power
SSC	Sector Skills Council
SME	Small and Medium Enterprises
STORR	Short Term Operating Reserve Requirement
STP	Solar Thermal Power
TSB	Technology Strategy Board
TWh	Terawatt Hours
UKCES	UK Commission for Employment and Skills
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change

REFERENCES

[1] BP, 2009. *BP Statistical Review of World Energy*. [Online]
Available at: Hhttp://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2008/STAGING/local_assets/2009_downloads/statistical_review_of_world_energy_full_report_2009.pdf

[2] Department of Energy and Climate Change, 2009. Digest of United Kingdom Energy Statistics (DUKES) 2009 edn. [Online]
Available at: Hhttp://www.decc.gov.uk/en/content/cms/statistics/publications/dukes/dukes.aspx

[3] Platt, 2010. Russia dismisses competition from western European shale gas. EU Energy, p24. [Online] Available at: Hhttp://www.tilburguniversity.nl/tilec/admin/website/weekly/LeighHancher_article_EUEnergy.pdf

[4] United Nations, 1992. United Nations Framework Convention on Climate Change. [Online] Available at: Hhttp://unfccc.int/essential_background/convention/items/2627.php

[5] United Nations, 1997. Kyoto Protocol. [Online]
Available at: Hhttp://unfccc.int/kyoto_protocol/items/2830.php

[6] Keily, K., 2009. Senators rally across party lines to fight climate change. USA Today, 16 December. [Online]
Available at: Hhttp://www.usatoday.com/news/washington/2009-12-15-senate-climate-change_N.htm

[7] Tollefson, J., 2009. Developing nations tackle climate. Nature News, [Online]. 460, pp 158-159. Available at: Hhttp://www.nature.com/news/2009/090708/full/460158a.html

[8] Hewitt, G., 2009. Copenhagen's climate change battle. BBC News, [Online] 30 October. Available at: Hhttp://www.bbc.co.uk/blogs/thereporters/gavinhewitt/2009/10/copenhagens_climate_change_bat.html

[9] Taylor, P., 2009. EU looks lonely on climate high ground. Reuters [Online] 2 November. Available at: Hhttp://blogs.reuters.com/columns/2009/11/02/eu-looks-lonely-on-climate-high-ground/?p=1242?tempedition=debatehub

[10] United Nations Framework Convention on Climate Change, 2009. Copenhagen Accord. Draft decision -/CP.15. [Online] Available at: Hhttp://unfccc.int/resource/docs/2009/cop15/eng/l07.pdf

[11] MacKenzie, K., 2010. Key points from the BASIC Copenhagen Accord meeting. Financial Times, 25 January. [Online] Available at: Hhttp://blogs.ft.com/energy-source/2010/01/25/key-points-from-the-basic-copenhagen-accord-meeting/

[12] Vidal, J., 2010. Fifty-five countries pledge to cut greenhouse emissions. The Guardian, 2 February. [Online] Available at: Hhttp://www.guardian.co.uk/environment/2010/feb/02/55-countries-greenhouse-emissions-pledge

[13] European Commission, 2002. Sixth Environment Action Programme of the European Community. [Online]
Available at: Hhttp://ec.europa.eu/environment/newprg/index.htm

[14] European Parliament, 2009. Directive 2009/29/EC of the European Parliament and of the Council of 23 April 2009 amending Directive 2003/87/EC so as to improve and extend the greenhouse gas emission allowance trading scheme of the Community (Text with EEA relevance). [Online] Available at: Hhttp://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32009L0029:EN:NOT

[15] Pop, V., 2009. EU's Energy Policy a Big Failure'. Business Week, [Online]

Available at: Hhttp://www.businessweek.com/globalbiz/content/jun2009/gb2009061_310444.htm?chan=top+news_top+news+index+-+temp_global+business

[16] European Commission, 2009. EU External Energy Policy. [Online]
Available at: Hhttp://ec.europa.eu/external_relations/energy/index_en.htm

[17] European Union, 2006. Green Paper: A European strategy for sustainable, competitive and secure energy. [Online]
Available at: H http://europa.eu/legislation_summaries/energy/european_energy_policy/l27062_en.htm

[18] Council of the European Union, 2007. Brussels European Council 8/9 March 2007, Presidency Conclusions, Annex 1. [Online]
Available at: Hhttp://register.consilium.europa.eu/pdf/en/07/st07/st07224-re01.en07.pdf

[19] Power-Technology.com, 2009. Is the EU's Energy Policy Secure Enough for Supplies? [Online]
Available at: Hhttp://www.power-technology.com/features/feature57117

[20] Kemfert, C. The EU energy and climate objectives: a combination of market economy and regulatory policy. Does it make sense? European Energy Review. [Online]
Available at: Hhttp://www.europeanenergyreview.eu/site/pagina.php?id=35

[21] Parliamentary Office of Science and Technology, 2008. The Transition to a Low Carbon Economy. Postnote 318, December. [Online]
Available at: Hhttp://www.parliament.uk/documents/upload/postpn318.pdf

[22] Committee on Climate Change, 2008. Building a low-carbon economy- the UK's contribution to tackling climate change. [Online] December.
Available at: Hhttp://www.theccc.org.uk/pdf/TSO-ClimateChange.pdf

[23] Department for Trade and Industry, 2006. The Energy Challenge. [Online]
Available at:
Hhttp://www.decc.gov.uk/en/content/cms/publications/energy_rev_06/energy_rev_06.aspx

[24] Health and Safety Executive, 2006. The Health and Safety Risks and Regulatory Strategy Related to Energy Developments. [Online] 28 June.
Available at: Hhttp://www.hse.gov.uk/consult/condocs/energyreview/energyreport.pdf

[25] Department for Trade and Industry, 2007. Meeting the Energy Challenge. [Online]
Available at:
Hhttp://www.decc.gov.uk/en/content/cms/publications/white_paper_07/white_paper_07.aspx

[26] HMSO, 2008. Climate Change Act 2008. [Online]
Available at: Hhttp://www.opsi.gov.uk/acts/acts2008/pdf/ukpga_20080027_en.pdf

[27] Department of Energy and Climate Change, 2009. The UK Low Carbon Transition Plan. [Online]
Available at: Hhttp://www.decc.gov.uk/en/content/cms/publications/lc_trans_plan/lc_trans_plan.aspx

[28] HMSO, 2008. Planning Act 2008. [Online]
Available at: Hhttp://www.opsi.gov.uk/acts/acts2008/pdf/ukpga_20080029_en.pdf

[29] Government Office of CCS at DECC [Online].Available at:
Hhttp://www.decc.gov.uk/en/content/cms/what_we_do/uk_supply/energy_mix/ccs/occs/occs.aspx

[30] HM Treasury, 2006. Stern Review: The Economics of Climate Change. [Online]
Available at: Hhttp://www.hm-treasury.gov.uk/stern_review_report.htm

31 House of Lords, 2008. Select Committee on Economic Affairs, 4th Report of Session 2007-08, The Economics of Renewable Energy. [Online]
Available at: Hhttp://www.publications.parliament.uk/pa/ld200708/ldselect/ldeconaf/195/195i.pdf

32 Cline, W.R., 2008. Comments on the Stern Review. Peterson Institute for International Economics, 5 January. [Online]
Available at: Hhttp://www.iie.com/publications/papers/paper.cfm?ResearchID=874H Check

33 Department for Business, Enterprise and Regulatory Reform, 2008. Growth Scenarios for UK Renewables Generation and Implications for Future Developments and Operation of Electricity Networks. Report URN/06/1021, Sinclair, Knight Merz. [Online]
Available at: http://www.berr.gov.uk/files/file46772.pdf

34 Diaz-Rainey, I. and Ashton, J. K. 2008. Stuck Between a ROC and a Hard Place? Barriers to the Take-Up of Green Energy in the UK. Energy Policy, Vol. 36, No. 8, pp. 3043-3051. Available at SSRN: Hhttp://ssrn.com/abstract=1030326

35 Department for Trade and Industry, 2006. Renewable Energy Awareness and Research. [Online]
Available at: Hhttp://www.berr.gov.uk/files/file29360.pdf

36 Department for Business, Innovation and Skills, 2009. Investing in a Low Carbon Britain. [Online]
Available at: Hhttp://interactive.bis.gov.uk/lowcarbon/vision/

37 Department for Business, Enterprise and Regulatory Reform, 2009. Building Britain's Future: New Industry, New Jobs. [Online]
Available at: Hhttp://www.dius.gov.uk/~/media/publications/N/new_industry_new_jobs

38 Department for Business, Enterprise and Regulatory Reform, 2009. The Low Carbon Industrial Strategy [Online]
Available at:
Hhttp://www.berr.gov.uk/whatwedo/sectors/lowcarbon/lowcarbonstrategy/page50105.html

39 Department of Energy and Climate Change, 2009. The UK Renewable Energy Strategy. [Online]
Available at:
Hhttp://www.decc.gov.uk/en/content/cms/what_we_do/uk_supply/energy_mix/renewable/res/res.aspx

40 Department for Environment, Food and Rural Affairs, 2008. Building a Low Carbon Economy; Unlocking Innovation and Skills. [Online]
Available at: Hhttp://www.defra.gov.uk/environment/business/innovation/commission/pdf/cemep-response.pdf

41 DECC Industrial strategy for CCS in the UK. [Online]
Available at:
Hhttp://www.decc.gov.uk/en/content/cms/what_we_do/uk_supply/energy_mix/ccs/occs/occs.aspx

42 Office for Gas and Electricity Markets. Renewables Obligation [Online]
Available at:
Hhttp://www.ofgem.gov.uk/Sustainability/Environment/RenewablObl/Pages/RenewablObl.aspx

43 Renewable Energy Foundation, 2004. 2005-2006 Review of the Renewables Obligation. [Online]
Available at: Hhttp://www.ref.org.uk/Files/ref.response.ro.review.28.10.04.pdf

44 Scottish and Southern Energy, 2009. Memorandum [Online]
Available at:
Hhttp://www.publications.parliament.uk/pa/cm200809/cmselect/cmworpen/memo/fuel/uc0202.pdf

[45] Friends of the Earth, 2008. Briefing Note: What is a feed-in tariff and why does the UK need one to support renewable energy? [Online]
Available at: Hhttp://www.foe.co.uk/resource/briefing_notes/feedin_tariff.pdf

[46] HM Revenue and Customs. Climate Change Levy – Introduction. [Online]
Available at:
Hhttp://customs.hmrc.gov.uk/channelsPortalWebApp/channelsPortalWebApp.portal?_nfpb=true&_pageLabel=pageExcise_InfoGuides&propertyType=document&id=HMCE_CL_001174

[47] Hetherington, K. and Wilde, J., 2004. Conclusions of the Renewables Innovation Review. [Online]
Available at: Hhttp://www.carbontrust.co.uk/NR/rdonlyres/38D313DE-8FAC-4862-B1C8-67C78828CF4B/0/renewable_innovations_review.pdf

[48] Department of Energy and Climate Change, 2010. Cash Rewards for Low Carbon Electricity and Heating. Press Release, 1 February. [Online]
Available at: Hhttp://www.decc.gov.uk/en/content/cms/news/pn10_010/pn10_010.aspx

[49] HM Treasury, 2009. Budget 2009, Building Britain's Future. [Online]
Available at: Hhttp://www.hm-treasury.gov.uk/bud_bud09_index.htm

[50] Department of Energy and Climate Change, 2009. A framework for the development of clean coal: consultation document. [Online]
Available at: Hhttp://www.hm-treasury.gov.uk/bud_bud09_index.htm

[51] Building Research Establishment, Community Sustainable Energy Programme. [Online]
Available at: Hhttp://www.communitysustainable.org.uk/

[52] Department of Energy and Climate Change, Low Carbon Buildings Programme. [Online]
Available at: Hhttp://www.lowcarbonbuildings.org.uk/home/

[53] European Commission, 2009. EC launches call for proposals under Energy Programme for Recovery. [Online]
Available at: Hhttp://euroalert.net/en/news.aspx?idn=8764

[54] European Commission, Emission Trading System. [Online]
Available at: Hhttp://ec.europa.eu/environment/climat/emission/citl_en.htm

[55] Pew Center on Global Climate Change, 2003. Press Release: U.S. Technology and Innovation Policies: Lessons for Climate Change. [Online] 19 November.
Available at: Hhttp://www.pewclimate.org/press_room/sub_press_room/november19.cfm

[56] HM Government, 2009. Press Release, North East is UK's first Low Carbon Economic Area. [Online] 20 July.
Available at:
Hhttp://www.hmg.gov.uk/buildingbritainsfuture/news/news_archive/20_july_2009_north_east_uk's_first_low_carbon_economic_area.aspx

[57] Department of Energy and Climate Change, 2009. Carbon Budgets [Online]
Available at:
Hhttp://www.decc.gov.uk/en/content/cms/what_we_do/lc_uk/carbon_budgets/carbon_budgets.aspx

[58] Macalister, T. and Adam, M., 2009. Warning over renewables as economic crisis leaves funding gap. The Guardian, 21 March. [Online]
Available at: Hhttp://www.guardian.co.uk/environment/2009/mar/21/renewable-energy-economic-crisis

[59] KPMG, 2008. Turning up the Heat. [Online]
Available at:
Hhttp://www.kpmg.com/Global/en/IssuesAndInsights/ArticlesPublications/Documents/Turning-up-the-heat.pdf

[60] REN21, 2009. Renewables Global Status Report 2009 Update. [Online]
Available at: Hhttp://www.ren21.net/pdf/RE_GSR_2009_update.pdf

[61] Macalister, T., 2009. Green lobby and nuclear groups clash over role of renewable energy. The Guardian, 16 March. [Online]
Available at: Hhttp://www.guardian.co.uk/business/2009/mar/16/nuclear-power-renewables-edf

[62] Vidal, J., Macalister, T. and Jowitt, J., 2009. Budget 2009: £1.4bn package to create low-carbon economy is inadequate, campaigners say. The Guardian, 22 April. [Online]
Available at: Hhttp://www.guardian.co.uk/uk/2009/apr/22/budget-low-carbon-economy

[63] Smith, A., 2007. Emerging in between: the multi-level governance of renewable energy in the English regions. SPRU Electronic Working Papers Seriess, no 159, University of Sussex. [Online]
Available at: Hhttp://www.sussex.ac.uk/spru/documents/sewp159.pdf

[64] Wicks, M., 2005. Renewable Energy. Hansard, House of Commons, 21 July. [Online]
Available at:
Hhttp://www.publications.parliament.uk/pa/cm200506/cmhansrd/vo050721/wmstext/50721m13.htm

[65] Lean, G., 2009. 'Green revolution' could create 400,000 jobs, claim ministers. The Daily Telegraph, 4 July. [Online]
Available at: Hhttp://www.telegraph.co.uk/earth/earthnews/5734229/Green-revolution-could-create-400000-jobs-claim-ministers.html

[66] Newman, N., 2009. The true cost of going green: who will foot the bill for renewable energy? The Institution for Engineering and Technology, 21 July. [Online]
Available at: Hhttp://kn.theiet.org/magazine/issues/0913/costs-of-going-green-0913.cfm

[67] Ault, G., Elders, I., McDonald, J., Burt, G. and Tumilty, R., 2006. Electricity Network Scenarios for 2020. Electricity Networks Strategy Group. [Online]
Available at: Hhttp://www.ensg.gov.uk/assets/dwg_pg1-p01_scenarios.pdf

[68] National Grid, 2009. Transporting Britain's Energy 2009: Development of Energy Scenarios. Report. [Online]
Available at: Hhttp://www.nationalgrid.com/uk/Gas/OperationalInfo/TBE/

[69] European Commission, 2009. Regulation of the European Parliament and of the Council concerning measures to safeguard security of gas supply and repealing Directive 2004/67/EC. [Online] Available at: Hhttp://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2009:0363:FIN:EN:PDF

[70] Keenan, R., 2009. Port Hedland Ore Exports Gain 14% as China buys more. Bloomberg.com, 8 September. [Online]
Available at: Hhttp://www.bloomberg.com/apps/news?pid=20601081&sid=aMZ48vOWQY24

[71] Lord, R.A., Atkinson, J., Scurlock, J.M.O., Lane, A.N., Rahman, P.K.S.M., Connolly, H.E and Street, G., 2007. Biomass, Remediation, Re-generation (Bioregen Life Project): Reusing Brownfield Sites for Renewable Energy Crops. Proceedings of the 15th European Biomass Conference. [Online]
Available at: Hhttp://www.bioregen.co.uk/file_download/3

[72] The Institution of Engineering and Technology, 2008 . Evidence to the House of Lords Economic Affairs Committee Inquiry into the Economics of Renewable Energy, 16 June. [Online]
Available at: Hhttp://www.theiet.org/publicaffairs/submissions/sub802.pdf

[73] House of Commons, 2008. Innovation, Universities, Science and Skills - Fifth Report. Select Committee report, 11 June, Chapter 9, Skills. [Online]
Available at: Hhttp://www.publications.parliament.uk/pa/cm200708/cmselect/cmdius/216/21612.htm

[74] Department for Environment, Food and Rural Affairs; Department for Business, Innovation and Regulatory Reform, 2007. Commission on Environmental Markets and Economic Performance. Report. [Online]
Available at: Hhttp://www.defra.gov.uk/environment/business/innovation/commission/pdf/cemep-report.pdf

[75] Department for Culture Media and Sport; Department for Business, Innovation and Skills, 2009. Digital Britain. Report. [Online]
Available at: Hhttp://www.culture.gov.uk/images/publications/digitalbritain-finalreport-jun09.pdf

[76] Department for Environment, Food and Rural Affairs. Skills for a Low Carbon and Resource Efficient Economy: A review of evidence. Report by Pro Enviro. [Online]
Available at: Hwww.defra.gov.uk/environment/business/scp/pdf/LCREE-final-report.pdf

[77] UK Government, 2009. Memorandum submitted by the Aldersgate Group (GJS11), 3 June. [Online]
Available at:
Hhttp://www.publications.parliament.uk/pa/cm200809/cmselect/cmenvaud/memo/greenjobs/uc1102.htm

[78] Higher Education Funding Council for England, 2009.. [Online]
Available at: Hhttp://www.bis.gov.uk/assets/biscore/corporate/docs/h/09-1447-higher-ambitions.pdf

[79] Department for Business, Innovation and Skills, 2009. Skills for Growth: The national skills strategy. Report, November. [Online] Hhttp://www.bis.gov.uk/assets/biscore/corporate/docs/s/09-1467-skills-strategy-command-paper.pdf

[80] Department for Chldren, Schools and Families, 2008. New Reforms to Improve the Delivery of Skills for Adults and Young people. Press Release, 17 March. [Online]
Available at: Hhttp://www.dcsf.gov.uk/pns/DisplayPN.cgi?pn_id=2008_0053

[81] Higher Education Funding Council for England. Website. [Online]
Available at: Hhttp://www.hefce.ac.uk/

[82] Department for Business, Innovation and Skills, 2010. Low carbon skills consultation. Press Release, 31 March. [Online] Available at: Hhttp://www.bis.gov.uk/news/features/2010/3/low-carbon-skills-consultation

[83] Department for Business, Enterprise and Regulatory Reform, 2008. Microgeneration Strategy Progress Report. [Online]Available at: Hhttp://www.berr.gov.uk/files/file46372.pdf

[84] Energy and Utility Skills. Website. [Online]
Available at: Hhttp://www.euskills.co.uk/

[85] Department of Energy and Climate Change. Office for Renewable Energy Deployment. [Online]
Available at:
Hhttp://www.decc.gov.uk/en/content/cms/what_we_do/uk_supply/energy_mix/renewable/ored/ored.aspx

[86] National Skills Academy. Website. [Online]
Available at: Hhttp://www.nationalskillsacademy.co.uk

[87] Crossley, P., 2009. Skills shortages for UK renewables industry revealed. Renewable Energy Focus, 25 March. [Online]
Available at: Hhttp://www.renewableenergyfocus.com/view/917/skills-shortages-for-uk-renewables-industry-revealed/

[88] Greater London Authority, 2004. Skills and Jobs from Renewable Energy Policies and Targets. Report. [Online]
Available at: Hhttp://www.london.gov.uk/mayor/environment/energy/docs/renew_skills.pdf

[89] Graddon-Hodgson, B., 2009. Decline of rare earth Metals Used In Clean Tech Might Compromise Future Innovations. Clean Technica, 13 September. [Online]
Available at: Hhttp://cleantechnica.com/2009/09/13/decline-of-rare-earth-metals-used-in-clean-tech-might-compromise-future-innovations/

[90] Ofgem, 2010. Project Discovery: Options for delivering secure and sustainable energy supplies. Consultation Document, 3 February. [Online] Available at:
Hhttp://www.ofgem.gov.uk/Markets/WhlMkts/Discovery/Documents1/Project_Discovery_FebConDoc_FINAL.pdf

[91] Earthscan. Barriers to Renewable Energy. [Online]
Available at: Hhttp://www.earthscan.co.uk/Portals/0/Files/Sample%20Chapters/9781844074662.pdf

[92] Howe, S., 2009. Lack of Government Funding Could Lead to Crisis for Renewable Energy. The Green Village, 21 March. [Online]
Available at: Hhttp://thegreenvillage.co.uk/news/lack-of-government-funding-could-lead-to-crisis-for-renewable-energy-199/

[93] Macalister, T. and Adam, D., 2009. Warning over renewables as economic crisis leaves funding gap. The Guardian, 21 March. [Online]
Available at: Hhttp://www.guardian.co.uk/environment/2009/mar/21/renewable-energy-economic-crisis

[94] Environment Agency. Tidal barrages and barriers: Position Statement. [Online]
Available at: Hhttp://www.environment-agency.gov.uk/research/library/position/41199.aspx

[95] House, K.Z., 2009. The limits of energy storage technology. Bulletin of the Atomic Scientists, 2o January. [Online]
Available at: Hhttp://www.thebulletin.org/web-edition/columnists/kurt-zenz-house/the-limits-of-energy-storage-technology

[96] Fehrenbacher, K., 2009. FAQ: Energy Storage for the Smart Grid. Earth2tech, 13 May. [Online]
Available at: Hhttp://earth2tech.com/2009/05/13/faq-energy-storage-for-the-smart-grid/

[97] Department for Business, Enterprise and Regulatory Reform. Renewables Innovation Review. Presentation. [Online]
Available at:Hhttp://www.berr.gov.uk/files/file26273.pdf

[98] Jha, A., 2009. Environment: green jobs to rise to a million by 2017. The Guardian, 29 June. [Online]
Available at: Hhttp://www.guardian.co.uk/politics/2009/jun/29/green-jobs-brown

[99] Markusson, L. and Haszeldine, S., 2008. How ready is 'capture ready'? - Preparing the UK power sector for carbon capture and storage. Report for WWF-UK. [Online]
Available at: Hhttp://www.wwf.org.uk/filelibrary/pdf/capture_ready_ccs.pdf

[100] Shell, 2008. Shell Energy Scenarios to 2050. [Online]
Available at:
Hhttp://www.shell.com/home/content/aboutshell/our_strategy/shell_global_scenarios/shell_energy_scenarios_2050/shell_energy_scenarios_02042008.html

[101] Hughes, N., Mers, J. and Strachan, N., 2009. Review and Analysis of UK and International Low Carbon Energy Scenarios. UKERC and Eon.UK/EPSRC Transition Pathways Project. [Online]
Available at:
Hhttp://www.lowcarbonpathways.org.uk/lowcarbon/publications/Hughes_et_al_x2009x_UKERC_Scenarios_WP2_web.pdf

[102] Foresight Directorate, 2006. Office of Science and Innovation, Foresight – Horizon Scanning: Review of Futures Studies Conducted on Energy. [Online]
Available at: Hhttp://www.foresight.gov.uk/Energy/Review_of_Futures.pdf

[103] Martinot, E. Renewable Energy Futures website. [Online]
Available at: Hhttp://www.martinot.info/futures.htm

[104] Energy Technology Systems Analysis Programme. MARKAL. [Online]
Available at: Hhttp://www.etsap.org/markal/main.html

[105] Cambridge Econometrics. E3MG: An Energy-Environment-Economy (E3) Model at the Global Level. [Online]
Available at: Hhttp://www.camecon.com/suite_economic_models/e3mg.htm

[106] Adica.com. Wien Automatic System Planning Package (WASP IV). [Online]
Available at: Hhttp://www.adica.com/wasp_iv.html

[107] UK Energy Research Centre. Interactions Between Gas and electricity Newtworks. [Online]
Available at: Hhttp://www.ukerc.ac.uk/support/tiki-index.php?page=Interactions

[108] UK Energy Research Centre. Building Energy Modelling, The United Kingdom Domestic Carbon Model UKDCM. [Online]
Available at: Hhttp://www.ukerc.ac.uk/Downloads/PDF/E/ESMT_household_UKDCM.pdf

[109] Layberry, R. and Hinnells, M., 2007. Transforming UK non- residential buildings: achieving a 60 % cut in CO_2 emissions by 2050. Conference Proceedings. [Online]
Available at: Hhttp://www.eceee.org/conference_proceedings/eceee/2007/Panel_5/5.355/Paper/

[110] Brand, C., 2009. Introducing… the UK Transport Carbon Model (UKTCM). Conference Proceedings, Modelling the UK transport system for climate change policy analysis, 18 March. [Online]
Available at: Hhttp://www.eci.ox.ac.uk/news/articles/090501ukerc2050.php

[111] Transport for London. Hydrogen Bus Trial. [Online]
Available at: Hhttp://www.tfl.gov.uk/corporate/6585.aspx

[112] Leppard, D., 2009. Boris Johnson takes to the hydrogen highway. Timesonline, 23 August. [Online]
Available at: Hhttp://www.timesonline.co.uk/tol/news/science/article6806473.ece

[113] Simonite, T., 2009. New hydrogen-powered city car takes to the road. New Scientist, 16 June. [Online]
Available at: Hhttp://www.newscientist.com/article/dn17316-new-hydrogenpowered-city-car-takes-to-the-road.html

[114] Rae, B., 2009. We've got the power to build. Sheffield Star, 9 July. [Online]
Available at: Hhttp://www.thestar.co.uk/business/We39ve-got-the-power-to.5443084.jp

[115] UKERC, 2008. Pathways to a Low Carbon Economy: Energy Systems Modelling. Report. [Online]
Available at:
Hhttp://www.ukerc.ac.uk/Downloads/PDF/U/UKERCEnergy2050/281108UKERC2050PathwaysLowCarbonEconomy.pdf

[116] Institution of Mechanical Engineers (ImechE), 2009. UK 2050 Energy Plan: Making Our Commitment a Reality. Report. [Online]
Available at: Hhttp://www.imeche.org/NR/rdonlyres/BB6FF365-FAFD-4B3E-8C8C-6D85084F43E7/0/IMechE_UK_Energy_2050_Report.PDF

[117] Parliamentary Office of Science and Technology (POST), 2005. Carbon Capture and Storage (CCS). Post Note 238. [Online]
Available at: Hhttp://www.parliament.uk/documents/upload/POSTpn238.pdf

[118] Parliamentary Office of Science and Technology (POST), 2005. CO_2, Transport and Storage. Post Note 335. [Online]
Available at: Hhttp://www.parliament.uk/documents/upload/postpn335.pdf

[119] Metz, B., Davidson, O. R., Bosch, P. R., Dave, R. and Meyer, L. A. (eds), 2007. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. HCambridge University PressH, Cambridge, United Kingdom and New York, NY, USA. [Online]
Available at: Hhttp://www.ipcc.ch/publications_and_data/ar4/wg3/en/ch4s4-3-6.htmlH (for CO2 storage capacities)

[120] Department for Business, Enterprise and Regulatory Reform, 2009. Accelerating the Deployment of Carbon Abatement Technologies – with special focus on Carbon Capture and Storage. Advisory Document from ACCAT, URN 09/Z108, February. [Online]
Available at: Hhttp://www.berr.gov.uk/files/file50470.pdf

[121] New Energy Focus, 2009. Minister opens £7.4 m Oxycoal CCS demonstration project, 27 July. [Online]
Available at:
Hhttp://www.newenergyfocus.com/do/ecco/view_item?listid=1&listcatid=32&listitemid=2860

[122] Scottish Power, 2009. UK first at Longannet as Scottish Power brings clean coal technology one step closer to reality. Press Release, Scottish Power website, 29 May. [Online]
Available at: Hhttp://www.scottishpower.com/PressReleases_1876.htm

[123] Vattenfall, 2009. First anniversary for CCS at Schwarze Pumpe. Vattenfall website, 11 September. [Online]
Available at:
Hhttp://www.vattenfall.com/www/co2_en/co2_en/399862newsx/404068press/index.jsp?pmid=79440

[124] POWER Magazine, 2009. Three CCS Tests Worldwide [Online]
Available at: http://www.powermag.com/coal/Three-CCS-Tests-Worldwide_2259.html

[125] Bellona, 2010. Total inaugurates Lacq CCS project [Online]
Available at: Hhttp://www.bellona.org/articles/articles_2010/total_lacq?printerfriendly=yes'

[126] US Department of Energy, 2009. Worldwide Carbon Capture and Storage Projects on the Increase. News Release, 13 November. [Online]

Available at: Hhttp://www.netl.doe.gov/publications/press/2009/09079-DOE_Unveils_CCS_Database.html

127 New Energy Focus, 2009. Kingsnorth joins UK carbon capture competition. Article, 10 November. [Online]
Available at:
Hhttp://www.newenergyfocus.com/do/ecco/view_item?listid=1&listcatid=32&listitemid=3196

128 Department of Energy and Climate Change, 2009. Funding for design studies in clean coal competition. Press Release, 12 March. [Online]
Available at: Hhttp://www.decc.gov.uk/en/content/cms/news/pn10_041/pn10_041.aspx

129 Department of Energy and Climate Change, 2009. Carbon Capture and Storage. [Online]
Available at: Hhttp://www.decc.gov.uk/en/content/cms/what_we_do/uk_supply/energy_mix/ccs/ccs.aspx

130 Department of Energy and Climate Change, 2009. No new coal without CCS – Milliband. Press Release, 23 April. [Online]
Available at: Hhttp://www.decc.gov.uk/en/content/cms/news/pn050/pn050.aspx

131 The Scottish Government, 2009. Scotland Can Lead the Way in European Carbon Dioxide Storage. Press Release, 1 May. [Online]
Available at: Hhttp://www.geos.ed.ac.uk/sccs/regional-study/CO2-JointStudy-PressRelease.pdf

132 Department of Energy and Climate Change, 2008. CCS: EU Information. [Online]
Available at:
Hhttp://www.decc.gov.uk/en/content/cms/what_we_do/uk_supply/energy_mix/ccs/CCS_EU_info/CCS_EU_info.aspx

133 European Union: EUROPA Press Release, 2009. List of 15 energy projects for European economic recovery. [Online]
Available at: Hhttp://europa.eu/rapid/pressReleasesAction.do?reference=MEMO/09/542

134 Department of Energy and Climate Change, 2009. A framework for the development of clean coal: consultation document. [Online]
Available at: Hhttp://www.decc.gov.uk/en/content/cms/consultations/clean_coal/clean_coal.aspx

135 Carbon Sequestration Leadership Forum, 2009. Energy Ministers Endorse CCS as Key to Combating Climate Change. [Online]
Available at: Hhttp://www.cslforum.org/pressroom/publications/pr_communique_101309.pdf

136 Hhttp://decc.gov.uk/en/content/cms/news/pn10_043/pn10_043.aspx

137 Anderson, J. et al, 2007. The ACCSEPT (Acceptance of CO_2 Capture, Storage Economics, Policy and Technology) Project. Summary of the Main Findings and Key Recommendations. [Online}
Available at: Hhttp://www.accsept.org/outputs/wp_5_2dec_2007_final.pdf

138 Flavell-White, C., 2009. Germany 'numbyists' derail CCS project. The Chemical Engineer – tce today, 30 July. [Online]
Available at: Hhttp://www.tcetoday.com/tcetoday/NewsDetail.aspx?nid=11970

139 Health and Safety Executive, 2008. Interim guidance on conveying CO_2 in pipelines in connection with carbon capture, storage and sequestration projects. [Online]
Available at: Hhttp://www.hse.gov.uk/pipelines/co2conveying.htm

140 Madrigal, A., 2008. Top 5 Ways to Cause a Man-Made Earthquake. Wired Science, 4 June. [Online]

Available at: Hhttp://www.wired.com/wiredscience/2008/06/top-5-ways-that/

[141] Scottish Centre for Carbon Storage. [Online]
Available at: Hhttp://www.geos.ed.ac.uk/sccs/storage/storageSitesFree.html

[142] Milne, R., 2008. Gas storage will help UK cope with depleted North Sea reserves. Utiliy Week, 19 September. [Online]
Available at: Hhttp://www.utilityweek.co.uk/features/utility-engineering/gas-storage-will-help-uk-cope.php

[143] Parliamentary Office of Science and Technology (POST), 2004. The Future of UK Gas Supplies. Post Note 230. [Online]
Available at: Hhttp://www.parliament.uk/documents/upload/POSTpn230.pdf

[144] Willis, S., 2009. Investing in UK gas storage capacity, drivers and barriers to development. Centrica, presentation. [Online]
Available at: Hhttp://www.igem.org.uk/download/aceu09/1-1-0930-SimonWills-ACEU09.pdf

[145] Costain Oil, Gas and Process Ltd, 2009. Underground Gas Storage in the UK
Costain's Experience. Presentation, Gas Transport and Storage Summit, Barcelona, 30 January. [Online]
Available at: Hhttp://www.undergroundgasstorage.com/editorimages/UGS%20Presentation%20Jan%202009.pdf

[146] Nakanishi, N. and Solem, R. Reuters, 2009. UK's SSE says Aldbrough gas storage in operation. [Online]
Available at: Hhttp://www.reuters.com/article/idUSL114205620090701

[147] Crabb, S., 2009. Gas Storage. Westminster Hall debate, 24 February. [Online]
Available at: Hhttp://www.theyworkforyou.com/whall/?id=2009-02-24b.46.0

[148] Project Wyre Group. [Online]
Available at: Hhttp://www.pwgroup.org.uk/about%20pwg.htm

[149] Mokhatab, S., Finn, A. and Shah, K., 2008. Offshore LNG Industry Developments. PTQ, Q4, pp59-62. [Online]
Available at: Hhttp://www.costain-floating-lng.com/editorimages/PTQ%20Sept%202008.pdf

[150] Parliamentary Office of Science and Technology (POST), 2008. Renewable Energy in a Changing Climate. Post Note 315. [Online]
Available at: Hhttp://www.parliament.uk/documents/upload/Postpn315.pdf

[151] Department of Energy and Climate Change, 2010. Renewable Obligation Certificate (ROC) Banding. [Online]
Available at: Hhttp://chp.decc.gov.uk/cms/roc-banding/?phpMyAdmin=ff232c1d3b302ac6e951f554eeeaefdf

[152] Department of Energy and Climate Change, 2009. Consultation on Renewable Electricity Financial Incentives. [Online]
Available at: Hhttp://www.decc.gov.uk/en/content/cms/consultations/elec_financial/elec_financial.aspx

[153] Sinden, G., 2005. Wind Power and the UK Wind Resource. Environmental Change Institute, University of Oxford, 2005. [Online]
Available at: Hhttp://www.eci.ox.ac.uk/publications/downloads/sinden05-dtiwindreport.pdf

[154] Macalister, T., 2008. Queen of green: Crown Estate's offer fans interest in wind farming. The Guardian, 21 October. [Online]

Available at: Hhttp://www.guardian.co.uk/environment/2008/oct/21/windpower-renewableenergy

[155] British Wind Energy Association. UKWED- UK Wind Energy Database. [Online]
Available at: Hhttp://www.bwea.com/ukwed/index.asp

[156] British Wind Energy Association. UKWED Statistics. [Online]
Available at: Hhttp://www.bwea.com/statistics/

[157] Health and Safety Executive, 2009. Emerging Energy Technologies programme, Register of UK Projects.

[158] The Crown Estate, 2009. Round 3. [Online]
Available at:
Hhttp://www.thecrownestate.co.uk/our_portfolio/marine/offshore_wind_energy/round3/r3-developers.htm

[159] Department of Energy and Climate Change, 2009. Low Carbon Energy Demonstration, ETF Offshore Wind Demonstration, Call for Proposals. [Online]
Available at: Hhttp://www.berr.gov.uk/files/file51564.doc

[160] Key offshore wind locations named, 2010. BBC News, 4 February. [Online]
Available at: Hhttp://news.bbc.co.uk/1/hi/scotland/8497183.stm

[161] UpWind website. [Online]
Available at: Hhttp://www.upwind.eu/

[162] Vidal, J., 2009. UK wind farm plans on the brink of failure. The Guardian, 19 October. [Online]
Available at: Hhttp://www.guardian.co.uk/environment/2008/oct/19/renewable-energy-greenhouse-carbon-emissions

[163] BBC News website. Wind turbines in graphics. [Online]
Available at: Hhttp://news.bbc.co.uk/1/hi/in_depth/629/629/7102346.stm

[164] Gardner, S., 2008. The single European energy grid is coming. Climate News for Business, 8 May. [Online]
Available at: Hhttp://www.climatechangecorp.com/content.asp?ContentID=5309

[165] Smith, L., 2008. Sites named for new offshore wind farms. The Times, 5 June. [Online]
Available at: Hhttp://www.timesonline.co.uk/tol/news/environment/article4068845.ece

[166] Caithness Windfarms Information Forum, 2009. Summary of Wind Turbine Accident Data to 31 December 2009. [Online]
Available at: H http://www.caithnesswindfarms.co.uk/accidents.pdf

[167] British Wind Energy Association website. Marine Renewable Energy. [Online]
Available at: Hhttp://www.bwea.com/marine/devices.html

[168] Pelamis Power website. [Online]
Available at: Hhttp://www.pelamiswave.com/

[169] Parliamentary Office of Science and Technology (POST), 2009. Marine Renewables. Post Note 324. [Online]
Available at: Hhttp://www.parliament.uk/documents/upload/postpn324.pdf

[170] Voith Hydro Wavegen Ltd, website. [Online]
Available at: Hhttp://www.wavegen.co.uk/what_we_offer_nearshore_owc_tech_info.htm

[171] Copping, J., 2008. Ocean currents can power the world, say scientists. The Daily Telegraph, 29 November. [Online]
Available at: Hhttp://www.telegraph.co.uk/earth/energy/renewableenergy/3535012/Ocean-currents-can-power-the-world-say-scientists.html

[172] National Renewable Energy Laboratory website. What is ocean thermal energy conversion? [Online]
Available at: Hhttp://www.nrel.gov/otec/what.html

[173] Engineering and Physical Sciences Research Council, Hhttp://www.epsrc.ac.uk/CMSWeb/Downloads/Publications/Other/SupergenBrochure.pdf

[174] The Carbon Trust, 2006. Wave and tidal power could supply a fifth of UK energy needs. Press Release, 25 January. [Online]
Available at:
Hhttp://www.carbontrust.co.uk/news/news/archive/2006/Pages/06_01_25_waveandtidal.aspx

[175] Ayling, D. Marine Renewable Energy: A Global Opportunity: Safe, Secure Sustainable. British Wind Energy Association presentation. [Online]
Available at: Hhttp://www.bwea.com/pdf/marine/080613%20Marine%20Strategy%20Group.pdf

[176] DECC, 2009. Severn Tidal Power: The Feasibility Study [Online]
Available at: HDepartment of Energy and Climate Change, 2009. Carbon Capture and Storage. [Online]http://www.decc.gov.uk/en/content/cms/what_we_do/uk_supply/energy_mix/renewable/severn_tidal_power/feasibility/feasibility.aspx

[177] Smith, L., 2009. Tidal Energy Project will be Funded by the Taxpayer. The Times, 27 January. [Online]
Available at: Hhttp://www.timesonline.co.uk/tol/news/environment/article5592523.ece

[178] Jha, A., 2008. First tidal power turbine gets plugged in. The Guardian, 17 July. [Online]
Available at:
Hhttp://www.guardian.co.uk/environment/2008/jul/17/waveandtidalpower.renewableenergy

[179] Gompertz, S., 2008. Portugal embraces wave power. BBC News, 24 september. [Online]
Available at: Hhttp://news.bbc.co.uk/1/hi/programmes/working_lunch/7633597.stm

[180] Pelamis Wave Power, 2010. Orcadian Wave Farm [Online]
Available at: Hhttp://www.pelamiswave.com/content.php?id=150

[181] 2009. Update on the Seagen project and information on similar projects around the world. Northern Ireland Assembly, Research and Library Services, Briefing Note 14/09. [Online]
Available at: Hhttp://www.niassembly.gov.uk/io/research/2009/1409.pdf

[182] The Crown Estate, 2010. Wave and Tidal. [Online] Available at:
Hhttp://www.thecrownestate.co.uk/our_portfolio/marine/wave-tidal/pentland-firth-orkney-waters.htm

[183] The Crown Estate, 2010. Pentland Firth and Orkney Waters Round 1 Development Sites. [Online]
Available at: Hhttp://www.thecrownestate.co.uk/pfow_development_sites_map.pdf

[184] Jha, A., 2008. Second generation tidal turbines promise cheaper power. The Guardian, 4 September. [Online]
Available at: Hhttp://www.guardian.co.uk/environment/2008/sep/04/waveandtidalpower.renewableenergy

[185] Mueller, M. and Jeffery, H., 2008. UKERC Marine (Wave and Tidal Current) RenewableEnergy Technology Roadmap. [Online]
Available at: Hhttp://www.ukerc.ac.uk/Downloads/PDF/0705ESMDTIDEFRAreport.pdf

[186] Marine Energy Accelerator. The Carbon Trust. [Online]
Available at: Hhttp://www.carbontrust.co.uk/technology/technologyaccelerator/mea.htm

[187] Department for Energy and Climate Change, 2010. Marine Action Plan. [Online]
Available at:
Hhttp://www.decc.gov.uk/en/content/cms/what_we_do/uk_supply/energy_mix/renewable/explained/wave_tidal/funding/marine_action_/marine_action_.aspx

[188] British Wind Energy Association. Marine Renewable Energy. [Online]
Available at: Hhttp://www.bwea.com/marine/index.html

[189] New Energy Focus, 2009. Offshore renewable consultation launched in Northern Ireland, 21 December. [Online] Available at:
Hhttp://www.newenergyfocus.com/do/ecco/view_item?listid=1&listcatid=32&listitemid=3368#

[190] Biomass Energy Centre. What is Biomass? [Online]
Available at:
Hhttp://www.biomassenergycentre.org.uk/portal/page?_pageid=76,15049&_dad=portal&_schema=PORTAL

[191] 2008. Biomass power station planned. BBC News, 19 August. [Online]
Available at: Hhttp://news.bbc.co.uk/1/hi/england/bristol/7571001.stm

[192] Department of the Deputy Prime Minister, 2004. Planning for Renewable Energy: A Companion Guide to PPS22. [Online]
Available at: Hhttp://www.communities.gov.uk/documents/planningandbuilding/pdf/147447.pdf

[193] Jha, A., 2008. Alstom to build £50m biomass plant for Drax. The Guardian, 20 May. [Online]
Available at: Hhttp://www.guardian.co.uk/environment/2008/may/20/renewableenergy.alternativeenergy

[194] Bioethanol. British Sugar website. [Online]
Available at: Hhttp://www.britishsugar.co.uk/RVE29c095ba629149d391ce49792e8ab37b,,.aspx

[195] Biodiesel and bioethanol fuel producers. Renewable Energy Centre website. [Online]
Available at: Hhttp://www.therenewableenergycentre.co.uk/biomass-and-biofuel/biodiesel-and-bioethanol-fuel-producers/

[196] Leake, J., 2010. Methane galore on whisky island. The Times, 17 January. [Online] Available at:
Hhttp://business.timesonline.co.uk/tol/business/industry_sectors/natural_resources/article6990985.ece

[197] Fehrenbacher, K., 2008. 15 Algae Startups Bringing Pond Scum to Fuel Tanks. Earth2tech, 27 March. [Online]
Available at: Hhttp://earth2tech.com/2008/03/27/15-algae-startups-bringing-pond-scum-to-fuel-tanks

[198] Carbon Trust. Algae Biofuels Challenge. [Online]
Available at: Hhttp://www.carbontrust.co.uk/technology/directedresearch/algae.htm

[199] Departments for; Environment, Food and Rural Affairs,Transport, Trade and Industry, 2007. UK Biomass Strategy. Report. [Online]
Available at:
Hhttp://www.decc.gov.uk/en/content/cms/what_we_do/uk_supply/energy_mix/renewable/explained/bioenergy/policy_strat/policy_strat.aspx

[200] Department for Business, Enterprise and Regulatory Reform. Biomass Energy: in your Community. [Online]
Available at:
Hhttp://www.berr.gov.uk/energy/sources/renewables/explained/biomass/community/page17019.html

[201] Department of Energy and Climate Change. International Strategy. [Online]
Available at:
Hhttp://www.decc.gov.uk/en/content/cms/what_we_do/change_energy/tackling_clima/intl_strat/intl_strat.aspx

[202] Biomass Energy Centre website. [Onlone]
Available at:
Hhttp://www.biomassenergycentre.org.uk/portal/page?_pageid=73,1&_dad=portal&_schema=PORTAL

[203] EPSRC. Supergen Biomass and Bioenergy Consortium website. [Online]
Available at: Hhttp://www.supergen-bioenergy.net/

[204] Department for Business, Enterprise and Regulatory Reform, 2009. Progress Report on Implementation of the Government Response to the Biomass Task Force Report. [Online]
Available at: Hhttp://www.berr.gov.uk/files/file52050.pdf

[205] E.ON. Steven's Croft Biomass Power Station. [Online]
Available at: Hhttp://www.eon-uk.com/generation/stevenscroft.aspx

[206] Department for Environment, Food and Rural Affairs, 2007. Waste Strategy for England. Report. [Online]
Available at: H http://www.defra.gov.uk/ENVIRONMENT/WASTE/strategy/index.htm

[207] Department for Environment, Food and Rural Affairs, 2008. Waste Wood as a Biomass Fuel. Report/ [Online]
Available at: Hhttp://www.defra.gov.uk/environment/waste/topics/documents/wastewood-biomass.pdf

[208] MGT Power, 2009. Large Scale Biomass Power Plant to be Built on Teeside. Press Release, 15 July. [Online]
Available at: Hhttp://www.mgtpower.com/files/2009-07-15 S36 Press Release.pdf

[209] MGT Power, 2009. MGT Power Announce Plans for 295 MW Biomass Power Station at the Port of Tyne. Press Release, 10 August. [Online]
Available at: Hhttp://www.mgtpower.com/files/2009-09-10 Tyne REP Press Release.pdf

[210] Drax Group plc. Biomass. [Online]
Available at: Hhttp://www.draxgroup.plc.uk/corporate_responsibility/environment/fuels/biomass/

[211] Murray, J., 2009. Government approves 60MW biomass and waste power plant. BusinessGreen.com, 27 August. [Online]
Available at: Hhttp://www.businessgreen.com/business-green/news/2248579/government-green-lights-60mw

[212] E.ON UK, 2008. E.ON welcomes approval for new biomass power station in Sheffield. Press Release, 27 August. [Online]
Available at: Hhttp://pressreleases.eon-uk.com/blogs/eonukpressreleases/archive/2008/07/15/1257.aspx

[213] UK Business Park. Biomass. Activity Report. [Online]
Available at: Hhttp://www.ukbusinesspark.co.uk/prod/biomass.htm

[214] Department for Environment, Food and Rural Affairs, 2009. Anaerobic digestion: new Task Group to deliver shared goals. Information Bulletin 35/09, 17 February. [Online]

Available at: Hhttp://www.defra.gov.uk/news/2009/090217c.htm

[215] Department for Environment, Food and Rural Affairs, 2009. Developing an Implementation Plan for Anaerobic Digestion - Report of the Anaerobic Digestion Task Group. Report. [Online]
Available at: Hhttp://www.defra.gov.uk/environment/waste/ad/documents/implementation-plan.pdfH

[216] Health and Safety Executive, 2003. Tree Work Accidents. Information Leaflet INDG278. [Online]
Available at: Hhttp://www.hse.gov.uk/pubns/indg278.pdf

[217] Girling, R., 2008. Biofuels: Fields of dreams. The Times, 9 March. [Online]
Available at: Hhttp://www.timesonline.co.uk/tol/news/environment/article3489640.ece

[218] Hhttp://www.google.co.uk/search?hl=en&q=biodiesel+kits&meta=

[219] Health and Safety Executive. Domestic production of biodiesel – health and safety warning. [Online]
Available at: Hhttp:/www.hse.gov.uk/pubns/biodiesel.htm

[220] Energy Saving Trust. Solar Energy. [Online]
Available at: Hhttp://www.energysavingtrust.org.uk/Generate-your-own-energy/Solar-electricity

[221] Eames, P., 2008. Solar Energy: Current Status and Future Prospects. Presentation. [Online]
Available at: Hhttp://royalsociety.org/WorkArea/DownloadAsset.aspx?id=5440

[222] Department of Energy and Climate Change. Bright
future for UK solar PV. [Online]
Available at: Hhttp://www.ukrenewables.com/news-1/january-2008/bright-future-for-uk-solar-pv

[223] Department for Business, Innovation and Skills. Solar Energy: Current UK Use. [Online]
Available at: Hhttp://www.berr.gov.uk/energy/sources/renewables/explained/solar/current-use/page16374.html

[224] Everest. Solar Panels. [Online]
Available at: Hhttp://www.everest.co.uk/solar-panels.asp

[225] Department for Energy and Climate Change, 2010. Press Release: Cash Rewards for Low Carbon Electricity and Heating, 1 February. [Online]
Available at: Hhttp://www.decc.gov.uk/en/content/cms/news/pn10_010/pn10_010.aspx

[226] Leggett, J., 2009. Green feed-in tariff needs to maximise solar power. The Guardian, 14 May. [Online]
Available at: Hhttp://www.guardian.co.uk/environment/2009/may/14/feed-in-tariff-solar-power

[227] Macalister, T., 2009. Renewable energy firms hit by solar subsidies freeze. The Guardian, 12 March. [Online]
Available at: Hhttp://www.guardian.co.uk/environment/2009/mar/12/renewableenergy-carbonfootprints

[228] Seager, A., 2007. Germany sets shining example in providing a harvest for the world. The Guardian, 23 July. [Online]
Available at: Hhttp://www.guardian.co.uk/business/2007/jul/23/germany.greenbusiness

[229] Southern Electric website. [Online]
Available at: Hhttp://www.southern-electric.co.uk/Help/ForYourHome/Microgeneration/SolarPVTariff.aspx

[230] Seager, A., 2008. Solar future brightens as oil soars. The Guardian, 16 June. [Online]
Available at: Hhttp://www.guardian.co.uk/environment/2008/jun/16/renewableenergy.energy

[231] The Carbon Trust, 2007. Carbon Trust launches new £5million project to make solar PV cost effective in ten years. Press Release, 4 October. [Online]
Available at: Hhttp://www.carbontrust.co.uk/news/news/archive/2007/Pages/041007_PV.aspx

[232] Solar Trade Association. Membership. [Online]
Available at: Hhttp://www.solar-trade.org.uk/findamember.cfm

[233] Silicon Valley Toxics Coalition, 2009. Toward a Just and Sustainable Solar Energy Industry. Report, 14 January. [Online]
Available at: Hhttp://www.svtc.org/site/DocServer/Silicon_Valley_Toxics_Coalition_-_Toward_a_Just_and_Sust.pdf

[234] McMahon, S., 2009. PV module market to contract by 15% in worst growth year since '94 says Greentech Media. PV-tech.org, 4 March. [Online]
Available at: Hhttp://www.pv-tech.org/news/_a/pv_market_to_contract_by_15_in_worst_growth_year_since_94_says_greentech_me/

[235] Department of Energy and Climate Change. Hydroelectricity: current UK use. [Online]
Available at:
Hhttp://www.decc.gov.uk/en/content/cms/what_we_do/uk_supply/energy_mix/renewable/explained/hydro/use/use.aspx

[236] Department of Energy and Climate Change. Geothermal. [Online]
Available at:
Hhttp://www.decc.gov.uk/en/content/cms/what_we_do/uk_supply/energy_mix/renewable/explained/geothermal/geothermal.aspx

[237] Southampton City Council. Geothermal and CHP scheme. [Online]
Available at: Hhttp://www.southampton.gov.uk/s%2Denvironment/energy/Geothermal/

[238] Engineered Geothermal Systems (egs). The Plan. [Online]
Available at: Hhttp://www.egs-energy.com/about-egs-energy/the-egs-plan.html

[239] Morris, S., 2009. Eden Project reveals 'hot rocks' geothermal energy plan. The Guardian, 2 June. [Online]
Available at: Hhttp://www.guardian.co.uk/environment/2009/jun/01/eden-project-geothermal-energy

[240] Engineered Geothermal Systems (egs). Commercialisation. [Online]
Available at:Hhttp://www.egs-energy.com/egs-technology/commercialisation.html

[241] Calpine Corporation. Welcome to the geysers. [Online]
Available at: Hhttp://www.geysers.com/

[242] Engineered Geothermal Systems (egs). Geothermal in general. [Online]
Available at: Hhttp://www.egs-energy.com/resource/geothermal-in-general.html

[243] AltaRock Energy Inc, 2009. AltaRock EGS Demonstration Project Status with NCPA at The Geysers. Update, 19 October. [Online]
Available at: Hhttp://altarockenergy.com/demo.html

[244] Engineered Geothermal Systems (egs). Overview. [Online]
Available at:Hhttp://www.egs-energy.com/egs-technology/egs-overview.html

[245] Department of Energy and Climate Change. Geothermal: current and future UK use. [Online]

Available at:
Hhttp://www.decc.gov.uk/en/content/cms/what_we_do/uk_supply/energy_mix/renewable/explained/geothermal/current_future/current_future.aspx

[246] DECC, 2010, Deep Geothermal Challenge Fund. [Online]
Available at:
Hhttp://www.decc.gov.uk/en/content/cms/what_we_do/uk_supply/energy_mix/renewable/explained/geothermal/challenge_fund/challenge_fund.aspx

[247] Institution of Engineering and Technology (IET). Environment and Energy. [Online]
Available at: Hhttp://www.theiet.org/factfiles/energy/

[248] Wolfe, P., 2008. The implications of an increasingly decentralised energy system. Energy Policy (36), pp 4509-4513. [Online]
Available at: Hhttp://www.foresight.gov.uk/Energy/EnergyFinal/wolfe paper-section 6.pdf

[249] Combined Heat and Power Association. CHP FAQ. [Online]
Available at: Hhttp://www.chpa.co.uk/about_chp/chp_faq.shtml

[250] Energy Saving Trust UK. Ground source heat pumps. [Online]
Available at: Hhttp://www.energysavingtrust.org.uk/Generate-your-own-energy/Ground-source-heat-pumps

[251] Fuel Cells 2000 website. [Online]
Available at: Hhttp://www.fuelcells.org/

[252] Supergen. Supercapacitors. What are they? [Online]
Available at: Hhttp://www.energystorage.org.uk/supercaps.html

[253] Department for Trade and Industry, 2007. Review of Distributed Generation. Report. [Online]
Available at: Hhttp://www.berr.gov.uk/files/file39025.pdf

[254] Woking Council. Energy: Good Practice. Climate Neutral Development: A good practice guide. [Online]
Available at: Hhttp://www.woking.gov.uk/council/planning/publications/climateneutral2/energy.pdf

[255] Department of Energy and Climate Change. Microgeneration. [Online]
Available at:
Hhttp://www.decc.gov.uk/en/content/cms/what_we_do/uk_supply/energy_mix/renewable/explained/microgen/microgen.aspx

[256] Department of Trade and Industry, 2005. Microgeneration and Low Carbon Buildings Programme: Consultation. [Online]Available at: Hhttp://www.berr.gov.uk/files/file13989.pdf

[257] Department of Energy and Climate Change, 2009. Low Carbon Buildings, Programme Phase 2. [Online]
Available at: Hhttp://www.lowcarbonbuildingsphase2.org.uk/

[258] House of Lords, 2009. Economic Affairs Committee – First Report. Government Response to Report on the Economics of Renewable Energy. Report, 10 February. [Online]
Available at: Hhttp://www.publications.parliament.uk/pa/ld200809/ldselect/ldeconaf/33/3302.htm

[259] The Microgeneration Certification Scheme, 2009. Welcome to the Microgeneration Certification Scheme website. [Online]
Available at: Hhttp://www.microgenerationcertification.org/

[260] Department of Trade and Industry, 2006. Our Energy Challenge: Power from the People – Microgeneration Strategy. [Online]
Available at:
Hhttp://www.decc.gov.uk/en/content/cms/what_we_do/uk_supply/energy_mix/renewable/explained/microgen/strategy/strategy.aspx

[261] Ofgem. Distributed Generation. [Online]
Avsailable at:
Hhttp://www.ofgem.gov.uk/Networks/ElecDist/Policy/DistGen/Pages/DistributedGeneration.aspx

[262] Ofgem, 2009. Next steps in delivering the electricity distribution structure of charges project: decision document, 20 March. [Online]
Available at:
Hhttp://www.ofgem.gov.uk/Pages/MoreInformation.aspx?docid=480&refer=Networks/ElecDist/Policy/DistChrgs

[263] Smart, P. et al, 2006. Accommodating Distributed Generation. Ecconect report for Department of Trade and Industry. [Online]
Available at: Hhttp://www.berr.gov.uk/files/file31648.pdf

[264] Smartgrids website. European Technology Platform for the Electricity Networks of the Future. [Online]
Available at: Hhttp://www.smartgrids.eu/

[265] Department of Trade and Industry, 2004. Status of Electrical Energy Storage Systems. Report DG/DTI/00050/00/00; URN Number 04/1878. [Online]
Available at: Hhttp://www.berr.gov.uk/files/file15189.pdf

[266] IBM, 2009. Energy storage on wheels. Research Project, 13 August. [Online] Available at: Hhttp://www.zurich.ibm.com/pdf/csc/EDISON_Think_3-09_e.pdf

[267] H.M. Government, 2010. Electric vehicle charging points trialled. Press Release, 25 February. [Online] Available at: Hhttp://interactive.bis.gov.uk/lowcarbon/2010/02/electric-vehicle-charging-points-trialled/

[268] Parliamentary Office of Science and Technology (POST), 2008 Electricity Storage. Post Note 306. [Online]
Available at: Hhttp://www.parliament.uk/documents/upload/postpn306.pdf

[269] Holzman, D. C., 2007. The Vanadium Advantage: Flow Batteries Put Wind Energy in the Bank. Environ. Health Perspect., June, 115(7), A358-A361. [Online]
Available at: Hhttp://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1913571

[270] TGT Energy website. [Online]
Available at: Hhttp://tgtenergy.com/index.html

[271] National Grid. Operating in 2020. [Online]
Available at: Hhttp://www.nationalgrid.com/uk/Electricity/Operating+in+2020/

[272] SuperGen Energy Storage, 2008. Research Themes. [Online]
Available at: Hhttp://www.energystorage.org.uk/research.html

[273] Gaelectric, 2009. Larne has the potential to be at the cutting edge of an Energy Storage Project. Press Release, 2 March. [Online]
Available at: Hhttp://www.gaelectric.ie/news-detail.asp?nid=52&id=5

[274] HSE Website, 2008. Horizon Scanning- Hydrogen Economy [Online]

Available at: Hhttp://www.hse.gov.uk/horizons/hydrogen.htm

[275] Newsholme, G. 2004. Fuel Cells - hazards and risk management TD5-048 [Online]
Available at: Hhttp://www.hse.gov.uk/foi/internalops/hid/din/548.pdfH

[276] Transport for London, Hydrogen Vehicles [Online]
Available at: Hhttp://www.tfl.gov.uk/corporate/projectsandschemes/environment/8444.aspx

[277] Transport for London, Hydrogen Vehicles, Next Steps [Online]
Available at: Hhttp://www.tfl.gov.uk/corporate/projectsandschemes/environment/8448.aspx

[278]Energy Minister "Drives" London Taxi Fuel Cell System at Intelligent Energy, 2009. Intelligent Energy press release, 9 October [Online]
Available at: Hhttp://www.intelligent-energy.com/index_article.asp?SecID=8&secondlevel=25&artid=4074

[279] Fuel Cell Europe press release, 2009. Royal Mail, CENEX, Post Europ and FuelCellEurope Join Forces to Accelerate Development of Hydrogen Fuel Cell Postal Vans, 23 March. [Online]
Available at: Hhttp://www.fuelcelleurope.org/relFiles/PR Announcement development of hydrogen fuel cell postal van 23032009.pdf

[280] The Engineer, 2009. Fuel-cell postal vans. 14 April. [Online]
Available at: Hhttp://www.theengineer.co.uk/news/fuel-cell-postal-vans/310774.article

[281] Hydrogen revolution gets a second wind, 2010. The Times, 10 January. [Online]
Available at: Hhttp://www.timesonline.co.uk/tol/driving/features/article6980876.ece

[282] Hydrogen refuel station unveiled, 2008. BBC News, 9 July. [Online]
Available at: Hhttp://news.bbc.co.uk/1/hi/technology/7496331.stm

[283] Intelligent Energy announce CHP joint venture with Scottish and Southern Energy, 2008. Intelligent Energy press release, 3 March. [Online]
Available at: Hhttp://www.intelligent-energy.com/index_article.asp?SecID=8&secondlevel=25&artid=3999%20

[284] Hydrogen car to be 'open source', 2009. BBC News, 16 June. [Online]
Available at: Hhttp://news.bbc.co.uk/1/hi/sci/tech/8103106.stm

[285] Mercedes-Benz launches B-class F-cell, leases to begin in early 2010, 2009. Autoblog, 28 August. [Online]
Available at:Hhttp://www.autoblog.com/2009/08/28/report-mercedes-benz-launches-b-class-f-cell-leases-to-begin-i/

[286] Fuel cell powered scooter unveiled by Intelligent Energy, 2009. Intelligent Energy press release, 22 October. [Online]
Available at: Hhttp://www.intelligent-energy.com/index_article.asp?SecID=8&secondlevel=25&artid=4075

[287] Hydrogen-powered vehicles on horizon, 2009. The Washington Times, 24 August. [Online]
Available at: Hhttp://www.washingtontimes.com/news/2009/aug/24/hydrogen-powered-vehicles-on-horizon/?page=2

[288] Nissan starts vehicle testing of new fuel-cell technology, 2009. Japanese Sport Cars, 25 February. [Online]
Available at: Hhttp://www.japanesesportcars.com/nissan-testing-vehicle-new-fuel-cell-technology_5298.html

[289] Hyundai will have hybrids next year- and fuel cells in 2012?, 2008. Wired, 24 March. [Online]
Available at: Hhttp://www.wired.com/autopia/2008/03/hyundai-will-ha/

[290] BMW Clean Energy: The BMW Hydrogen 7 [Online]
Available at:
Hhttp://www.bmw.com/com/en/insights/technology/efficient_dynamics/phase_2/clean_energy/bmw_hydrogen_7.html

291 Roundup: BMW hydrogen to electric; Tesla PHEV, GM and incentives; BYD Production; Honda's doubts, 2008. Calcars: The Californian Cars Initiave, 4 February. [Online]
Available at: Hhttp://www.calcars.org/calcars-news/913.html

292 Renault ditches hybrids, 2009. Autocar, 26 February. [Online]
Available at :Hhttp://www.autocar.co.uk/News/NewsArticle/AllCars/238404/

293 Hopes for battery technology push hydrogen cars to back burner, 2009. Current, 8 July. [Online]
Available at: Hhttp://current.com/items/90362655_hopes-for-battery-technology-push-hydrogen-cars-to-back-burner.htm

294 H2WALES website.Accessed 2010, 11 Februaury. [Online]
Available at: Hhttp://www.h2wales.org.uk/pilot-plants.html

295 Renewable hydrogen research and demonstration centre. H2WALES [Online]
Available at: Hhttp://www.h2wales.org.uk/hydrogen_centre.html

296 Fuel cell research, University of Birmingham. [Online]
Available at: Hhttp://www.fuelcells.bham.ac.uk/

297 Centre for energy policy and technology, Imperial College London. [Online]
Available at: Hhttp://www3.imperial.ac.uk/icept/ourresearchactivities/hydrogenandfuelcell

298 Hydrogen Solar website. [Online]
Available at: Hhttp://www.hydrogensolar.com/

299 £7.2 million for hydrogen and fuel cell demonstration programme. Low Carbon Knowledge Transfer Network. [Online]
Available at: Hhttp://www.low-carbon-ktn.org.uk/showdoc.asp?doc_id=11610

300 Cenex: Centre of excellence for low carbon and fuel cell technology. [Online]
Available at: Hhttp://www.cenex.co.uk/

301 UK Sustainable hydrogen energy consortium, social science workstream. Publications. [Online]
Available at: Hhttp://www.psi.org.uk/ukshec/publications.htm

302 Pritchard, D.K., Royle, M. and Willoughby, D. Installation and permitting guidance for hydrogen and fuel cell stationary applications: UK version. 2009. HSE Research report 715. [Online]
Available at: Hhttp://www.hse.gov.uk/research/rrpdf/rr715.pdf

303 The EC network of excellence for hydrogen safety 'Hysafe' [Online]
Available at: Hhttp://www.hysafe.org/

304 Hobss, J. 2006. The hydrogen economy- Evaluation of the materials science and engineering issues. HSL/2006/59, Engineering Control Group, HSL. [Online]
Available at: Hhttp://www.hse.gov.uk/research/hsl_pdf/2006/hsl0659.pdfH

305 Greenpeace. The Greenpeace case against coal fired power generation. [Online]
Available at: Hhttp://www.greenpeace.org.uk/files/pdfs/climate/caseagainstcoal200909.pdf

306 Webster, B., 2009. Green activists claim victory over coal power. The Times, 8 October. [Online]
Available at: Hhttp://www.timesonline.co.uk/tol/news/environment/article6865464.ece

307 Greenpeace. Myths and Facts of 'clean coal' technologies. [Online]
Available at: Hhttp://www.greenpeace.org/seasia/en/asia-energy-revolution/dirty-energy/clean-coal-myth/clean-coal-myths-and-facts

[308] Fineren, D., 2009. Kingsnorth freeze means more addiction to gas. Article, 9 October. [Online] Available at: Hhttp://uk.reuters.com/article/idUKLNE59802V20091009

[309] Stoves Online. Types (Ranks) of Coal. [Online]
Available at: Hhttp://www.stovesonline.co.uk/coal-types.html

[310] Reuters UK, 2007. FACTBOX – Types of coal and their uses. Article, 15 August. [Online]
Available at:
Hhttp://uk.reuters.com/article/idUKL1570461420070815?pageNumber=3&virtualBrandChannel=0

[311] UK Coal. Coal can be found in every continent in the world. [Online]
Available at: Hhttp://www.ukcoal.com/coal-around-the-world

[312] CoalImp. Coal in the UK - 2008. [Online]
Available at: Hhttp://www.coalimp.org.uk/3.html

[313] Coalpro. UK Coal Consumption. [Online]
Available at: Hhttp://www.coalpro.co.uk/index.shtml

[314] IEA Clean Coal Centre. Clean Coal Technologies: Pulverised coal combustion (PCC). [Online]
Available at: Hhttp://www.iea-coal.org.uk/site/ieacoal_old/databases/ccts/pulverized-coal-combustion-pccH?

[315] World Coal Institute, 2010. Improving Efficiencies. [Online] Available at:
Hhttp://www.worldcoal.org/coal-the-environment/coal-use-the-environment/improving-efficiencies/

[316] IEA Clean Coal Centre. Clean Coal Technologies: Integrated gasification combined cycle (IGCC). [Online]
Available at: Hhttp://www.iea-coal.org.uk/site/ieacoal_old/clean-coal-technologies-pages/clean-coal-technologies-integrated-gasification-combined-cycle-igcc?

[317] IEA Clean Coal Centre. Clean Coal Technologies: Fluidised bed combustion (FBC). [Online]
Available at:Hhttp://www.iea-coal.org.uk/site/ieacoal_old/clean-coal-technologies-pages/clean-coal-technologies-fluidised-bed-combustion-fbc?

[318] US Department of Energy, 2009. Fluidized Bed Technology - Overview. [Online]
Available
at:Hhttp://fossil.energy.gov/programs/powersystems/combustion/fluidizedbed_overview.html

[319] US Department of Energy, 2009. Gasification Technology R&D. [Online]
Available at: Hhttp://www.fossil.energy.gov/programs/powersystems/gasification/index.html

[320] BBC News, 2005. Clean coal technology: How it works. [Online] 28 November.
Available at: Hhttp://news.bbc.co.uk/1/hi/sci/tech/4468076.stm

[321] IEA Clean Coal Centre. Clean Coal Technologies: Particulate emissions control technologies. [Online]
Available at: Hhttp://www.iea-coal.org.uk/site/ieacoal_old/clean-coal-technologies-pages/particulate-emissions-control-technologies?

[322] Department of Trade and Industry, 2001. Case Study: On-Line Monitoring of Particulate Emissions from Coal Utilisation. [Online]
Available at: Hhttp://www.berr.gov.uk/files/file20813.pdf

[323] Carpenter, A.M. et al, 2006. NOx - emissions and control. IEA Clean Coal Centre, Coal Online. [Online]
Available at: Hhttp://www.coal.org.uk/site/coalonline/content/browser/81423/NOx-emissions-and-control

[324] IEA Clean Coal Centre. Clean Coal Technologies: NOx emissions abatement and control by primary measures. [Online]
Available at: Hhttp://www.iea-coal.org.uk/site/ieacoal_old/clean-coal-technologies-pages/clean-coal-technologies-nox-emissions-abatement-and-control-by-primary-measures-?

[325] Adams, D.M.B. et al, 2006. SOx - emissions and control. IEA Clean Coal Centre, Coal Online. [Online]
Available at: Hhttp://www.coalonline.org/site/coalonline/content/browser/81432/SOx-emissions-and-control

[326] Manchester Metropolitan University. Industrial Emission Controls. Atmosphere Climate and Environment Information Programme. [Online]
Available at: Hhttp://www.ace.mmu.ac.uk/eae/Acid_Rain/Older/Industrial_Emission_Controls.html

[327] Department of Trade and Industry, 2000. Flue Gas Desulphurisation (FGD) Technologies. Report DTI/Pub URN 00/652. [Online]
Available at: Hhttp://www.berr.gov.uk/files/file19291.pdf

[328] World Coal Institute, 2009. Coal Use and the Environment. [Online]
Available at: Hhttp://www.worldcoal.org/coal-the-environment/coal-use-the-environment/

[329] Benson, S.A et al, 1994. Trace Element Emissions. US Department of Energy, Conference Paper. [Online]
Available at: Hhttp://www.osti.gov/bridge/servlets/purl/10191055-Kotqgc/webviewable/10191055.pdf

[330] Department of Energy and Climate Change, 2009. Consultation on a framework for the development of clean coal. [Online]
Available at:Hhttp://www.decc.gov.uk/en/content/cms/consultations/clean_coal/clean_coal.aspx

[331] BCG Energy Ltd. Firth of Forth UCG. [Online]
Available at: Hhttp://www.britishcoalgasification.co.uk/News-item1.html

[332] Coal Research Forum, 2009. Newsletter of the Coal Research Forum, No. 56, September 2009. [Online]
Available at: Hhttp://www.coalresearchforum.org/crfnews.pdf

[333] BCG Energy Ltd. Underground Coal Gasification. [Online]
Available at: Hhttp://www.britishcoalgasification.co.uk/UCG.html

[334] BCG Energy Ltd. Controlled Retractable Ignition Point (CRIPS). [Online]
Available at:Hhttp://www.britishcoalgasification.co.uk/crips.html

[335] Coal Mining, 2009. Scientists discover ancient bugs turn coal into natural gas. Article, 30 June. [Online]
Available at: Hhttp://www.miningcoal.com.au/article/scientists-discover-ancient-bugs-turn-coal-into-natural-gas/488643.aspx

[336] Bullis, K., 2009. Fuel from Coal-Eating Microbes. MIT Technology Review, 8 January. [Online]
Available at: Hhttp://www.technologyreview.com/energy/21932/

[337] Pearce, F., 2008. Time to bury the 'clean coal' myth. The Guardian, 30 October. [Online]

Available at: Hhttp://www.guardian.co.uk/environment/2008/oct/30/fossilfuels-carbonemissions

[338] Madrigal, A., 2009. Back to the FutureGen: 'Clean' Coal Plant Gets New Backing. Article 12 June. [Online]
Available at: Hhttp://www.wired.com/wiredscience/2009/06/futuregen/

[339] Ricketts, C., DOE cools off on FutureGen's clean coal plant. Greenbeat, 2 September. [Online]
Available at: Hhttp://green.venturebeat.com/2009/09/02/doe-cools-off-on-futuregens-clean-coal-plant/

[340] Queensland Government, 2008. ZeroGen Mark II – world's first clean coal power a step closer: Bligh. Media Centre, 19 March. [Online]
Available at: Hhttp://www.dme.qld.gov.au/media_centre.cfm?item=477.0

[341] Biopact, 2007. Report : clean coal and CCS 'feasible' in the UK – towards carbon negative energy? Article, 15 May. [Online]
Available at: Hhttp://news.mongabay.com/bioenergy/2007/05/report-clean-coal-and-ccs-feasible-in_15.html

[342] Bradbrook, S., 2009. Carbon Capture and Storage. Health and Safety Executive Horizon Scanning Short Form Report SR018. [Online]
Available at: Hhttp://www.hse.gov.uk/horizons/carbon-capture.pdf

[343] Ellwood, P.A., 2007. Methane Gas Hydrates. Health and Safety Executive Horizon Scanning Short Form Report SR009. [Online]
Available at: Hhttp://www.hse.gov.uk/horizons/methanegas.pdf

[344] Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007
Available at:
Hhttp://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg3_report_mitigation_of_climate_change.htm

[345] Health and Safety Executive, Horizon Scanning – Hydrogen Economy. [Online]
Available at: Hhttp://www.hse.gov.uk/horizons/hydrogen.htm

[346] Poyry, 2009. Impact of Intermittency. How wind variability could change the shape of the British and Irish electricity markets. Report, July. [Onine] Available at:
Hhttp://www.poyry.com/linked/group/study

[347] British Wind Energy Association. About BWEA. [Online]
Available at: Hhttp://www.bwea.com/about/index.html

[348] Department for Business, Enterprise and Regulatory Reform. Renewables Innovation Review. Presentation. [Online]
Available at: Hhttp://www.berr.gov.uk/files/file22016.pdf

[349] Miliband, E., 2009. Low Carbon Transition Plan. Statement to the House of Commons, 15 July. [Online]
Available at:Hhttp://www.decc.gov.uk/en/content/cms/news/lctp_statement/lctp_statement.aspx

[350] New Energy Focus, 2009. Renewables industry supports 'socialised' grid access model, 20 November. [Online] Available at:
Hhttp://www.newenergyfocus.com/do/ecco/view_item?listid=1&listcatid=32&listitemid=3243

[351] Department for Business, Enterprise and Regulatory Reform. The World Offshore Renewable Energy Report 2004-2008. [Online]

Available at: Hhttp://www.berr.gov.uk/files/file43217.pdf

[352] Tidal Today. A call for early grid connection applications for the Pentland Firth. [Online]
Available at: Hhttp://social.tidaltoday.com/news/call-early-grid-connection-applications-pentland-firth

[353] New Energy Focus, 2009. National Grid 'needs clear signals' from marine sector. Hydro and Marine News, 3 July. [Online]
Available at:
Hhttp://www.newenergyfocus.com/do/ecco.py/view_item?listid=1&listcatid=128&listitemid=2794

[354] Penn Energy, 2009. UK Wave Hub project secures National Grid connection contract. Article, 4 August. [Online]
Available at: Hhttp://www.pennenergy.com/index/power/smart-grid/display/367316/s-articles/s-pennenergy/s-power/s-smart-grid/s-uk-wave-hub-project-secures-national-grid-connection-contract.html

[355] Ofgem. Distribution Price Control Review 5 (DPCR5). [Online]
Available at: Hhttp://www.ofgem.gov.uk/Networks/ElecDist/PriceCntrls/DPCR5/Pages/DPCR5.aspx

[356] Department of Energy and Climate Change, 2009. Consultation on Smart Metering for electricity and gas. [Online]
Available at:
Hhttp://www.decc.gov.uk/en/content/cms/consultations/smart_metering/smart_metering.aspx

[357] Low Carbon Economy, 2009. Ofgem proposes smart grid cities to cut carbon emissions. Low Carbon News, 4 August. [Online]
Available at: Hhttp://www.lowcarboneconomy.com/community_content/_low_carbon_news/6826

[358] Webb, T., 2009. Ofgem plans 'smart grid cities' as it gears up to go green. The Guardian, 3 August. [Online]
Available at: Hhttp://www.guardian.co.uk/business/2009/aug/03/ofgem-smart-grid-cities

[359] Sandeberg, P. and Stendius, L. Large
scale Offshore Wind Power Energy evacuation by HVDC Light.® [Online]
Available at:
Hhttp://www.ewec2008proceedings.info/ewec2008/allfiles2/212_EWEC2008fullpaper.pdf

[360] Barnes, M. Sustainable Energy Infrastructure and Supply Technologies - Offshore HVDC Grids. Joule Centre project summary. [Online]
Available at: Hhttp://www.joulecentre.org/research/4th_call/Summary for website -Barnes.pdf

[361] ENSG, 2009. Our Electricity Transmission Network: A Vision for 2020. Addendum Report - Further Analysis - 2030 Generation and Demand Scenarios.
URN: 09D/715. [Online]
Available at: Hhttp://www.ensg.gov.uk/assets/ensg__2030_transmission_addendum_final_issue_1.pdf

[362] National Grid, 2007. New €600 Million Electricity Link to Be Built Between Netherlands and UK. Transmission and Distribution World, 24 May. [Online]
Available at: Hhttp://tdworld.com/underground_transmission_distribution/national-grid-electricity-link-netherlands-uk/

[363] New Energy Focus, 2009. Scotland plans "big push" towards European grid connection. Article, 30 June. [Online]
Available at:
Hhttp://www.newenergyfocus.com/do/ecco.py/view_item?listid=1&listcatid=32&listitemid=2784

[364] The European Wind Energy Association, 2005. Large Scale Integration of Wind Energy in the European Power Supply: analysis, issues and recommendations. [Online]
Available at:
Hhttp://www.ewea.org/fileadmin/ewea_documents/documents/publications/grid/051215_Grid_report.pdf

[365] Hobson, S., 2009. 'Wire we waiting' asks National Grid transmission boss. Utility Week, 12 June. [Online]
Available at: Hhttp://www.utilityweek.co.uk/features/interviews/wire-we-waiting-asks-national.php

[366] Taylor, S., 2009. Interconnectors are key to a single market and security of supply. European Voice, 23 July. [Online]
Available at: Hhttp://www.europeanvoice.com/article/imported/interconnectors-are-key-to-a-single-market-and-security-of-supply/65587.aspx

[367] Scottish Council for Development and Industry, 2009. The Future of Britain's Electricity Networks. Report. [Online]
Available at: Hhttp://www.scdi.org.uk/pi/2009/TheFutureOfBritainsElectricityNetworks.pdf

[368] National Grid. 2009 Seven Year Statement. [Online]
Available at: Hhttp://www.nationalgrid.com/uk/Electricity/SYS/

[369] Hettlage, R. and Steilin, M., 2006. The Critical Incident Technique in Knowledge Management-Related Contexts - A tool for exploration / planning, evaluation and empowerment / animation. Hlevetas report. [Online]
Available at: Hhttp://www.i-p-k.ch/files/CriticalIncidentTechnique_in_KM.pdf

[370] Department of Trade and Industry, 2006. The Energy Challenge, Chapter 3 – Distributed Energy. [Online]
Available at: Hhttp://www.berr.gov.uk/files/file32004.pdf

[371] National Grid, 2009. National Grid calls for UK Masterplan to meet climate change energy challenge. Press Release, 23 March. [Online]
Available at:
Hhttp://www.nationalgrid.com/corporate/Media+Centre/Press+Releases/Global+Press+Releases/230309.htm

[372] Centrica, 2008. Securing future energy supplies. [Online]
Available at: Hhttp://www.centrica.com/index.asp?pageid=474

[373] Norwegian Mission to the EU. The Norwegian energy sector and Europe. [Online]
Available at: Hhttp://www.eu-norway.org/eu/policyareas/Energy/

[374] Norwegian Government, 2003. Historic UK-Norway energy agreement paves way for huge gas supply projects. Press Release, 3 October. [Online]
Available at: Hhttp://www.regjeringen.no/nn/dokumentarkiv/Regjeringa-Bondevik-II/oed/233575/233913/historic_uk-norway_energy_agreement.html?id=251043

[375] BBC, 2009. Safety Briefing on LNG Terminals. BBC News, 8 January. [Online]
Available at: Hhttp://news.bbc.co.uk/1/hi/wales/south_west/7816153.stm

[376] Health and Safety Executive. LNG Terminals – Consent and operational issues. [Online]
Available at: Hhttp://www.hse.gov.uk/GAS/supply/ingterminals.htm

[377] Minsaas, R., and Strowger, V., 2008. Under the influence of oil: UK gas prices and their prospects in a global gas market looking towards 2020. Eclipse Energy Group. [Online]

Available at: Hhttp://www.centrica.co.uk/files/pdf/180708_influence_of_oil.pdf

[378] Health and Safety Executive. Gas Supply Health and Safety. [Online]
Available at: Hhttp://www.hse.gov.uk/gas/supply/index.htm

[379] Amos, W.A., 1998. Costs of Storing and Transporting Hydrogen. Report – National Renewable Energy Laboratory. [Online]
Available at: Hhttp://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/25106.pdf

[380] Bradbrook, S., 2009. Wind Energy. Health and Safety Executive Horizon Scanning Short Form Report SR020. [Online]
Available at: Hhttp://www.hse.gov.uk/horizons/wind-energy.pdf

[381] Bradbrook, S., 2009. Biomass. Health and Safety Executive Horizon Scanning Short Form Report SR019. [Online]
Available at: Hhttp://www.hse.gov.uk/horizons/biomass.pdf

[382] Bradbrook, S., 2009. Solar Energy. Health and Safety Executive Horizon Scanning Short Form Report SR022. [Online]
Available at:Hhttp://www.hse.gov.uk/horizons/sr022.pdf

[383] European Parliament, 2001. Directive 2001/80/EC of the
European Parliament and of the Council. Official Journal of the European Union, 27 November. [Online]
Available at: Hhttp://eur-lex.europa.eu/LexUriServ/site/en/oj/2001/l_309/l_30920011127en00010021.pdf

[384] European Commission, 2009. Adapting to climate change : towards a European framework for action. White
Paper, 1 April. [Online]
Available at: Hhttp://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52009DC0147:EN:NOT

[385] European Commission, 2001. Final Report: ECCP Working Group 1 'Flexible Mechanisms'. Report, 2 May. [Online]
Available at: Hhttp://ec.europa.eu/environment/climat/pdf/final_report.pdf

[386] European Parliament, 2009. Directive 2009/31/EC of the
European Parliament and of the Council. Official Journal of the European Union, 5 June. [Online]
Available at: Hhttp://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0114:0135:EN:PDF

[387] H.M. Government, 2006. Tomorrow's Climate – Today's Challenge. UK Climate Change Programme 2006. [Online]
Available at: Hhttp://www.jncc.gov.uk/pdf/BRAG_CC_ClimateChangeTheUKProgramme.pdf

[388] UK Climate Impact Programme. UK Climate Projections. [Online]
Available at: Hhttp://ukclimateprojections.defra.gov.uk/

[389] Department of Health, 2008. Health effects of climate change in the UK 2008: an update of the Department of Health report 2001/2002. Health Protection Agency Report, 12 February. [Online]
Available at:
Hhttp://www.dh.gov.uk/en/Publicationsandstatistics/Publications/PublicationsPolicyAndGuidance/DH_080702

[390] Environment Agency. Climate Change Adaptation Strategy 2008-2011. [Online]

Available at: Hhttp://www.environment-agency.gov.uk/static/documents/Leisure/adaptation_strategy_2083410.pdf

[391] Department for Communities and Local Government, 2005. Planning Policy Statement: Planning and Climate Change – Supplement to Planning Policy Statement 1. [Online]
Available at: Hhttp://www.communities.gov.uk/planningandbuilding/planning/planningpolicyguidance/planningpolicystatements/planningpolicystatements/ppsclimatechange/

[392] The National Assembly for Wales, 2000. Wales: Changing Climate, Challenging Choices. The impacts of climate change in Wales from now to 2080. Summary Report. [Online]
Available at: Hhttp://www.jncc.gov.uk/page-4005

[393] Welsh Assembly Government, 2007. One Wales A progressive agenda for the government of Wales. [Online]
Available at: Hhttp://wales.gov.uk/about/programmeforgovernment/strategy/publications/onewales/?lang=en

[394] Welsh Assembly Government, 2008. Consultation on further amendments to the draft planning for Climate Change Ministerial Interim Planning Policy Statement (MIPPS) (12/06). Submission, 2 July. [Online]
Available at: Hhttp://playlearngrowwales.gov.uk/publications/accessinfo/drnewhomepage/environmentdrs2/environmentdrs2008/consultamendstomipps1206/?lang=en

[395] Welsh Assembly Government, 2009. Wales Climate Change Strategy (in preparation). [Online]
Available at:H http://wales.gov.uk/topics/environmentcountryside/climatechange/tacklingchange/strategy/walesstrategy/;jsessionid=gJ68LY3ZNGkPksV5BJC9MjyDRcszLCJSTJR0ybtPrvcR37DdYQzJ!686978193?lang=en

[396] Scottish Executive, 2006. Changing Our Ways: Scotland's Climate Change Programme. Report ISBN 0-7559-4984-6. [Online]
Available at: Hhttp://www.scotland.gov.uk/Resource/Doc/100896/0024396.pdf

[397] The Scottish Government, 2009. Preparing for a Changing Climate: Second Consultation to Inform Scotland's Climate Change Adaptation Framework. Document, 27 April. [Online]
Available at: Hhttp://www.scotland.gov.uk/Publications/2009/04/23145206/0

[398] The Scottish Parliament, 2009. Climate Change (Scotland) Bill (SP Bill 17). [Online]
Available at: Hhttp://www.scottish.parliament.uk/s3/bills/17-ClimateChange/index.htm

[399] Scotland and Northern Ireland Forum for Environmental Research (SNIFFER), 2007. Preparing for a Changing Climate in Northern Ireland. Project Summary. [Online]
Available at: Hhttp://www.sniffer.org.uk/Resources/UKCC13/Layout_Default/0.aspx?backurl=http per cent3A per cent2F per cent2Fwww.sniffer.org.uk per cent3A80 per cent2Fproject-search-results.aspx per cent3Fsearchterm per cent3Dukcc13&selectedtab=completed