House of Commons

Science and Technology Committee

# Meeting UK Energy and Climate Needs:

## The Role of Carbon Capture and Storage

## First Report of Session 2005–06

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# Summary

As evidence of the harmful effects of climate change and ocean acidification accumulates, carbon dioxide ($CO_2$) emissions around the world continue to grow. The UK is struggling to meet its targets to reduce $CO_2$ emissions by 20% below 1990 levels by 2010 and 60% by 2050, while growing energy demand in countries such as China and India is expected to fuel a dramatic, and potentially disastrous, increase in global emissions over coming years. At the same time, domestic concerns over security of supply are increasingly dominating the debate about energy policy, reflecting unease over UK dependence on imported gas sourced from certain unstable parts of the world, higher and more volatile energy prices, and the need to replace the UK's ageing fleet of coal-fired and nuclear power plant.

In this inquiry we find that there is significant scope for Carbon Capture and Storage (CCS) technology to contribute both to reducing $CO_2$ emissions in the UK and abroad, and to enhancing the security of the UK's future energy supplies. Most of the technology is already proven and available but there is a lack of experience in integrating the component technologies in single projects at the scale required. Multiple full scale demonstration projects using different types of capture technology and storage conditions are urgently needed.

In this Report, we conclude that the costs of CCS are comparable to other low carbon approaches to electricity generation and that there is the potential for substantial cost reduction due to technological development, increased experience and economies of scale. Enhanced oil recovery can also help to offset the cost of CCS by lengthening the life of the North Sea oil fields, as well as releasing stranded oil assets. We recommend that capture readiness be made a requirement for statutory licensing of new plant in order to maximise the opportunity to fit capture technology to new UK plant, and to promote the concept to other countries.

The available evidence suggests that geological storage is relatively safe and secure and that, with an appropriate regulatory framework in place and a concerted effort to communicate the risks and benefits of the technology to the public, CCS can achieve widespread acceptance. The Government must now redouble its efforts to secure clarification or amendment of the international conventions governing marine pollution, i.e. the OSPAR Convention and London Convention/Protocol, to ensure that geological storage of $CO_2$ under the seabed is permissible under international law. In addition, there is a pressing need for the Government to address the regulatory barriers to reuse of the North Sea infrastructure for the purposes of enhanced oil recovery and CCS, before decommissioning of oil and gas fields begins in earnest.

We find that the UK is well positioned to play a leading role in demonstrating CCS technology. The UK has rich expertise in geology and in oil and gas exploration and production. It is also fortunate in having an abundance of well characterised potential storage sites. UK industry has made it clear that it is poised to make substantial investments in CCS and full scale demonstration projects could be up and running by the end of the decade. However, the Government will need to display much greater ambition and commitment than it has done to date in order to take advantage of this opportunity.

This includes increasing investments in research, development and demonstration (RD&D) by an order of magnitude, in order to 'pump prime' the initial demonstration projects. All that remains is for the Government to put in place a long term incentive framework and a policy signal to give industry the confidence to proceed. We urge the Government to ensure that the Energy Review finally provides this.

The Government needs to respond to this challenge with the urgency it demands. The imperative comes not just from the opportunity to deliver benefits for the UK, but also from the danger that a lack of progress in demonstrating CCS technology could prevent it from being deployed in time to make any significant impact on the forecast growth in emissions from China and India, at a potentially heavy global cost.

# 1 Introduction

1. Climate change and energy policy are demanding ever more attention, both in the UK and abroad. The two-pronged challenge facing the UK Government was articulated by the Prime Minister Tony Blair in his keynote speech to the 2005 Labour Party Conference:

> "Global warming is too serious for the world any longer to ignore its danger or split into opposing factions on it.
>
> And for how much longer can countries like ours allow the security of our energy supply to be dependent on some of the most unstable parts of the world?"[1]

The Government's other priority of guaranteeing the affordability of energy is, in part, a function of security of supply. These UK concerns are set against an international backdrop of burgeoning consumption of fossil fuels in countries such as India and China. The rapid growth in carbon dioxide ($CO_2$) emissions forecast from these countries imparts a sense of urgency to efforts to develop solutions which can mitigate $CO_2$ emissions without impeding economic growth.

2. We decided to launch an inquiry into Carbon Capture and Storage (CCS) to examine the potential for these technologies to make a significant contribution to both meeting the Government's objectives of reducing domestic $CO_2$ emissions and securing energy supply, and to reducing emissions associated with fossil fuel combustion in China and India. We announced our inquiry into CCS on 21 July 2005, inviting evidence on the following points:

- The viability of CCS as a carbon abatement technology for the UK, in terms of:
  - The current state of R&D in, and deployment of, CCS technologies;
  - Projected timescales for producing market-ready, scalable technologies;
  - Cost;
  - Geophysical feasibility; and
  - Other obstacles or constraints.
- The UK Government's role in funding CCS R&D and providing incentives for technology transfer and industrial R&D in CCS technology.[2]

3. In the course of this inquiry we held three oral evidence sessions, during which we heard from:

- Officials from the Department of Trade and Industry (DTI), HM Treasury and the Department for Environment, Food and Rural Affairs (DEFRA);

1 See http://news.bbc.co.uk/1/hi/uk_politics/4287370.stm

2 Press notice 4 of Session 2005–06

- The British Geological Survey;
- The UK Carbon Capture and Storage Consortium;
- Air Products Plc, BP Plc, E.ON UK Plc and Alstom Power;
- Friends of the Earth, Green Alliance and Greenpeace; and
- Minister for Energy, Malcolm Wicks.

4. The transcripts of these sessions are published with this Report, together with the 40 written submissions received in response to our call for evidence and requests for supplementary information. In addition, a private seminar with CCS experts was held at the outset of the inquiry. We undertook visits to E.ON UK's Ratcliffe power station, the British Geological Survey's offices in Keyworth and BP's offices in Sunbury. We are grateful to all those who have contributed to this inquiry and assisted in the visit arrangements. We would also like to place on record our thanks to our specialist advisers: Professor Stuart Haszeldine, Professor of Geology at the University of Edinburgh and the UK Energy Research Centre, and Dr Paul Freund, one of the convening lead authors of the Intergovernmental Panel on Climate Change Special Report on CCS.

# 2 Background

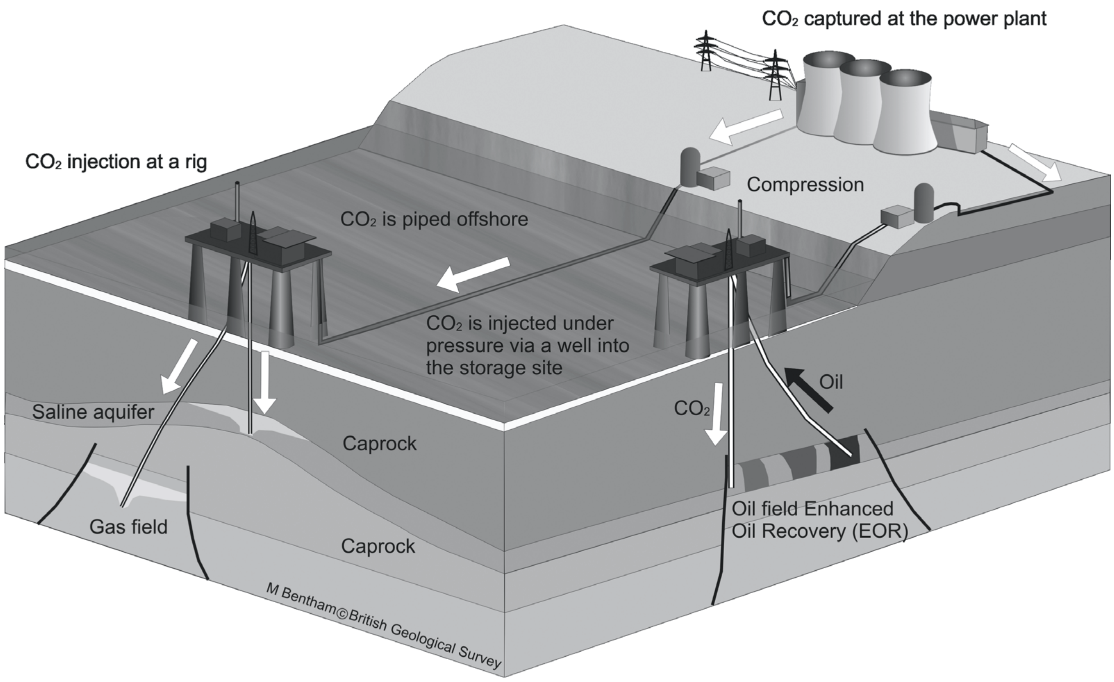
## Definitions

### *Carbon Capture and Storage*

5. Carbon Capture and Storage (CCS) refers to the capture and storage of carbon dioxide ($CO_2$) from emissions to prevent it from entering the atmosphere. The term 'CCS' refers to the application of carbon abatement technologies to industrial emissions, rather than to biological processes such as the take-up and storage of $CO_2$ by forests. The term 'carbon sequestration' is often applied to these biological processes, although it may sometimes also be used to denote CCS.

6. CCS can be broadly divided into three stages: capture, transport and storage. An overview of the process as applied to a power plant is provided in Figure 1. In brief, $CO_2$ is captured from the power plant either before or after combustion, prior to being compressed for transportation and injection into the storage site, typically a depleted oil or gas field or a saline aquifer. Further information on the capture, transportation and storage processes is contained in chapter three.

**Figure 1: An overview of the CCS process**




7. The objective of this Report is not to provide a detailed technical appraisal of CCS technology, which can, instead, be found in the recently published Intergovernmental Panel on Climate Change (IPCC) Special Report on CCS.[3] Useful and accessible summaries of CCS are also provided by two recent publications from the Parliamentary Office of Science and Technology: POSTnotes 238 and 253 which focus, respectively, on

3 IPCC, *Special Report on Carbon Dioxide Capture and Storage*, Autumn 2005, www.ipcc.ch/activity/srccs/index.htm.

$CO_2$ storage and cleaner coal technologies.[4] In addition, the House of Commons Environmental Audit Committee will be publishing in early 2006 a Report examining investment options for meeting future requirements for new electricity generating capacity.

## Enhanced oil recovery

8. Enhanced Oil Recovery [EOR] is a special case of CCS.[5] $CO_2$ pumped into a near-depleted field dissolves in the oil, making it more mobile and easier to extract. This can lengthen the life of the field and increase the overall yield of oil. EOR is an established onshore technology but it has not so far been used commercially offshore. Although some of the injected $CO_2$ returns to the surface with the oil, this is recaptured and added back to the $CO_2$ being injected. The climate change benefit of EOR arises if the $CO_2$ has been captured from fossil fuel combustion and if most of it is left in the reservoir at the end of its productive life. Further discussion of EOR can be found in paragraph 108.

## Leakage

9. It should be noted that throughout this Report the term 'leakage' will be used to refer to the unintended physical release of $CO_2$ from storage sites or pipelines transporting $CO_2$ between capture and storage sites. This should be distinguished from the definition of leakage commonly used in climate change discussions to refer to the spatial displacement of sources of emissions from one place to another.

## Gasification and pulverised fuel plant

10. There are two main methods for generating electricity from coal: combustion and gasification. The most common type of combustion plant is often called a 'pulverised fuel' (PF) station since the coal is finely ground before being injected into the combustion chamber. Superheated steam is then produced in a boiler and used to drive a steam turbine to produce electricity. Integrated gasification combined cycle (IGCC) plant employ gasification technology. The coal is converted to a synthesis gas (or 'syngas') which is fired in gas turbines to produce electricity. The hot exhaust gases are then used to produce superheated steam to drive a steam turbine, producing further electricity. IGCC is a newer and more efficient technology than PF and there are currently only four coal-fired IGCC plant around the world.[6]

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4 *Carbon Capture and Storage*, POSTnote 238, Parliamentary Office of Science and Technology, March 2005 and *Cleaner Coal*, POSTnote 253, Parliamentary Office of Science and Technology, December 2005.

5 Throughout this Report, CCS refers to EOR using $CO_2$ ($CO_2$-EOR) rather than other approaches to EOR.

6 See POSTnote 253 for further information.

**Box 1: Energy And Emissions Units**

Most of the statistics on power generation and consumption are quoted in kilowatts (kW), megawatts (MW) or gigawatts (GW) in this Report.

The watt (W) is the unit of power. This is a very small amount of power – in this Report, the smallest unit encountered is the kilowatt (kW): the unit normally used to measure consumption of domestic electricity.

- 1 kW = 1000 W
- 1 MW = 1000 kW
- 1 GW = 1000 MW

A kilowatt is roughly equivalent to the heat energy put out by a single bar electric heater. A car engine typically produces 50 to 100 kW. A typical coal-burning power station produces about 1000 MW (i.e. 1 GW) of power.

Electric energy generation or consumption is often measured in kilowatt hours (kWh). 1 kWh is roughly equivalent to a 100-watt light bulb burning for 10 hours. The average annual electricity consumption of a household in the UK is 4,700 kWh.

Carbon dioxide emissions are usually measured in kg or tonnes (1 tonne = 1000 kg).

- 1 megatonne (Mt) = 1,000,000 tonnes
- 1 gigatonne (Gt) = 1000 Mt

A tonne of $CO_2$ would occupy just over 500 cubic metres at standard temperature and pressure. $CO_2$ emissions may also be expressed in tonnes of carbon equivalent–many policy discussions take place in terms of tonnes of carbon. One tonne of carbon is equivalent to approximately 3.7 tonnes of $CO_2$.

A typical (1GW) coal-fired power station emits around 7 Mt $CO_2$ per year.

## Climate change policy

11. Climate change has been steadily working its way up the Government's list of policy priorities and formed one of the two key themes of the UK's G8 Presidency in 2005. It is widely accepted that rising atmospheric concentrations of $CO_2$ are fuelling climate change and ocean acidification and, in recognition of this, the UK, like other countries, is taking steps to reduce its $CO_2$ emissions. Global atmospheric carbon dioxide levels have risen from 280 parts per million (ppm) to 380 ppm since pre-industrial times – an increase attributed largely to the burning of fossil fuels.[7] Global average temperatures have risen by 0.6 degrees Celsius over the past century and further temperature increases, rising sea levels and a higher frequency of extreme weather events are predicted as $CO_2$ levels continue to rise.[8] There is also growing evidence of ocean acidification caused by higher levels of atmospheric $CO_2$ being absorbed by the oceans. This is thought to be exerting a detrimental effect on marine ecosystems.[9] For many years discussions about greenhouse gas emissions have focussed on limiting $CO_2$ levels to 550 ppm (approximately double pre-industrial levels) but many scientists now argue that even this level of $CO_2$ could be dangerously high.[10] The latest evidence suggests that atmospheric $CO_2$ concentrations

7 E.g. *Rapid Climate Change*, POSTnote 245, Parliamentary Office of Science and Technology, July 2005.

8 E.g. See IPCC, *Climate Change 2001: The scientific basis*, 2001 and *Avoiding Dangerous Climate Change*, International Symposium on the Stabilisation of Greenhouse Gas Concentrations, Report of the International Scientific Steering Committee, Met Office, May 2005.

9 The Royal Society, *Ocean acidification due to increasing atmospheric carbon dioxide*, June 2005.

10 E.g. *Rapid Climate Change*, POSTnote 245, July 2005, Parliamentary Office of Science and Technology.

would need to stay below 400 ppm in order to limit average global temperature increases to 2 degrees Celsius above pre-industrial levels. [11]

12. The UK has committed to meeting the following $CO_2$ emissions reduction targets:

- Kyoto protocol target to reduce $CO_2$ emissions by 12.5% below 1990 levels by 2008–2012—this represents the UK's share of the EU Kyoto target; and
- Domestic targets to reduce $CO_2$ emissions by 20% below 1990 levels by 2010, and by 60% below 1990 levels by 2050.

13. On current progress, it would seem that the UK is on track to meet its Kyoto Protocol target of a 12.5% reduction by 2008–2012. However, present Government projections suggest that $CO_2$ emissions will be around 13% below the 1990 level by 2010, significantly short of the domestic target of 20%.[12] Moreover, if the UK continues along its present trajectory, it will have little hope of meeting the Government's longer term domestic target of a 60% reduction in $CO_2$ emissions by 2050. A comprehensive summary of climate change mitigation in the UK is provided by the House of Commons Environment, Food and Rural Affairs Committee's 2005 Report on climate change.[13]

## *Role of CCS in climate change mitigation*

14. CCS provides a potential means of decreasing emissions of $CO_2$. The technology is generally best applied to large stationary sources of emissions, such as power plant. In 2002, total UK emissions of $CO_2$ were estimated to be 536 Mt, of which 228 Mt resulted from power generation. Twenty UK power plants alone were responsible for emitting 119 Mt of $CO_2$.[14] It is expected that fitting a power plant with CCS could reduce associated $CO_2$ emissions by around 85%, so the application of CCS technology to power plant could have a dramatic effect on $CO_2$ emissions. BP told us that if CCS was "applied to only 5% of the new electricity generating capacity which the world is projected to require by 2050, the world would have the potential of reducing global $CO_2$ emissions by around one billion tonnes [1 Gt] a year".[15] CCS also has the potential to contribute to reducing industrial emissions through direct application to energy-intensive processes such as oil refining and steel and cement manufacture. In addition, it may be possible for CCS to contribute to reducing emissions from the transport sector by providing a low carbon means of generating electricity for powering electric vehicles, or hydrogen for hydrogen-fuelled vehicles. This Report focuses on the use of CCS in power generation but the potential for these additional applications of CCS is discussed further in paragraph 39.

11 *Avoiding Dangerous Climate Change*, International Symposium on the Stabilisation of Greenhouse Gas Concentrations, Report of the International Scientific Steering Committee, Met Office, May 2005.

12 *Greenhouse gas emissions figures released today*, Department for the Environment, Food and Rural Affairs press release 134/05, 21 March 2005.

13 Ninth Report from the Environment, Food and Rural Affairs Committee, Session 2004–05, *Climate Change: looking forward*, HC 130–I.

14 Department for Trade and Industry, *Monitoring Technologies for the Geological Storage of $CO_2$,* Technology Status Report, Cleaner Fossil Fuels Programme, March 2005.

15 Ev 139

15. Clearly, CCS is not the only possible approach to reducing $CO_2$ emissions and a multi-pronged approach will need to be adopted if reductions are to be made in the timeframe desired. Other elements of the strategy may include reducing energy consumption, increasing energy efficiency and moving from carbon intensive sources of energy such as conventional coal to gas, nuclear and, in particular, renewables. Enhancing sequestration of $CO_2$ in so-called biological sinks, e.g. forests, could also play a role. The IPCC has produced a number of publications providing detailed information about these various options. The previous House of Commons Science and Technology Committee also published a Report entitled *Towards a Non-Carbon Fuel Economy: Research, Development and Demonstration* in 2003.[16] While these other measures will undoubtedly make key contributions to mitigating $CO_2$ emissions, detailed consideration of their respective roles is not within the remit of this Report.

## *International context*

16. The UK is responsible for around 2% of global $CO_2$ emissions. Whilst this country is making progress in the right direction, $CO_2$ emissions from some other countries are not only increasing, but are expected to continue to do so for the foreseeable future. According to the International Energy Agency (IEA), global emissions of $CO_2$ will be 52% higher by 2030 unless the world curbs its energy consumption and, even if developed nations implement climate change mitigation policies, global $CO_2$ emissions are still expected to rise by about 30% by 2030.[17]

17. Much of this growth will be attributable to the increasing use of coal by China and India. At present, the US is the largest consumer of coal for power generation but China and India, which have substantial coal reserves, are the fastest growing users. Current global coal-fired electricity generation capacity is estimated to be around 1000 Gigawatts. However, as Dr Nick Riley from the British Geological Survey told us in oral evidence, "China is installing one Gigawatt of coal powered generation a week. That is four megatons of $CO_2$ a week increase in China just from its coal plant generation".[18] Brian Morris, Head of Carbon Abatement Technologies at the DTI, also told us of his concerns over China and India's plans to build a vast fleet of new coal-fired plant: "Each year they are putting in coal fired power plants equal to the total capacity of the UK […] What is worrying is the possibility of carbon lock in".[19]

18. Current forecasts predict that by 2030, coal-fired power in India and China will add 3,000 million extra tonnes of $CO_2$ to the atmosphere every year—equivalent to around 13 times the UK's current total $CO_2$ emissions from power generation.[20] During the same period, emissions from China alone are forecast to grow by as much as those of the entire industrialised world. Other middle income countries such as Brazil may also add substantially to global emissions over this period. **It is indisputable that—in the absence**

16 Fourth Report from the Science and Technology Committee, Session 2002–03, *Towards a Non-Carbon Fuel Economy: Research, Development and Demonstration*, HC 55–I.

17 IEA, *World Energy Outlook 2005.*

18 Q 67

19 Q 12

20 Greg Cook and Paul Zakkour, "The new face of King Coal", Environmental Finance, August 2005.

**of CCS—fossil fuel consumption in countries such as China and India will have a profound and potentially catastrophic impact on global atmospheric $CO_2$ levels, eclipsing any reductions made by the UK and others.** The implications of this are discussed further in paragraphs 67–70.

19. Brian Morris, Head of Carbon Abatement Technologies at the DTI, stressed that China was "very aware of the consequences of climate change [and] the damage that burning coal without trying to control the emissions is going to do not just to the planet but to their own prospects in the future".[21] Mr Morris' view contrasted with evidence given by BP's Gardiner Hill, who said that in his experience, China was "not prepared to invest money on reducing $CO_2$ emissions".[22] Mr Hill told us: "China has particularly large challenges facing it today. They are not particularly focussed on the issues of climate change; they are much more focussed on providing the energy they need to develop their country".[23] However, Mr Hill proposed that China's concerns over air quality might provide an alternative entry point for promoting the uptake of CCS technologies: "I think when we get to the air quality issues conversation, there is an opportunity for us also to adopt CCS type technologies which will address air quality and start to address climate change. If we can make these links, we can perhaps make inroads to a country like China quicker than we would otherwise if we just went in on the climate change plan".[24] We consider the potential for CCS to help curb the forecast growth in emissions from China and India in chapter four.

## UK energy policy

20. On 29 November 2005, the Government launched a fundamental review of UK energy policy. The Government described the purpose of the review as being to "assess progress against the four goals set by the 2003 energy White Paper:

- to put ourselves on a path to cut the UK's carbon dioxide emissions—the main contributor to global warming—by some 60 per cent. by about 2050 with real progress by 2020;
- to maintain the reliability of energy supplies;
- to promote competitive markets in the UK and beyond, helping to raise the rate of sustainable economic growth and to improve our productivity; and
- to ensure that every home is adequately and affordably heated".[25]

The statement emphasised that the Energy Review "will consider all options including the role of current generating technologies, such as renewables, coal, gas and nuclear power, and new and emerging technologies, for example carbon capture and storage". Malcolm Wicks, the Energy Minister, has subsequently said: "Within the context of this review,

21 Q 15

22 Q 168

23 Q 153

24 Q 153

25 HC Deb, 29 Nov 2005, col 12WS.

Carbon Capture and Storage is increasingly becoming a serious longer-term option" and told us in oral evidence that the Government was "very, very interested" in it.[26,27]

21. In addition, the UK Climate Change Programme, which lays out the Government's policies for achieving its national target of reducing $CO_2$ emissions to 20% below 1990 levels by 2010, is currently under review and Sir Nicholas Stern, Head of the Government Economic Service, has also been charged with leading a review of the economics of climate change, due to be published in Autumn 2006.

### Government action on CCS

22. A review of CCS was already underway when the 2003 Energy White Paper was published. The White Paper also included a commitment to facilitate a demonstration of $CO_2$-based EOR, as well as acknowledging "the potentially significant strategic role that might be played by CCS in longer-term energy security".[28] Over the last three years the DTI has published three reports pertaining to CCS:

- Review of the Feasibility of Carbon Dioxide Capture and Storage in the UK (September 2003);[29]
- Implementing a Demonstration of Enhanced Oil Recovery Using $CO_2$ in the North Sea (May 2004);[30] and
- Carbon Abatement Technologies (CAT) Strategy for Fossil Fuel Use (June 2005).[31]

23. The CAT Strategy states that fossil fuels will be a major source of energy for decades to come and, if the UK is to meet its climate change targets, they will have to be used much more cleanly than at present. It further acknowledges that technologies to make fossil fuels more environmentally acceptable need to be developed and brought to market. The Strategy identified three technology areas which could deliver carbon savings from fossil use:

- Higher efficiency power generation (up to 20% saving);
- Co-firing with lower carbon fuels such as biomass (up to 10% saving); and
- Carbon Capture and Storage (up to 85% saving).[32]

The modelling work undertaken for the Strategy demonstrated that, under a number of scenarios, CCS would need to be deployed to some degree if the UK was to meet its target

26 *North Sea Rim Accord Paves Way for Sub-Sea Storage*, DTI press release P/2005/384, 30 November 2005.

27 Q 234

28 DTI, *Our Energy Future–Creating a Low Carbon Economy*, 2003.

29 DTI, *Review of the Feasibility of Carbon Dioxide Capture and Storage in the UK*, Cleaner Fossil Fuels Programme, September 2003.

30 DTI, *Implementing a Demonstration of Enhanced Oil Recovery Using $CO_2$ in the North Sea*, Cleaner Fossil Fuels Programme, May 2004

31 DTI, *A Strategy for Developing Carbon Abatement Technologies for Fossil Fuel Use*, Carbon Abatement Technologies Programme, June 2005.

32 As above.

to reduce $CO_2$ emissions by 60% by 2050. The Strategy also emphasised the need for cost reduction, especially at the capture stage, and for demonstration of safe and reliable geological storage. It additionally accepted the need for Government support to enable CCS to become commercially viable.[33] These findings are discussed in detail in the body of this Report.

24. Overall responsibility for CCS technologies lies with the Minister for Energy in the DTI but several Government Departments have an interest in the subject. The DTI Energy Group is responsible for Government policy to stimulate R&D for CCS technologies and enable them to be brought to market by industry. The Office of Science and Technology (OST) allocates Science Budget funding to the Research Councils which are, in turn, responsible for decisions on the scientific merits of specific investments in R&D in universities and Research Council institutes. The Department for the Environment, Food and Rural Affairs (DEFRA) has an interest in CCS technologies due to their potential to reduce carbon emissions from fossil fuels. HM Treasury's involvement relates to overall investment decisions and setting regulatory and investment frameworks which may impact on the development and deployment of CCS technologies. Finally, as discussed in chapter five, the Environment Agency and Health and Safety Executive additionally have responsibilities that relate to CCS technology.

25. Energy policy has been in a state of flux with many recent reviews and initiatives. By the end of 2006 the Government should have done the work necessary to establish a settled policy, at least for the medium term. Previous Government reviews have already identified a potential contribution for CCS in the UK energy portfolio. We now explore how this potential can be realized within wider energy policy and the conditions that would be required to maximise this.

33 DTI, *A Strategy for Developing Carbon Abatement Technologies for Fossil Fuel Use*, Carbon Abatement Technologies Programme, June 2005.

# 3 Technology

## Capture technologies

26. The purpose of $CO_2$ capture is to generate a concentrated stream of pure $CO_2$ for transport and injection into the storage site. $CO_2$ capture technology has been routinely used for many years to separate $CO_2$ from natural gas (known as natural gas 'sweetening') and for industrial processes such as ammonia production. However, none of these applications employ capture technology at the scale that would be required for capturing $CO_2$ from the emissions of a large-scale power plant. Box 2 provides an overview of the three main approaches to the capture of $CO_2$ from emissions: pre-combustion, post-combustion and oxyfuel. A summary of experience to date with capture technology is provided at Annex A.

**Box 2: Capture technologies**

**Pre-combustion capture**

- Currently used in the industrial manufacture of hydrogen and ammonia;
- Natural gas, coal, oil residuals or biomass is reacted with oxygen, air and/or steam to generate a synthesis gas or 'syngas' consisting mainly of carbon monoxide and hydrogen;
- The carbon monoxide is reacted with steam to give $CO_2$ and more hydrogen;
- The resulting gas mixture contains predominantly hydrogen gas and $CO_2$ (15– 40%) at a high pressure;
- The $CO_2$ is separated from the hydrogen, usually by physical solvent absorption although membranes may be a promising option for the future.

**Post-combustion capture**

- Currently used to separate $CO_2$ from the exhaust streams of power stations for use in the food industry. Similar technology has been in use since 1996 separating 1 Mt/y of $CO_2$ from a natural gas stream for injection into an aquifer beneath the Norwegian North Sea (the Sleipner project);
- $CO_2$ is captured from flue gas by separating it from nitrogen and oxygen gases; the $CO_2$ content is low (3 to 13%) and the separation is done at low pressure;
- The leading technology in post-combustion capture is chemical solvent absorption using amine-based solvents (commonly referred to as 'amine scrubbing') although other solvents are being developed.

**Oxyfuel capture**

- This technique is still at the laboratory scale;
- Fossil fuels, especially coal, are burnt in oxygen rather than air, producing a flue gas comprised mainly of $CO_2$ and water. This greatly facilitates the separation of $CO_2$;
- Pure oxygen is produced by cryogenic separation of air into mainly oxygen and nitrogen; this part of the process is relatively expensive at the moment and uses significant amounts of energy;
- Burning fuel in pure oxygen results in an extremely high flame temperature so part of the flue gas is recycled to the combustion chamber to control the flame temperature;
- Finally, water is condensed from the flue gas that is not recycled; some additional clean up of the $CO_2$ may also be required.

27. Different capture technologies are likely to be favoured depending on the circumstances, but the costs of the various capture options are expected to be comparable. Jon Gibbins, leader of the UK CCS Consortium (UKCCSC), told us:

> "It is a bit of a waste of time to worry about which [capture] technology is the best technology. You should say, 'Which is the best technology for which application?'

> There are a number of different applications and scenarios […] It is pretty obvious, looking at the numbers now, that the cost differences are not going to be that great”.[34]

There was general agreement that there was no merit in ‘picking winners’: all three capture options offer potential advantages and should be pursued.

28. The various capture technologies are at varying stages of maturity. Oxyfuel technology is the least developed of the three capture options, although it is generally considered to be a promising option for the future. Gardiner Hill, Manager Group Environmental Technology at BP, explained that the current limitations for oxyfuel capture were “around material choice to manage the high combustion temperatures and the cost of supplying the vast quantities of oxygen required”.[35] He predicted that although “there will be some demonstration small-scale of oxy-firing [oxyfuel capture] that will be undertaken by a number of companies in the next five years, […] there is probably a 15-year timeframe [before] we might expect to see [it] perhaps being used on a much larger scale”.[36]

29. E.ON UK pointed out that post-combustion capture of $CO_2$ using amine scrubbing “has been used for over 80 years for gas sweetening in the petrochemical industry and there are hundreds of plants in service today”.[37] There is also extensive experience of pre-combustion capture for industrial production of hydrogen. Indeed, most of the technology that underpins CCS is tried and tested although it has not yet been combined in a single CCS project at the scale required to make an impact on emissions from power generation. George Marsh, a DTI adviser on carbon abatement technologies, summed it up as follows: “most of the technology that we are talking about is available and deployed. The new thing that needs to be done is to combine it in an integrated process for carbon capture and storage”.[38]

### *Polygeneration*

30. The hydrogen which is produced by pre-combustion capture can be used for electricity generation, for carbon dilution of natural gas, or as a transportation fuel. BP highlighted the need to “be aware of the economic advantages offered by pre- (as opposed to post-) combustion” capture, commenting that “If the resultant $CO_2$ stream can be securely geologically stored, ‘green’ power can be manufactured from the hydrogen at a comparable cost to the nuclear or renewable alternatives, or the hydrogen can be added to the natural gas grid as a form of carbon dilution”.[39] Air Products further argued that the ability to generate “$H_2$ [hydrogen] from coal as a transport fuel would also break the monopoly position of oil”.[40]

34 Q 70

35 Q 124

36 Q 125

37 Ev 25

38 Q 14

39 Ev 85

40 Ev 73

31. Fossil fuels can be an important source of chemicals and with the continuing depletion of oil reserves, coal and gas could become significant sources of chemical feedstocks. Out of the three capture options, only pre-combustion capture enables the production of a key chemical, hydrogen, in tandem with electricity generation. Mr Hill from BP noted that this was one of the reasons that he believed China would be interested in pre-combustion technology: "Primarily it will be the pre-combustion technologies that will enable chemicals from coal to really underpin the Chinese economy so they can convert coal to fuels: they will want to convert coal to hydrogen; and they will want to convert coal to electricity without any impact on the environment".[41] Co-production of electricity and chemicals is sometimes referred to as 'polygeneration'. However, the volumes of chemical feedstocks that could be produced through pre-combustion capture are minor compared to power use and it is not yet clear whether polygeneration at a single plant will prove more economical or efficient than producing electricity and chemicals from separate plant.

32. The Royal Academy of Engineering told us that "Pre-combustion carbon capture combined with integrated gasifier combined cycle gas turbine (IGCC) technology is likely to emerge as the eventual natural gas or coal fuelled option that may be sustainable in a carbon constrained world".[42] We agree. **Although it is clearly important that pre-combustion, post-combustion and oxyfuel capture technologies be developed, we believe that for new plant pre-combustion capture offers a significant advantage, in a carbon constrained world, as a potential source of hydrogen. As the technology develops, the Government should take into account the potential strategic importance of polygeneration systems based on pre-combustion capture technology and consider the case for putting in place incentives to promote the use of this technology in new build plant.**

### *Retrofitting*

33. Retrofitting of existing plant with CCS technology could accelerate the contribution that CCS makes to reducing $CO_2$ emissions. However, much of the evidence we received was sceptical about the commercial viability of retrofitting UK coal-fired plant. The UK fleet of coal-fired power stations comprises combustion plant designed more than 30 years ago, which is relatively inefficient in modern terms.[43] Fitting a plant with CCS decreases the thermal efficiency of that plant so retrofitting already inefficient UK coal-fired plant is not likely to make economic sense, given currently available technology. The Royal Academy of Engineering for instance argued that "The efficiency penalty of currently available carbon capture technology is too high to be considered for a simple bolt-on addition to an existing power station" and noted that "the economics of retrofitting a power plant that may be at or beyond its design lifetime or emissions control capability would need close scrutiny".[44]

34. These concerns were echoed by industrial contributors to the inquiry. In oral evidence, Colin Scoins, Director of New Business at E.ON UK, told the Committee: "much of [the

41 Q 168

42 Ev 23

43 POSTnote 253

44 Ev 21

UK's] plant is very old, potentially 40 years old. It is probably not an economic decision to retrofit a plant of that age".[45] BP also noted that retrofitting was likely to entail shutting down the plant for a period of about 12 months, which could add prohibitively to the cost. Mitsui Babcock has estimated the cost of these lost 12 months to be around £50M.[46]

35. An alternative would be to undertake a major refurbishment of coal-fired plant by fitting new boilers and turbines to increase the efficiency of the plant substantially – in conjunction with such changes, installation of capture technology might be more attractive. Air Products, for example, argued that the "combination of a boiler/steam turbine upgrade plus the oxyfuel conversion would ensure $CO_2$ capture and delivery to a pipeline system at high pressure with only a very small reduction in overall station efficiency".[47] The DTI also suggested that "for existing coal stations it would be desirable to retrofit advanced boilers with the capture plant".[48] Although the possibility of upgrading some existing plant is an interesting one, its practicability is likely to depend on the specific circumstances of each plant. **In our view, no convincing case has yet been made for retrofitting of the UK's ageing fleet of coal-fired power stations with capture technology. Combining retrofitting with boiler and turbine replacement may provide a means of overcoming the loss in efficiency associated with current capture technology, but it remains to be seen whether this will prove economic for the majority of UK coal-fired plant.**

36. Due to time constraints, we did not look in any detail in the inquiry at the case for retrofitting gas-fired plant. The Government suggested in its evidence that "For existing gas plant one retrofit option is to retrofit pre-combustion capture and burn hydrogen in the existing gas turbines". It also noted that "Some existing gas turbines may be unsuited for this in which case post combustion capture (flue gas scrubbing) would be the only option".[49] It has also been proposed that retrofitting of gas-fired plant could provide an opportunity to incorporate a coal gasification facility – essentially converting the plant to an IGCC station. We consider this to be an interesting possibility and worthy of further investigation.

### *Capture ready plant*

37. E.ON UK highlighted the fact that up to 8GW of nuclear and 19GW of coal and oil-fired plant will need to be replaced in the UK by 2015.[50] This is equivalent to nearly a third of the UK's total electricity generating capacity. As discussed later, CCS technology may not be commercialised in time to enable significant amounts of the replacement plant to be built fitted with the technology. Yet new build plant is expected to have a lifespan of at least 30 years and, if CCS is not deployed on a significant scale by 2020, it is hard to see how it will be able to contribute to $CO_2$ emissions reductions in the required timeframe. The UK could then become 'locked in' to unacceptably high $CO_2$ emissions.

45 Q 122

46 Personal communication.

47 Ev 74

48 Ev 183

49 Ev 183

50 Ev 78

38. One possible solution that has been proposed to resolve the mismatch in timescales is the idea of building new plant 'capture ready'. This would mean making a small investment at the time of building to provide the future option of retrofitting capture technology at relatively low cost. At its simplest, capture ready just means giving due consideration to factors such as space and location during the planning stages of building a new plant, in order to facilitate subsequent instalment of CCS technology. The Government told us, for example:

> "Capture ready refers to plant designed to enable $CO_2$ capture equipment to be retrofitted with minimum disruption and in a manner that is optimal for future plant operations. Some key requirements are: availability of land for the capture plant; availability of space for the pipe-work and other systems needed to incorporate capture into the power plant; and the design of boiler and turbine systems to facilitate optimal integration. It has been suggested that location relative to $CO_2$ storage sites might be an additional 'capture ready' criterion".[51]

The Government additionally told us that there was a G8 initiative seeking to arrive at an agreed definition for capture readiness and noted that, once such an agreement had been reached, the licensing and consents process could be used to encourage new plant to be built capture ready. This would be a sensible approach, providing that it could be implemented sufficiently rapidly. **We recommend that Government makes capture readiness a requirement for statutory licensing of all new fossil fuel plant. This would compel the developer to demonstrate that consideration has been given in the planning and design of the plant to facilitating subsequent addition of suitable carbon dioxide capture technology, as and when it becomes available and economic.**

### *Capture of emissions from other processes*

39. The IPCC report, along with much of the evidence submitted to this inquiry, indicates that the major contribution of CCS to the mitigation of climate change will result from its deployment in the electricity sector. Nevertheless, other applications are also worth investigating. Corus pointed out in written evidence that "the steel industry, worldwide, accounts for approximately 5% of the total anthropogenic $CO_2$ emissions to atmosphere".[52] Corus is thus participating in an EU-funded research project entitled Ultra Low $CO_2$ Steelmaking (ULCOS), the aim of which is to investigate new steel production processes to drastically reduce $CO_2$ and other greenhouse gas emissions.[53] Dr Gibbins from the UKCCSC also emphasised the potential versatility of CCS: "Carbon capture and storage applies immediately to the electricity industry but in the longer term it can be applied to all sectors. You can produce decarbonised energy vectors – that is hydrogen or electricity for use in transport and in the building sector – so it really can apply to a very broad range of our energy usage".[54] **Although in the near term CCS is most likely to be employed in the power sector, it has the potential to be applied to a range of industrial processes, as well**

51 Ev 182

52 Ev 88

53 As above.

54 Q 61

**as in the building and transport sectors. We recommend that the Government support for CCS research includes applications in these sectors.**

## Storage

40. This section focuses on geological storage of $CO_2$ and, more specifically, on the prospects for storage of $CO_2$ in depleted oil and gas fields and deep saline aquifers. Saline aquifers are porous rock formations found deep underground which contain salty water unsuitable for use as potable water. Other approaches to storage, including storage in unmineable coal deposits, are considered in paragraphs 48 to 50. Geological storage of $CO_2$ has been occurring naturally for millions of years and accumulation of $CO_2$ in underground reservoirs for very long timescales is a common geological phenomenon.[55] It is proposed that, by analogy, the $CO_2$ captured from energy production and industrial processes could be injected into suitable geological formations in the earth's crust for extremely long term (tens of thousands of years) storage.

41. The basic principle entails the trapping of $CO_2$ in the pores—spaces between the sand grains—in sedimentary rocks.[56] At the pressures encountered at depths below 800–1000 m, $CO_2$ enters a so-called 'supercritical' state in which it has a density similar to that of a liquid;[57] this enables efficient use of the storage space. There are four mechanisms of $CO_2$ trapping and all may contribute at different times at any one site. Firstly, although the injected $CO_2$ is buoyant in the water in the rock formation, the presence of an impermeable layer of rock above the storage site, known as caprock, provides a seal to prevent the $CO_2$ migrating upwards. Secondly, the $CO_2$ can dissolve in the water which normally fills the pore spaces in the sedimentary rock, helping to trap it in the site. Thirdly, $CO_2$ may move slowly through the rock pores, driven by buoyancy; small bubbles of $CO_2$ are left stranded during this movement and become trapped in disconnected pores. Finally, the $CO_2$ may become trapped through chemical reactions with minerals in the surrounding rock and so, over the long term, may become immobilised in the form of carbonate minerals, similar to those which form natural limestone.

42. There are sufficient candidate geological storage sites for CCS to make a significant contribution to reducing UK $CO_2$ emissions over many tens, or even hundreds, of years. The BGS estimates that the theoretical storage potential of the UK's offshore oil and gas fields is equivalent to at least 4.7 Gigatonnes (Gt) of $CO_2$. This represents approximately 20 years' worth of all present day power generation emissions, although not all of this may be suitable for commercial exploitation.[58] According to the BGS, there is no significant potential for onshore $CO_2$ storage in oil or gas fields in the UK (with the possible exception of the Wytch farm oil field in Dorset). The UK's onshore aquifer storage potential has not yet been fully investigated.

55 IPCC, *Special Report on Carbon Dioxide Capture and Storage*, Autumn 2005.

56 Sedimentary rocks are made up of sediments, laid down millions of years ago, which may be second-hand fragments of other rocks, or remnants of living organisms.

57 Supercritical $CO_2$ occupies less than 1% of the space that $CO_2$ gas would fill at normal temperature and pressure.

58 Ev 72

43. There is extensive potential for $CO_2$ to be stored in deep saline aquifers in the North Sea. The BGS memorandum stated:

> "An estimate of 250Gt was calculated in the BGS led Joule 2 (1995) Project for all the aquifers (open and closed) in the UK N. Sea. With UK emissions at over 0.6Gt/year, a third of which comes from power generation it is clear that even if only 10% of this capacity was realized it would serve the UK's needs to beyond the period of fossil fuel dependency".[59]

This would be equivalent to more than 1000 years of storage, based on current UK power generation emissions. The IPCC report estimates global geological storage capacity to be sufficient for CCS to contribute up to 55% of the cumulative mitigation effort needed worldwide until 2100.[60] It should be noted that estimates of the storage potential offered by saline aquifers can vary wildly, reflecting the lack of data in this area.

44. The UK is especially fortunate in that many sources of $CO_2$ generation from onshore power plant and other industries lie within tens or hundreds of kilometres of potential storage sites in rocks beneath the offshore northern and southern North Sea and Irish Sea. This is within easy reach of pipeline transport, as proven by onshore $CO_2$ developments in the US and by offshore oil and gas transport around the UK. The geographic co-location of storage sites and $CO_2$ sources may be less favourable in some other countries, such as Japan, and has yet to be thoroughly investigated in many others. Professor Haszeldine commented on the UK's fortuitous situation in written evidence:

> "From hydrocarbon exploration, we have unrivalled knowledge of our offshore geology. These are some of the world's best-known and most accessible sediment basins, and contain both depleted oil and gas fields and deep aquifers of saline water".[61]

**The UK is fortunate in being very well endowed with potential $CO_2$ storage sites, many of which have been thoroughly characterised. This provides the UK with a competitive advantage in terms of access to potential $CO_2$ storage sites, both for its own use and to demonstrate UK geological skills to the rest of the world.**

45. In general, more is known about oil and gas fields than saline aquifers leading some people to suggest that the former are better candidates for immediate development as storage sites. The oil and gas fields in the North Sea have been particularly well characterised and both Friends of the Earth and Green Alliance were far more enthusiastic about CCS projects involving storage in oil and gas fields than those involving aquifers. Germana Canzi, Senior Climate Change Adviser for Friends of the Earth, told us: "We feel that the oil industry has a lot of experience with the geology of oil and gas fields and, therefore, we feel more confident that the science about the permanence of the $CO_2$ underground is more certain".[62] The evaluation of offshore saline aquifers for storage purposes is readily achievable, by application of the same techniques as are normally used

59 Ev 72

60 IPCC, *Special Report on Carbon Dioxide Capture and Storage*, Autumn 2005.

61 Ev 133

62 Q 213

in offshore oil and gas exploration and production. **Oil and gas fields have, in general, been better characterised than saline aquifers so may be more suitable for immediate development. Nevertheless, the best way of furthering understanding of storage of $CO_2$ in aquifers, which provide very substantial storage potential in the longer term, is through large scale demonstration projects.**

46. BP commented in its memorandum that the oil and gas industry had "over one hundred years of experience identifying and managing fluids in the deep sub-surface" and noted that the "geological storage of $CO_2$ is very similar to the management of other liquids and gases routinely handled by the industry throughout the world".[63] In addition, BP asserted that "the industry has considerable experience of oil and gas abandonment, and much of this will be used to form the basis for secure [field] abandonment to ensure long term safe, secure storage of $CO_2$ in the rock".[64] Furthermore, the British Geological Survey, which has developed an enviable reputation over its 170 years of operation, has innovated and maintained particular expertise in CCS since the early 1990s. **The UK's geological expertise through the hydrocarbon industry and British Geological Survey is recognised to be amongst the best in the world. This expertise should be leveraged to facilitate and promote UK demonstrations of CCS and, ultimately, uptake of CCS internationally.**

47. Globally, most experience to date of relevance to $CO_2$ injection has been obtained as a result of enhanced oil recovery (EOR) projects. There are more than 70 EOR projects around the world. Extensive experience in $CO_2$ injection into oil fields, for the purposes of enhanced hydrocarbon production, has been gained over a 30 year period, particularly in North America. The BGS commented on the fact that although there have been many commercial projects involving the injection of $CO_2$ for EOR, "few have been accessible to researchers".[65] At Weyburn and Rangely, there has been large scale $CO_2$ injection for EOR purposes. Apart from EOR projects, there are only two large-scale industrial projects worldwide, at In Salah in Algeria and Sleipner in Norway, where $CO_2$ is being injected underground at a rate of around 1Mt/year. Several more industrial size projects are planned to commence soon; Box 3 contains a summary of current and forthcoming projects involving $CO_2$ storage.

63 Ev 138

64 Ev 138

65 Ev 71

**Box 3: $CO_2$ storage: summary of experience**

**Summary**

At present, there are:

- Only a few commercial-scale examples storing more than 1 Mt/year $CO_2$:
  - Sleipner (Norway), In-Salah (Algeria).
- Many active research demonstrations of 1-100kt $CO_2$:
  - CRUST (Holland), Nagaoka (Japan), Frio (US), West Pearl Queen (US).
- Many imminent research demonstrations:
  - Teapot Dome (US), $CO_2$SINK (Germany), Otway (Australia).
- Numerous Enhanced Oil Recovery and acid gas injection projects:[66]
  - More than 70 worldwide, but none of these are offshore
  - Several involve more than 1Mt/y $CO_2$–Weyburn (Canada), Rangely (US).
- Large offshore developments planned:
  - Gorgon (Australia), Snohvit (Norway), Sibilla (Italy), Miller (UK).

**Enhanced Oil Recovery**

More than 70 EOR projects using $CO_2$ exist worldwide, 59 of which are in Texas.

- Research projects on EOR are Weyburn (Saskatchewan), operated as a commercial operation since 2000, to produce 122 M bbl extra oil over 15 years whilst storing 20 Mt $CO_2$ at 1.8Mt/yr.
- The Teapot Dome site in Wyoming will store 2.6Mt/y $CO_2$, whilst researching optimal methods, and monitoring technology.
- Rangely is monitoring $CO_2$ and $CH_4$ leakage from 25 Mt $CO_2$ injected since 1986.
- West Pearl Queen was the first US research injection project in 2002, and is monitoring the migration of 2100t $CO_2$.
- The Texas Frio brine $CO_2$ injection by the GEO-SEQ project demonstrated $CO_2$ injection and movement between two boreholes with extensive tracer studies.
- The Japanese Oil Development Co plans to recover up to 15Mt $CO_2$ /y $CO_2$ from existing power plants for injection in the Upper Zakum Field of United Arab Emirates, to offset Japanese emissions.
- At Liaohe Oil Field in China $N_2$ + $CO_2$ + steam flue gas has been injected since 1998 for EOR (not storage).
- In Italy, the Sibilla EOR project will store at least 1.5 Mt $CO_2$ from the API Refinery gassifier.

**Depleted oilfields**

- Canada has about 30 acid gas injection commercial projects for $CO_2$ + $H_2S$ disposal, at rates of 0.003 to 0.06 Mt/yr. Abu Dhabi injects 0.4Mt/y of such “sour gas”.

**Depleted gasfields and gas reservoirs**

- The Dutch project (CRUST) in the K12B well is injecting 20kt $CO_2$ /y (rising to 0.5Mt $CO_2$ /y) into an offshore sandstone depleted gas reservoir at 3,800m depth.
- BP operates In Salah in Algeria, commercially removing $CO_2$ from gas and injecting it into a gas reservoir at around 1 Mt/yr.

**Saline Aquifers**

- The best known is Sleipner, operated commercially by Statoil which has been the subject of extensive research, most recently by $CO_2$ STORE, offshore Norway.
  - This strips $CO_2$ from produced hydrocarbon, and re-injects into an aquifer 1000m below sea level at 1Mt/yr.
  - Statoil are well-advanced with Snohvit offshore in the Barents Sea, which is a similar project to inject removed $CO_2$ from gas at 0.7 Mt/y via a new pipeline.
- Australia’s offshore Gorgon field (Chevron) will be the largest from 2009, removing 5Mt/y $CO_2$ and storing it in an aquifer.

66 Acid gas is a mixture of acidic gases (typically hydrogen sulphide, carbon dioxide, etc) which may be produced in connection with oil and gas extraction and in other industrial processes.

- Nagaoka in Japan injected 10kt $CO_2$ in 2003, in an earthquake zone, and has monitored it since then.
- The $CO_2$SINK project at Ketzin to the north-west of Berlin will inject 30kt $CO_2$ /y into a shallow sandstone formation (previously a gas storage site), to be a research facility.

**Coal (ECBM – Enhanced Coal Bed Methane)**

- COAL-SEQ pilot studies of injection into permeable coal in New Mexico.
- The RECOPOL project in Poland has demonstrated that EU coals need artificial fracturing.
- A pilot scale injection is underway at Qinshui Basin of eastern China.
- Japan has made small scale demonstrations at 900m depth since 2003, as has Canada.

## *Other forms of storage*

48. Deep ocean storage has been proposed as an alternative to geological storage. In this case, captured $CO_2$ would be directly injected into the deep ocean (below 3000 m) where, being denser than water, it would be expected to form a 'lake', delaying its dissolution into the surrounding water. This storage mechanism is still at the research stage and there is unease about its potential environmental implications. It is not considered to be viable for the North Sea in any case due to the lack of storage sites of appropriate depth. It would also be illegal under current international law.

49. Unmineable coal seams offer another potential $CO_2$ storage opportunity. Enhanced Coal Bed Methane Recovery (ECBM) involves injecting $CO_2$ into coal seams, where it displaces methane and thereby enhances recovery of methane from the coal bed. This can give an economic return to help offset the costs of storage. Professor Peter Hall from the University of Strathclyde and Stephen Jewell from Composite Energy Ltd asserted that "the bituminous coals that constitute most of the resource of the UK have the ability to permanently store $CO_2$".[67] However, the majority of evidence published to date seems to suggest that UK coal is too impermeable to make this a practical option.[68] **On the basis of current information, coal seems unlikely to be a major storage option for the UK, at best being of small scale and local significance.** We do not, of course, exclude the possibility that future research or developments in technology will alter this situation.

50. Mineral carbonation has also been proposed as an alternative means of storing $CO_2$. Dr Sam Holloway, Senior Geologist at the British Geological Survey, told us: "It is a process that will work but the costs are likely to be extremely high" and asserted that it "would require very considerable advances in order for it to become anywhere near competitive with other methods of sequestering carbon".[69] Dr Riley, also from the BGS, put it in even stronger terms:

> "I think mineral storage is a distraction. The bulk of $CO_2$ storage is going to have to be done by injecting the carbon dioxide underground. The issue of can we create dolomite from seawater will make the problem worse because if you make carbonate

67 Ev 85

68 Ev 60, 118, 142

69 Q 79

> from seawater you evolve carbon dioxide back to the atmosphere. It sounds counterintuitive [but] it actually makes the situation worse in the short term".[70]

It has also been argued that it may be possible in future to use 'waste' $CO_2$ as feedstock for other processes. The Royal Society of Chemistry told us that "from a chemical science perspective $CO_2$ can also be seen as potential feedstock for the manufacture of useful chemicals and as such chemical conversion of significantly large amounts of carbon dioxide to inert or commercially useful material is an option that cannot be ignored".[71] The IPCC considered this possibility in its Special Report and concluded that "The potential for industrial uses of $CO_2$ is small" and that "the $CO_2$ is generally retained over short periods".[72] Furthermore, the IPCC cautioned that "Processes using captured $CO_2$ as feedstock instead of fossil hydrocarbons do not always achieve net life-cycle emissions reductions".[73] **It is clear that storage in geological formations, providing that it can be done safely and securely, is the most desirable and competitive way of storing $CO_2$ of the currently available options.**

## Transport

51. Captured $CO_2$ obviously needs to be transported to the storage site and there is agreement that this will generally be best done via pipeline. There are already more than 2500 km of pipelines, mainly in the Western United States, transporting 50 Mt $CO_2$ per year from natural sources to EOR sites.[74] The recent IPCC report concluded that there was "no indication that the problems for carbon dioxide pipelines are any more challenging than those set by hydrocarbon pipelines in similar areas, or that they cannot be resolved".[75] The risks associated with transportation by pipeline are discussed in paragraph 90.

52. Captured $CO_2$ is usually compressed prior to transportation in order to decrease the volume occupied by the gas. Providing that the $CO_2$ is dry and free from hydrogen sulphide, the risk of pipeline corrosion is minimal. The IPCC report suggests that it would be "desirable to establish a minimum specification for 'pipeline quality' $CO_2$".[76]

53. In the case of liquefied petroleum gas, liquefaction is used to decrease the volume for transportation by ship. Although similar technology could be applied to liquefaction of $CO_2$, Rodney Allam from Air Products pointed out that transportation of $CO_2$ in pressurised tankers would be expensive and there was a consensus amongst witnesses that development of a global market involving trading of emissions certificates between countries was far more likely, and preferable to, one where countries exported their $CO_2$ for storage in sites in other countries.[77]

70 Qq 80-81

71 Ev 145

72 IPCC, *Special Report on Carbon Dioxide Capture and Storage*, Autumn 2005.

73 As above.

74 As above.

75 As above.

76 As above.

77 Q 153

# 4 RD&D and international competitiveness

## Demonstration projects

54. The previous chapter outlined some of the main technological challenges that need to be addressed to render CCS a market-ready, scalable technology. It also highlighted the fact that **most of the component technologies of CCS are not novel: the key outstanding requirement is to integrate them within full-scale demonstration projects involving different elements of the technology and operating under different conditions (including offshore).** The evidence submitted to this inquiry was unanimous in supporting this view. The Government, for example, stated in its memorandum: "It is generally acknowledged that CCS has reached the stage where it needs to progress from small scale research and prototype development to near to full scale demonstration in order to give impetus to the innovation process and gain the benefits of 'learning by doing'".[78]

55. Royal Dutch Shell also advocated 'learning by doing' in its memorandum:

> "Given that 'learning-by-doing' is an important source of cost reduction, it would be desirable to have one or more $CO_2$ capture and storage demonstration projects. These projects should aim at demonstrating the whole CCS chain, namely $CO_2$ capture together with geological sequestration. An important value of these 'integrated demonstrations' is that they could, in addition to technology learning, provide clarification of the transaction costs and procedures for obtaining credits for $CO_2$ abated through geological $CO_2$ sequestration and, furthermore, shed light on regulatory compliance costs and procedures".[79]

In addition, the memorandum from E.ON asserted that "A full-scale demonstration project is the most effective way of identifying and addressing all the transport and storage issues associated with large scale $CO_2$ production from power plant" and noted that "building full-scale demonstration plants provides a signal to manufacturers that investment in CCS technology development is worth undertaking, hence stimulating competition and improvements in design".[80]

56. BP in conjunction with Scottish and Southern Energy, Shell and ConocoPhillips has plans for an offshore EOR/CCS project using the Miller Field offshore from North-East Scotland. BP told us in its memorandum that the "Decarbonised Fuels Project (known as DF1) based on the Peterhead Power Plant and the UKCS [UK Continental Shelf] Miller Field presents an immediate and effective way of establishing the necessary large-scale technology demonstration of CCS" and would reduce emissions of $CO_2$ by 1.3 Mt per year: "the equivalent of removing 300,000 cars from the roads".[81] Gardiner Hill from BP

78 Ev 58

79 Ev 109

80 Ev 80

81 Ev 137

explained that Miller was well suited for the first large scale industrial demonstration of offshore EOR because it had "$CO_2$ indigenous in the oil, and so the platform and the production facility were built with $CO_2$ in mind".[82] Professor Haszeldine confirmed the significance of this project to the UK, telling us:

> "Miller is a crucial CCS opportunity for the UK, and it is hard to over-emphasise the unique opportunity provided by the combination in sequence of: oilfield, pipeline, equipment, power station, willing companies, and timing. If this opportunity is missed, it is hard to see another such combination on the UKCS [UK Continental Shelf]. Miller can act as a crucial full-scale demonstration of CCS suitable for EOR, as a bridge to add-on EOR in neighbouring fields, and as learning for aquifer storage".[83]

57. The DF1 Project has three main components:

- the generation of 'carbon free' electricity through the construction of a gas reformer and new turbines to run on hydrogen within an existing gas-fired power station near Peterhead in Scotland;
- the manufacture of hydrogen – in order to supply the power station – by reforming North Sea gas and capturing the resulting carbon dioxide; and
- the transportation of the captured carbon dioxide via an existing offshore pipeline to the Miller oil and gas field in the North Sea – and injection into the reservoir to recover additional oil reserves and extend the productive life of the field by about twenty years.[84]

If successful, DF1 would be the largest hydrogen-fired power generation facility in the world and the largest offshore carbon dioxide EOR project.[85] The cost of DF1 has been estimated at around £330M.[86] **The BP-led DF1 project could be a crucial opportunity to test the viability of linked systems of onshore gas conversion, power generation and offshore $CO_2$ storage in the North Sea.**

58. DF1 is not the only demonstration project under development in the UK. A consortium including Progressive Energy Ltd and Renew Tees Valley Ltd is planning an 850 MW IGCC power station in Teesside, designed to capture approximately 5 Mt of $CO_2$ per annum.[87] Progressive Energy told us: "there are no insurmountable technical barriers to prevent investment in IGCC with CCS now", but warned of "real implementation challenges associated with securing the finance for the plant".[88] The issue of market incentives to stimulate investment in CCS is discussed in chapter 6. E.ON UK has also recently announced that it is considering building a 450 MW coal-fired power station fitted with CCS on the East coast of the UK. The decision will depend on the outcome of a

82 Q 136

83 Ev 134

84 Ev 138

85 Ev 138

86 Hydrogen power plant planned for Peterhead, Thomas Catan and Fiona Harvey, *Financial Times*, 1 July 2005.

87 Ev 98,129

88 Ev 130

feasibility study, which presumably will also depend on the incentives on offer for CCS. The cost is estimated at around £550M.[89] **We are encouraged by the number of companies considering investing in UK CCS demonstration projects. Industry evidently believes that CCS technology is sufficiently advanced to proceed with full scale demonstrations. What is needed now to complement this positive response from industry is a commensurate effort from the Government.** The role of the Government in facilitating CCS research, development and demonstration (RD&D) is discussed below.

**Box 4: CCS RD&D in the UK**

**Government funding for CCS RD&D in the UK:**

- Part of the current 3-year £20M DTI Cleaner Fossil Fuels programme (with part funding from industry).
- £2M (over 3 years) for UK Carbon Capture and Storage Research Consortium
- £1.6M (over 4 years) for Scottish Centre for Carbon Storage
- £0.5M (approx.) for work at BGS (in 2005/6)
- £0.32M over 5 years for UK Energy Research Centre
- £0.09M (over 3 years) Tyndall Centre study on public attitudes
- £0.1M other EPSRC projects (in 2005/6)
- Part of the 4-year £25M DTI Carbon Abatement Technologies (from 2006/7), plus an additional £10 M announced in the pre-budget report.

**UK Carbon Capture and Storage Consortium**

The UK Carbon Capture and Storage Consortium was set up in order to rapidly expand UK research capacity in the area of carbon capture and storage. It is a consortium of engineering, technological, natural, environmental, social and economic scientists, which aims to deliver viable large-scale Carbon Capture & Storage options for the UK. Its mission is "To promote an understanding of how options for decoupling fossil fuel use from carbon emissions through the use of carbon capture and storage could be used to assist the UK in achieving an energy system which is environmentally sustainable, socially acceptable and meets energy needs securely and affordably".[90] Initially, funding at the level of £2M for three years is being provided by the Natural Environment Research Council as part of the cross-Council *Towards a Sustainable Energy Economy* programme.

**British Geological Survey**

The British Geological Survey (BGS) is responsible for advising the UK Government on all aspects of geoscience and also provides impartial geological advice to industry, academia and the public. The BGS is a component organisation of the Natural Environment Research Council (NERC). Its annual budget is around £37M: about half of this comes from the Government's Science Budget; the remainder comes from research undertaken for the public and private sector.

**Scottish Centre for Carbon Storage**

Funding has been provided by the Scottish Funding Council to establish a centre of excellence on $CO_2$ storage in geological structures. Using skills and resources currently associated with oil and gas production, the Centre will provide infrastructure and links to global networks concerned with the emission of greenhouse gases.

**UK Energy Research Centre**

This organisation is funded with £14M over five years from the cross-Council *Towards a Sustainable Energy Economy* programme and is charged with drawing together national and international research in the UK in order to realise UK energy policy goals.

89 Coal begins to make its comeback from the bottom of a dark and very deep pit, *The Independent*, 23 December 2005.

90 www.ukccsc.co.uk

## Government RD&D funding

59. Current Government investment in CCS RD&D is summarised in Box 4. ScottishPower, whilst "welcoming the [Carbon Abatement Technologies] Strategy", noted that the £25 million committed to funding demonstration projects was "small relative to the funding already committed by the United States government for the development of CCS".[91] This may be, in part, a reference to the US FutureGen initiative—a flagship project of the US Department of Energy which aims to build a 275 MW zero-emissions coal-fired power plant that produces hydrogen and electricity in conjunction with CCS technology. The FutureGen IGCC plant is scheduled to take 10 years to build, with the US Department of Energy expected to invest around $620M. The remainder of the costs, approximately $250M, will be borne by an industry consortium.[92] The UK Government's investments pale into insignificance beside the US Government's $1 billion flagship CCS project. The difference remains significant when adjusted for the relative sizes of the economies or populations.

60. It is also worth noting that the £25M allocated by the Government in the CAT Strategy was only one quarter of the £100M requested for demonstrating carbon abatement technologies by the DTI's advisory board on the topic, chaired by Nick Otter.[93] In the December 2005 Pre-Budget Report, the Chancellor announced a further £10M for CCS technology demonstrations (in addition to the £25M already announced in the CAT Strategy).[94] The timing of this announcement was somewhat curious since the CAT Strategy had only been published in June 2005 and the Climate Change Programme Review and Energy Review, both of which are considering CCS, are due to report later in 2006. **The additional £10 million provided for demonstration of carbon abatement technologies in the pre-budget report is welcome but the piecemeal allocation of funding suggests a worrying lack of strategic vision in Government decision making.**

61. Furthermore, in view of the vast sums involved in launching the first CCS demonstration projects, the Government's allocation of a £35M funding stream for demonstrations of not only CCS but a range of other carbon abatement technologies is wholly inadequate. We do not believe it is the role of Government to bear the full costs for CCS demonstrations and, as discussed in chapter 6, putting in place an appropriate incentive framework would go a long way towards providing the private sector with the confidence that it needs to make the necessary investments. In the words of BP's Gardiner Hill, "we need the marketplace to create a pull on technology whereas investment in R&D is trying to create a push".[95] Nonetheless, **Government can play an essential role in 'pump priming' the initial demonstration projects. In order to do this effectively, Government support in the order of hundreds of millions of pounds needs to be forthcoming over the next five years.** To put this in context, the Government has allocated over £500 million to emerging renewables and low carbon technologies over the period 2002-08 in the form

91 Ev 108

92 http://www.fossil.energy.gov/programs/powersystems/futuregen/

93 Qq 172-174

94 HM Treasury, *Britain meeting the global challenge: Enterprise, fairness and responsibility*, 2005 Pre Budget Report, 5 December 2005, p157.

95 Q 163

of R&D and spending for capital grants, most of which represents expenditure earmarked for renewables.[96]

## Skills

62. We also heard evidence that the Government had a crucial role to play in maintaining and developing the skills base for energy RD&D. In oral evidence on 7 December, Nick Otter from Alstom told us of his "really serious concerns" regarding the skills capability in the UK and noted that the 2012 Olympics would put an additional strain on the supply of technically-skilled people.[97] Sussex Energy Group additionally asserted that it was "crucial to maintain a domestic CCS R&D programme whether or not the technologies that are deployed in the UK are indigenous or international" since "a UK skills base in complex technology areas such as this is vital if the UK is to retain the capability to absorb and utilise CCS technologies effectively".[98] Dr John Loughhead, executive director of the UK Energy Research Centre, has also issued a recent warning about the potential for skills shortages in energy-related research in the UK.[99]

63. We asked what steps the Government was taking to build the human resource base for CCS technologies and whether it had undertaken research to establish the skills needs of, and the availability of appropriately skilled personnel in, the UK. The DTI response was as follows:

> "People with the right skills will be motivated to work on CCS when there is a clear market demand and career path associated with these technologies. DTI's CAT Programme is addressing this at the innovation and technology development level by supporting R&D and demonstration activities. Additionally the UK can draw on a strong capability in power and process engineering to support full-scale design and construction activities".[100]

Our predecessor Committee published a number of Reports drawing attention to the importance of maintaining the supply of skilled scientists and engineers and we held an evidence session with the Minister for Higher Education in October 2005 on the subject of strategic science provision in English universities.[101] **Once again, we find the Government erring on the side of complacency over the continued supply of skilled scientists and engineers. In view of the strategic significance of energy policy at this time, failure to take active steps to build and safeguard the UK skills base in this area will prove costly.**

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96 HC Deb, 25 Feb 2005, col 888W.

97 Q 175

98 Ev 154

99 "Doing research is not like a tap you can turn on at a moment's notice", Tony Tysome, *Times Higher Educational Supplement*, 6 January 2005.

100 Ev 186

101 Science and Technology Committee, Oral evidence, *Strategic Science Provision in English Universities: follow-up*, 2 November 2005, HC 576-i.

## International co-operation

### *Europe*

64. Air Products stated in its written memorandum: "The role of the UK Government in funding issues should be seen in the context of funding provided by the European Union" and highlighted the need for coordinated action to attract these funds: "it is necessary for all interested UK bodies, industrial technology and equipment suppliers, power companies, oil companies, natural gas suppliers, motor companies, universities and any other institutions or organisations to link with groups in other EU countries to form the necessary project or research focused interest which can be the basis for an application for funding under FP-7".[102] We were pleased to hear from Nick Otter, Alstom, and Gardiner Hill, BP, that UK companies had been heavily engaged in the development of the new zero emissions fossil fuel power plant Technology Platform.[103] Mr Otter also indicated that the EU had plans to set up a flagship project to rival the US FutureGen initiative and noted that "if there is going to be a serious demonstration plant, we would like to see something here in the UK".[104] **The Government must do its utmost to work together with both the private sector and academia to give the UK the best chance of hosting any major EU-funded CCS demonstration project.**

### *Norway*

65. Norway has taken the lead in the development of offshore CCS thus far, having made very substantial investments in CCS. The BGS told us:

> "The Klimatek programme invested over NoK300 million between 1992–2000. Since 2002 funding has been circa NoK50 million/y. In 2005 "GASSNOVA" was set up which will fund CCS RD&D at a rate of NoK150 million/y for the foreseeable future."[105, 106]

Norway was also one of the first countries to introduce a carbon tax in 1991. The first offshore project, at Sleipner in the Norwegian North Sea, has been running since 1996 and will be followed in 2006 by another offshore project at Snohvit in the Barents Sea (see Box 3). Both of these projects capture $CO_2$ from produced gas rather than from power generation. If the DF1 project went ahead, the UK would be the first country to undertake offshore EOR using $CO_2$ captured from a full scale power plant.

66. The UK has recently signed a bilateral agreement with Norway aimed at encouraging CCS activity in both countries. This agreement was signed on 30 November 2005 by UK Energy Minister Malcolm Wicks and the Norwegian Energy Minister Odd Roger Enoksen, with both ministers pledging to explore areas of co-operation to encourage injection and permanent storage of $CO_2$ beneath the North Sea. **The increasing co-operation between**

102 Ev 128

103 Q 172

104 Q 172

105 The Norwegian Krone is worth approximately 0.09 Pounds Sterling.

106 Ev 75

**the UK and Norway on CCS is sensible, but the UK should also learn from the Norwegian Government's approach of backing its words with action and investment.**

## *China and India*

67. The most important element of the global context for the UK's investments in CCS technology is the massive predicted increase in $CO_2$ emissions from power generation in China and India (see paragraphs 16–19). The UK and EU have already entered into bilateral agreements with China. The EU-China collaboration, entitled *Near-Zero Emissions Coal with $CO_2$ Capture and Storage* (NZEC), aims to bring forward the time when new coal plant in China might be built with CCS. The first of the three planned phases of the project entails a feasibility study for CCS in China and capacity building of Chinese knowledge in this area.[107] The UK Government has provided £3.5M towards Phase I, with DEFRA contributing £3M and DTI £0.5M. Phase I is expected to last for three years and has an overall budget of 4.5–7.5M euros.[108] One of the ultimate goals of the co-operation is to develop and demonstrate, in China and the EU, near-zero emissions coal technology through CCS by 2020. The UK-China bilateral agreement, signed in October 2005, commits both countries to collaborate on R&D into clean technologies, including wave/tidal energy and photovoltaic technologies as well as CCS.[109] The UK has committed, in the first instance, £750,000 towards this collaboration.

68. Brian Morris, Head of Carbon Abatement Technologies at the DTI, told us that efforts to engage India were underway, but that China had "responded far more positively than India" to the UK's approaches regarding CCS.[110] **The UK and EU bilateral agreements to co-operate in the development of CCS technology with China are to be welcomed. However, the timescales envisaged and sums allocated in no way reflect the urgency with which CCS technology needs to be demonstrated and deployed if it is to be able to play a significant role in mitigating climate change. Efforts to engage China and India in this area are to be encouraged, but we doubt whether Memoranda of Understanding in themselves represent an effective way of expediting the development of carbon abatement technologies, or of promoting their uptake by these countries.**

69. It is also worth noting that, as well as the DTI and DEFRA, the Foreign and Commonwealth Office (FCO) and Department for International Development (DFID) have a potential interest in the development and uptake of CCS technologies by India and China. **The DTI and DEFRA should ensure that there is strong co-ordination between their activities in promoting CCS RD&D in China and India and those undertaken by the FCO and DFID in these countries.**

70. Even if CCS technology was available, questions would remain over the contribution that it could make to reducing $CO_2$ emissions in India and China. Firstly, these countries would need to be interested in adopting it. It is encouraging, therefore, that both China and India are already members of the Carbon Sequestration Leadership Forum and that China

107 Ev 182

108 Ev 194

109 Ev 194

110 Q 267

is reportedly planning to commence R&D into CCS as part of the Government's 11th Five Year Plan.[111] Nonetheless, concern remains that in the absence of acceptance by those countries of limits on $CO_2$ emissions and an international price on carbon, there will not be sufficient incentive for deployment of carbon abatement technologies by India, China and other countries facing similar dilemmas. Mr Allam from Air Products commented in oral evidence that the main barrier to the uptake of CCS by India and China was the fact that there was "No perceived value for the $CO_2$ that is separated at the moment". [112] Mr Allam was of the view that "Once there is a perceived value either internationally traded in some way or due to global regulations which govern $CO_2$ emissions, that is when the incentive will be there".[113] **The major obstacle to the adoption of CCS technologies by countries such as India and China is still the lack of value attached to carbon internationally.** It is essential that the UK Government—in partnership with other countries—continues to work towards an international framework for carbon trading. This is discussed further, together with the EU-Emissions Trading Scheme, in chapter 6.

## A leadership role for the UK?

71. The UK faces competition from a number of other countries if it wishes to take a leading role in developing CCS technology. As mentioned above, Norway has already taken a lead in some areas of CCS technology. The USA has been one of the biggest investors to date in CCS (see paragraph 59) and countries such as Germany and Canada have also made substantial investments. Australia has been active in this area as well and launched its first CCS project in 2006.[114]

72. Nevertheless, much of the evidence submitted to this inquiry suggested that the UK was well-placed to adopt a leadership role in the development of CCS technology. The BGS argued that "Because of its hydrocarbon infrastructure, sedimentary basins and large point source $CO_2$ emissions, together with the need to modernise/replace power plants, the UK is well placed to lead, develop and take advantage of CCS".[115] ScottishPower put the case even more strongly, asserting that "the UK must decide whether to be a leader or a follower in the development of carbon abatement technologies" and warning:

> "Unless moves are taken swiftly to develop UK-driven solutions, there will soon be greater advantage in importing technologies, which have been developed abroad. Failure to make progress today could preclude the UK from the manufacturing and technology transfer benefits that could be realised from a UK-driven initiative".[116]

George Marsh from the DTI was upbeat about the prospects for the UK to maintain a competitive advantage internationally, telling us:

111 Ev 183

112 Q 169

113 Q 169

114 www.co2crc.com.au

115 Ev 70

116 Ev 107

> "We still have quite a significant industry that is capable of both designing and constructing these technologies. If there is a major drive to reduce $CO_2$ emissions worldwide, we could be in a position to tap into quite a massive market. We make the boilers that are needed; we make the steam turbines. We have world class design capabilities for the cleaner coal technologies so there are a lot of opportunities there".[117]

In addition, Mr Morris from the DTI explained that the Government was developing "a technology road map which will focus very much on UK strengths, where should we collaborate, where do we buy in technology, to try and focus much more on where we are strong and where we should perhaps let somebody else do it".[118]

73. Gardiner Hill from BP emphasised that supporting deployment and demonstration of CCS technology was critical to maintaining the UK's competitive advantage.[119] He argued that:

> "By having these [demonstration] plants operating in the UK, our people, our engineers and our capability will be established and be known and be required by these other countries [...] there is a technical aspect, but I think there is also a skills, a jobs and a capability aspect to it".[120]

Dr Gibbins also highlighted the wider benefits that could be derived from early demonstration of the technology in the UK, telling us: "The UK has the opportunity to make this technology acceptable possibly ten years earlier [than would otherwise be the case] and that could have huge implications when the globe is going to say, 'Okay. It does not look too bad, tackling climate change; let's go for it'".[121] The Royal Society echoed this sentiment, telling us: "by showing leadership, the UK might engage with India and China in managing their potential future emissions of carbon dioxide effectively, to much greater global effect".[122] Dr Gibbins flagged up a further possible advantage to early action by the UK:

> "There is an awful lot of money going to be traded. There will have to be projects to verify and a lot of financing for projects. A lot of that is likely to come out of the City of London. If we can get that experience here first, we can make some money for the UK".[123]

**The UK is well positioned to take an international leadership role in demonstrating the viability of CCS. British leadership in the use of CCS technology will yield returns from domestic carbon reduction and also provide a strong indication to other major polluters of the potential of CCS to reduce global emissions.**

117 Q 53

118 Q 53

119 Q 174

120 Q 175

121 Q 96

122 Ev 132

123 Q 96

## *Export opportunities*

74. There was a consensus amongst the witnesses from industry that opportunities that did arise for UK companies would be in terms of knowledge and licensing since countries such as India and China were likely to manufacture the technology themselves. Colin Scoins, Head of New Business at E.ON UK, said: "I think we could expect to sell the knowledge. I think ultimately we will find that China and India will build their own equipment very quickly".[124] We agree with this assessment. **Export opportunities for UK companies are likely to derive from intellectual property and licensing of CCS technology.**

75. That said, it may be in the UK's interests to ensure that China and India have access to any relevant intellectual property and the Chinese Government is reported as saying it expects developed nations to pay for the costs of developing carbon abatement technologies.[125] Cambridge Environmental Initiative supported this stance, telling us: "China and India have a strong moral case for suggesting that developed countries must pay for the development of clean fuel technologies".[126] This should be taken into account when considering the scope for opportunities for UK companies to export CCS technology.

76. Many witnesses drew attention to the fact that although the UK had significant skills and expertise of relevance to CCS, UK companies would not be well placed to tap into the export market until more headway had been made in demonstrating CCS in the UK. UKCCSC commented in its memorandum that "much of the atmospheric carbon concentration abatement benefit to the UK from R&D on CCS is likely to arise through technologies and practices developed and demonstrated in the UK being replicated in other countries, particularly in connection with coal utilisation".[127] Dr Gibbins, who leads the UKCCSC, pointed out the difficulty of trying to sell a concept to another country which has not yet been adopted domestically: "it is obviously hopeless, as I am trying to do at the moment, to promote the idea of capture ready in China when we are not doing it in the UK".[128]

77. **If the UK is serious about making an impact on China and India, the most useful thing it could do would be to get full scale demonstrations of several different types of CCS technology up and running domestically as soon as possible. This would prove the viability of the technologies and give UK companies comparative advantage in terms of experience and know how. In the absence of such demonstrations, the idea of major export opportunities for UK companies is unrealistic.**

78. Retrofitting of plant being built in China and India today will be essential if reductions in emissions are to be made within the next 30–40 years. For the pulverised fuel plant that predominates in China, post-combustion capture is the only option. Fortunately, since the

124 Q 168

125 E.g. UK, "China in cleaner power plan", Roger Harrabin, *BBC News*, 1 September 2005.

126 Ev 168

127 Ev 146

128 Q 72

plant being built today is of higher efficiency than the UK coal-fired power stations retrofitting is more likely to be feasible. Rodney Allam of Air Products argued that:

> "the best thing we could do to ensure that we had a future market in China was for us to have a large-scale demo on a pulverised fuel power station in the UK. That would really give us the world-leading position in terms of supply of this technology into such a market as well as giving us the ability to do it here in the UK".[129]

**A major refurbishment of a UK coal-fired power station combined with retrofitting of CCS technology could afford a very valuable opportunity to demonstrate the post-combustion capture technology required to retrofit Chinese coal-fired plant, as well as providing useful experience of combined retrofit and upgrade of a UK plant.**

129 Q 168

# 5 Risks and Regulation

## Risks

### *Leakage*

79. Evidence to suggest that $CO_2$ storage in geological formations is safe and secure comes from a number of sources. POSTnote 238 on CCS points out that "Oil and gas have been 'stored' underground for millions of years" and there are natural $CO_2$ occurrences in the North Sea that demonstrate that storage can occur safely over millions of years.[130] In addition, experience from Sleipner, Weyburn and other $CO_2$ storage projects suggests that the gas can be securely stored in geological formations (see paragraph 47 and Box 3). A third strand of evidence is provided by industrial analogues for $CO_2$ storage. These include acid gas injection projects and underground natural gas storage projects which, as the IPCC report points out, "have operated successfully for almost 100 years".[131] According to the IPCC, the health, safety and environmental risks of CCS are comparable to existing hydrocarbon operations and practice, and the risk of leakage from geological storage is very low (99% retention over 1000 years for well chosen reservoirs).[132] **Experience to date has demonstrated that, over the timescales studied, $CO_2$ can be safely stored in both depleted oil and gas fields and aquifers. Current and future large scale demonstration projects will play a key role in building the evidence base for, and public confidence in, geological storage of $CO_2$.**

80. Nevertheless, risk of leakage of $CO_2$ from storage sites appears to be a cause of concern on the part of some environmental groups and a potential cause of concern to the general public. Green Alliance, for example, told us: "Acceptability of storage sites will depend on their gas leakage security", whilst the Greenpeace European Unit has said that "$CO_2$ leakage (both long-term slow seepage and short-term catastrophic releases) poses a risk to human health, the environment and the climate".[133] There are two main types of risk associated with leakage. Firstly, unintended release of $CO_2$ could have local health, safety and environmental risks. Secondly, longer term, ongoing, low-level release of $CO_2$ would undermine the climate change mitigation benefits of CCS.

81. Assessing the risks associated with CCS requires analysis of both the probability of leakage and the likely consequences of such leakage. The latter would depend heavily on the nature of any leakage, i.e. whether it was a short, intense burst or a slow but sustained release of low levels of the gas. $CO_2$ is not legally classified as a toxic substance and is present at ambient concentrations of around 380 parts per million, i.e. it comprises 0.038% of the earth's atmosphere. Research has demonstrated that $CO_2$ poses no risk to human health at concentrations of up to 1%.[134] Exposure to higher concentrations of $CO_2$ can be dangerous and, at airborne concentrations of greater than 3%, $CO_2$ can have toxic effects

130 POSTnote 238 and ev 133

131 IPCC, *Special Report on Carbon Dioxide Capture and Storage*, Autumn 2005.

132 As above.

133 Ev 179 and http://eu.greenpeace.org/issues/climate.html

134 IPCC, *Special Report on Carbon Dioxide Capture and Storage*, Autumn 2005.

on the respiratory and cardiovascular systems. The greatest danger to humans posed by $CO_2$ is the risk of asphyxiation as $CO_2$ levels rise above 5%. Sensitive populations such as the elderly could also experience ill effects at lower levels of $CO_2$. Air-breathing animals have similar responses to $CO_2$ but plants, insects and soil organisms may have significantly higher tolerance thresholds.[135]

82. Because $CO_2$ is denser than air, leakage of $CO_2$ into the atmosphere may lead to accumulation of $CO_2$ in lower lying areas unless dispersed by wind action. The Cambridge Environmental Initiative argued that "One further area for research is to investigate the spread of $CO_2$ plumes in UK conditions and the wind conditions required to disperse them", whilst also pointing out, "This may be no worse than the risks associated with existing oil and gas pipelines".[136] The Royal Society of Chemistry was particularly concerned about the risks of high concentration leaks, calling for researchers to "focus on the potential impacts on both offshore and onshore ecosystems of spatially restricted but very high concentration $CO_2$ leaks", noting that this would help "to define site performance and safety criteria".[137] The BGS also said that assessing the localised impacts of $CO_2$ leakage on ecosystems was "a particular challenge".[138] In addition, the scientific consultancy Quintessa was concerned that the "Impact of $CO_2$ upon marine organisms was poorly-known".[139]

83. There are some instances of naturally occurring leakages of $CO_2$ which can provide useful sources of information on the impacts of $CO_2$ on ecosystems. One example would be the cold marine seeps off the coast of California.[140] However, the utility of such comparisons has been called into question on the grounds that the ecosystems surrounding these sources of $CO_2$ have had long time periods to adapt to the increased level of $CO_2$, which would not reflect the situation with sudden leakage of $CO_2$ from a geological storage site. Incidents such as the explosive release of $CO_2$ from Lake Nyos in Cameroon, which caused mass fatalities in the surrounding area, are certainly not comparable to the seepage that would be expected from a geological storage site.

84. The climate change mitigation risk stems from the fact that the key benefit of CCS, namely the reduction of atmospheric carbon dioxide levels, would be undermined if $CO_2$ injected into storage sites were to leak back into the atmosphere. A risk of leakage, or a perception that this was the case, could also jeopardise the inclusion of CCS in emissions trading schemes. Quintessa noted that "Implicit in the acceptance of specific leakage rates for geological reservoirs is that monitoring of storage operations is sensitive enough to detect [low] leakage rates […] so that mitigation strategies can be employed, and ratification of carbon credits can be achieved by regulators".[141]

135 As above.

136 Ev 167

137 Ev 144

138 Ev 73

139 Ev 67

140 JP Barry, RE Kochevar, CH Baxter, "The influence of pore water chemistry and physiology on the distribution of vesicomyid clams at cold seeps in Monterey Bay: Implications for patterns of chemosynthetic community organisation", *Limnology and Oceanography*, vol 42 (2), pp 318-328, March 1997.

141 Ev 67

### *Boreholes*

85. There was a consensus in the evidence received that the most likely source of $CO_2$ leakage from geological storage sites was via boreholes. The BGS, for example, told us that "The main risk issue with $CO_2$ storage in hydrocarbon fields is the possibility that $CO_2$ may eventually leak upwards along pre-existing exploration and production wells".[142] This risk arises from the fact that the cement used to seal the boreholes can become corroded over time. If depleted oil and gas fields are being used for storage, pre-existing boreholes that may have been sealed several years previously could be particularly vulnerable. If a leak did occur at a borehole, the amount of $CO_2$ released would not be expected to be large relative to the total amount stored in the reservoir and, once it reached the seabed, it would be likely to escape to the atmosphere as bubbles rather than being retained in the sea.[143] The sealing of boreholes is a mature technology and, providing that appropriate monitoring and verification systems are in place, it is also expected that any leaks could be rapidly repaired. **The main source of leakage from $CO_2$ storage sites is likely to be via boreholes, although it is expected that any breach of the borehole seal could be remediated quickly. Further R&D to develop cements and sealants optimised for $CO_2$ storage would nevertheless be valuable.**

### *Site disruption*

86. Although the evidence suggests that under normal circumstances the risk of leakage of geologically stored $CO_2$ is low, some people have raised concerns about the possible effects of unintended disruption of the storage site, for example due to accidental drilling. Dr Holloway, a Senior BGS Geologist, told us: "Drilling through high pressure accumulations of gas is an every day fact of life in the oil industry because when you discover gas fields they are under pressure and that pressure is retained by dense mud inserted in the well".[144] He went on to explain that "Drilling through an existing $CO_2$ storage site should not in itself necessarily promote leakage because you can control your well drilling process and plug your well with suitable materials afterwards".[145] On the subject of the likely consequences of an earthquake striking a region containing a $CO_2$ storage site, Dr Holloway told us: "the saline aquifer storage experiment in Nagaoka in Japan was hit by a magnitude 6.3 earthquake during the experimental period and this did not in any way damage the site significantly at all", whilst also pointing out that "One would try and store $CO_2$ away from earthquake prone zones".[146]

### *Site characterisation*

87. Much of the evidence attests to the need for thorough site characterisation in order to reduce the risks associated with storage. Brian Morris from the DTI told us, for example:

142 Ev 72

143 Michael A. Celia *et al*, "Quantitative estimation of $CO_2$ leakage from geological storage: analytical models, numerical models, and data needs", paper 228, *Proceedings of the Seventh International Conference on Greenhouse Gas Control Technologies, Volume 1: Peer-Reviewed Papers and Plenary Presentations,* IEA Greenhouse Gas Programme, Cheltenham, UK, 2004.

144 Q 98

145 Q 98

146 Q 98

"one has to select each storage site carefully […] One will have to make sure that you survey the sites before you start doing it".[147] Although the main focus of the assessment will be the proposed storage reservoir (in terms of its geology, geochemistry, response to stress etc.), the rock layers above the reservoir should also be analysed to enable modelling of the behaviour of any $CO_2$ that did escape from the reservoir and migrate into these layers. There is currently no standardised methodology for site characterisation.[148] **We recommend that the Government works both with other interested parties within the UK and, over the longer term, internationally, in order to develop a standardised methodology for site characterisation. More generally, there is a need for codes of practice to be developed to ensure good design and management of $CO_2$ storage facilities.** Early experience from the first demonstration projects should assist considerably in these processes.

## *Monitoring and modelling*

88. Although all the large scale projects where $CO_2$ storage performance has been monitored suggest that storage is viable and apparently safe, none of these have been monitored for more than a decade so it is too early to draw long term conclusions. The DTI's March 2005 Technology Status Report on monitoring technologies for the geological storage of $CO_2$ provides an overview of the main techniques used for monitoring and verification of storage and the challenges facing the UK.[149] These are, therefore, not discussed in detail here. However, we received evidence arguing that better tools and models for identification of storage sites and subsequent monitoring and verification are needed. Royal Dutch Shell told us that the "key R&D theme" should be "feasibility and integrity of storage".[150] E.ON UK also stated: "it is in the development of methodologies for verifying $CO_2$ storage that the majority of effort needs to be focussed".[151]

89. The evidence emphasised the difficulty of predicting what would happen to stored $CO_2$ over the very long term. The BGS called for models to be developed that could "assess the risks of $CO_2$ storage to both humans and ecosystems over 5,000–10,000 year timescales".[152] The BGS further pointed out:

> "Simulators and models for $CO_2$ behaviour are still in their infancy. More field trials at laboratory and industrial scale are needed to history-match and refine these tools […] Tool testing, monitoring and verification at field-scale across the spectrum of geology, site conditions and ecosystems that could apply to storage operations is required".[153]

The Royal Society of Chemistry also highlighted the importance of studying the behaviour of $CO_2$ stored under a range of "reservoir conditions that include increased temperatures,

147 Q 20

148 IPCC, *Special Report on Carbon Dioxide Capture and Storage*, Autumn 2005.

149 DTI , *Monitoring Technologies for the Geological Storage of $CO_2$*, Technology Status Report,TSR025, March 2005.

150 Ev 109

151 Ev 81

152 Ev 70

153 Ev 71

pressures, and salinities, and account for the presence of other fluids and organics".[154] **Further research is needed to improve the tools for site selection and subsequent monitoring and verification of $CO_2$ stored in geological formations. Although companies will be expected to take steps to improve monitoring and verification in the projects that they sponsor, the Government must take primary responsibility for commissioning research in this area in view of its significance for public safety and confidence in the technology. We recommend that the Government makes this an RD&D priority.**

### *Transport*

90. As discussed above, $CO_2$ pipeline technology is well established and experience in the US suggests that the risks associated with $CO_2$ transportation are comparable to those for natural gas transportation (and arguably lower since $CO_2$, unlike natural gas, is not flammable). George Marsh, adviser to the DTI, told us in oral evidence: "There are established ways of dealing with pipelines and potential catastrophic leaks. The US has over 1,000 miles of $CO_2$ pipeline, they pipe about 30 million tonnes a year. This is not cutting edge technology".[155] Mr Marsh also indicated that there was already a regulatory framework in place for $CO_2$ transportation, telling us that it would fall under the Pipeline Directive.[156]

91. Between 1990 and 2002, there were 10 incidences of failure of $CO_2$ pipelines in the US, resulting in property damage of around half a million US dollars but no fatalities or injuries. This failure rate is of the same order of magnitude for US onshore gas pipelines.[157] The consequences of leakage incidents are, of course, influenced by the population density in the areas though which the pipelines pass and this should be taken into account when planning the route. The fact that $CO_2$ is denser than air should also be a consideration in designing the pipeline network so as to avoid, in case of accidental release, an accumulation of the gas in low lying areas. **Providing that the pipelines are designed and routes are selected in such as a way as to minimise risk, transportation of $CO_2$ by pipeline between capture and storage sites should not pose any greater threat to human health or the environment than natural gas transport and may indeed be lower.**

92. **Overall, the evidence suggests that for well-chosen sites the risk of leakage of $CO_2$ from geological storage reservoirs or pipelines is low. The risks associated with storage of $CO_2$ would be further mitigated by thorough site characterisation and management, monitoring and verification of storage sites.**

## Public confidence

93. CCS is still a relatively unknown technology amongst the public and an adverse public response could pose a serious risk to its wide-scale deployment. The Royal Society of Chemistry perceived this to be the greatest threat to the development of CCS in the UK:

154 Ev 144

155 Q 24

156 Q 24

157 IPCC, *Special Report on Carbon Dioxide Capture and Storage*, Autumn 2005.

"Although a number of technical issues dealing with storage safety, monitoring and longevity are still outstanding, the public acceptance of geological storage is probably the overriding issue".[158] In oral evidence, industry witnesses also emphasised the importance of public engagement and Gardiner Hill from BP described public acceptability as "a potential show stopper".[159] The environmental NGOs giving oral evidence were critical of the lack of Government action in this area. When asked how effective Government had been so far in communicating CCS technology to the public, Russell Marsh from Green Alliance said "not at all", while Doug Parr from Greenpeace asked "has there been any communication about it? I must have missed it".[160] By contrast, Dr Reiner from the Judge Business School and UKCCSC credited industry and Government with "active engagement with the non-governmental community".[161]

94. There is limited data available on public attitudes towards CCS but UKCCSC drew our attention to research carried out by the Tyndall Centre and the Judge Business School, Cambridge University, on this subject. UKCCSC told us that the results suggested that the public are not opposed, in principle, to CCS and "become more in favour as they learn more". According to this research, "acceptance of the technology is dependent on 1) acceptance of climate change as a serious and urgent problem and 2) that CCS would be implemented as part of a portfolio of measures (including renewables and energy efficiency) and not at the expense of other mitigation options".[162] It is also noteworthy, although perhaps not surprising, that CCS appears to be more acceptable to the public than nuclear power.[163]

95. Experience with other novel technologies has highlighted the importance of making clear and transparent information available. Our predecessor Committee took a longstanding interest in the Government's efforts to facilitate public dialogue and commented on more than one occasion on the need to initiate public engagement at an early stage in the development of a new technology.[164] We share our predecessor Committee's interest in this area. In the course of this inquiry, we heard similar messages from witnesses. Cambridge Environmental Initiative told us: "Transparency of information is essential to enable academic analysis and further research and to avoid a similar scenario to that of the nuclear energy age, when raw data was kept secret provoking public suspicion about the technology".[165] UKCCSC also argued that a coherent and concerted effort from Government in its public communications was vital to attract investment: "Government must consistently identify CCS as an energy technology area in the same way as 'nuclear', 'hydrogen', 'biomass', 'renewables' etc. and give it generally equivalent attention in official planning and communications if its possible contributions

158 Ev 144

159 Q 143

160 Q 215

161 Q 103

162 Ev 149

163 Ev 149

164 E.g. Third Report from the Science and Technology Committee, Session 2003–04, *The Work of the Biotechnology and Biological Sciences Research Council*, HC 6, paragraphs 63–65 and Fifth Report from the Science and Technology Committee, Session 2003–04, *Too little too late? Government Investment in Nanotechnology*, HC 56–I, paragraphs 101–107.

165 Ev 167

to UK energy supplies are to receive appropriate attention in R&D activities".[166] **Clear and transparent information about CCS at an early stage will be crucial for securing public acceptance. The Government must therefore adopt a pro-active approach to communication.**

96. We asked the Government what it had done to date to address this issue. The DTI response stated that there were "a number of current international initiatives focusing on public perception, public outreach and communications strategy" and that the "first step for DTI is to establish the content and range of these initiatives". The DTI also said that it would "draw together an expert group to define a communications strategy that will promote consistent and effective messaging, based on research into public perceptions and attitudes, and drawing from the best communications materials available".[167] The timescale for this would be first quarter 2006, with a provisional strategy available by late Spring 2006. Malcolm Wicks, Energy Minister, also told us: "I, myself, in my modest way, have discussed [CCS] on 30 or so radio and television programmes".[168] The Minister certainly has an important role to play in raising the profile of CCS, but an effective programme of communicating the features and risks of this technology to a wide audience will require more than the Minister discussing CCS in the course of his interviews with the media.

97. Having observed a marked increase in the media attention given to CCS between the start of the inquiry in July and the oral evidence sessions in November and December, we were interested to hear the views of witnesses on CCS media coverage. Rodney Allam from Air Products confirmed our perception about the dramatic increase in press interest, telling us: "We have had more exposure in the last seven days than we have had in the last seven years".[169] The witnesses appearing alongside Mr Allam also agreed that the quality of coverage was a source of concern. Mr Hill from BP was particularly uncomfortable with the description of CCS as 'carbon dumping'.[170] He told us: "I think there is a problem. If you want to choose to use that language, you could say, "What are we doing today?" and today we are dumping the $CO_2$ in the atmosphere".[171] The anxiety expressed by the witnesses from industry contrasts starkly with the Energy Minister's declaration that he was "very happy" and "very relaxed about where we are" in terms of public engagement and media coverage of CCS.[172] **The Government has done little so far to engage the public in a dialogue about CCS technology. We accept that it is early days for the technology but previous experience has emphasised the value of early engagement. The evidence we have seen does not support the view that the Minister's confident and relaxed attitude towards the Government's performance on this issue is justified. This is a source of concern.**

98. A number of contributors to the inquiry commented on the fact that the first demonstration projects in the UK could have a major impact on public attitudes towards

166 Ev 149

167 Ev 183

168 Q 312

169 Q 144

170 Ministers back carbon dumping, *The Guardian*, 15 June 2005.

171 Q 147

172 Q 310

CCS. Dr Reiner from the Judge Business School at Cambridge University and UKCCSC highlighted the fact that "Given low public levels of recognition of CCS and broad support for renewables, public attitudes towards CCS will be influenced by early successes (or failures) of major CCS projects".[173] **The first demonstration projects will need to give careful consideration to public engagement—early successes or failures are likely to have a disproportionate impact on subsequent public attitudes.**

99. Dr Reiner also made the point in oral evidence that "The public, at least based on our surveys, have no knowledge or virtually no knowledge of this issue so it really ends up being the press and the non-governmental community that you need to engage".[174] Brian Morris from the DTI also emphasised the critical role of the environmental NGOs, telling us: "we recognise that the NGOs are opinion formers".[175] To our great surprise, Friends of the Earth seemed reluctant to accept this mantle, saying: "we do not have influence over what the general public will ultimately think".[176] We disagree. **Environmental NGOs can make a major contribution to ensuring that public debate about CCS is conducted in a responsible way. Their suggestion that they do not have influence over public opinion was perplexing and unconvincing. We call on the NGOs and the Government to work collaboratively to inform public perceptions of the risks and benefits associated with CCS.**

## Regulatory framework

### *International conventions*

100. The London Convention 1972 is an international treaty that limits the discharge of wastes that are generated on land and disposed of at sea.[177] There are currently 81 Parties to the Convention (i.e. states that have signed, ratified, and otherwise acceded to it). Contracting Parties must take effective measures to prevent pollution of the marine environment caused by dumping at sea. The 1996 London Protocol is a separate agreement intended to update the London Convention. The Protocol is also more restrictive than the Convention: application of a precautionary approach is included as a general obligation; a 'reverse list' approach is adopted, which means that all dumping is prohibited unless explicitly permitted; incineration of wastes at sea is prohibited; and export of wastes for the purpose of dumping or incineration at sea is prohibited. Upon its entry into force, the Protocol will replace the Convention. So far, 22 states have acceded to the 1996 Protocol, including the UK; four more parties are needed for the Protocol to enter into force.

101. The 1992 OSPAR Convention is a regional treaty guiding international co-operation over the protection of the marine environment of the North-East Atlantic. The name

173 Ev 160

174 Q 103

175 Q 311

176 Q 217

177 www.londonconvention.org/

OSPAR derives from the Oslo and Paris Conventions which it replaced when it entered into force in 1998. The UK is one of 16 signatories to the Convention.[178]

102. The overall objective of both the OSPAR Convention and the London Convention/Protocol was to prohibit the dumping of waste into the marine environment. They were not designed to apply specifically to CCS and, as a result, there is uncertainty over whether long term storage of CCS in rocks under the seabed would constitute 'dumping'. RD&D activities are permissible under the treaties but there is a question mark over how large a demonstration project would be acceptable. EOR would be permitted on the grounds that the $CO_2$ is being injected under the seabed as part of the hydrocarbon recovery process and not solely for disposal purposes. Similarly, as the Government pointed out, projects "in which the $CO_2$ placed in geological storage is produced with the oil or gas being extracted (as with the Norwegian Sleipner project" are allowed.[179] **EOR can provide a useful stepping stone to CCS by enabling early proving of offshore $CO_2$ injection without contravening the multinational environmental agreements governing the disposal of waste in marine environments.**

103. The Government has acknowledged that the OSPAR and London Conventions need to be clarified or amended to allow CCS in geological structures under the seabed. Due to its global reach, the initial focus has been on negotiations to amend the London Convention/Protocol. The Government told us that the 27th Consultative Meeting of the London Convention had "established a process to consider whether the Convention, and/or the Protocol that will eventually replace it, need to be clarified and/or amended in order to facilitate or regulate CCS in sub-seabed geological structures".[180] Energy Minister Malcolm Wicks told us that he was "relaxed" that the OSPAR and London Conventions would be amended to allow CCS.[181]

104. The Royal Society expressed concern in its memorandum over the timescale entailed in securing amendment of such multinational environmental agreements, noting that "it may take several years to secure international agreement for the widespread storage of $CO_2$".[182] According to DEFRA, which leads the negotiations for the UK, "The whole process could take two or three years to complete".[183] DEFRA noted that the legal status of CCS projects could be unclear in the meantime: "since the Convention and/or Protocol as they stand were not drafted with the needs of carbon capture and storage in mind, trying to apply their current provisions to CCS is correspondingly complex, and views differ widely on the legality in these other cases".[184]

105. **It is commendable that the Government has taken a lead in international negotiations to amend the London Convention/Protocol to ensure that CCS projects are permissible. Whilst we appreciate that it may take time to secure international**

178 www.ospar.org/

179 Ev 185

180 Ev 184

181 Q 319

182 Ev 132

183 Ev 184

184 Ev 185

**agreement, it is vital that the UK does its utmost to expedite this process: industry needs to have one hundred per cent confidence that multinational environmental agreements are not going to serve as barriers to future deployment of CCS technology. In addition, we urge the Government to take steps to clarify the legality of the various types of CCS project to ensure that uncertainty and ambiguity in this area does not hinder the progress of CCS demonstration projects in or around the UK unnecessarily.**

### *Liability for stored $CO_2$*

106. A strong message that emerged during the course of the inquiry was the need for clarification of the status of stored $CO_2$. The Environment Agency told us of its concern about the "lack of clarity over the definition of carbon dioxide" and the "uncertainty over the jurisdictions of the various regulators and their responsibilities during the planning, permitting and operation of CCS activities".[185] Most of the evidence argues that the Government will ultimately need to take responsibility for the long term storage of $CO_2$. Dr Sam Holloway from the BGS asserted that "In terms of the long term liability, I think the state is probably the only organisation that believes it will exist in a few thousand years' time. In my view, they will have to accept the responsibility in some form or another".[186] BP's Gardiner Hill told us: "I would envisage some conditions in place so that as you hand the licence back, you would be satisfied that all reasonable precautions and measures had been taken to ensure complete integrity of the storage site and hence the liability would be transferred back".[187]

107. We asked DTI whether Government was willing to act as a long term guarantor for $CO_2$ stored in geological reservoirs. The response was as follows: "The proper domestic framework for regulation is under consideration and no decision on this question has been made".[188] However, in oral evidence the Minister appeared to acknowledge that the Government would ultimately need to take on liability for stored $CO_2$, saying "it is just plain common sense that in terms of the very long term […] it would be unrealistic to think that a company, even a very powerful company that was a big player in the 21st Century, may necessarily be there to manage it three million years later".[189] **The private sector should take responsibility for $CO_2$ during the injection phase of any CCS project but we believe that Government will have to take responsibility for the stored $CO_2$ thereafter. We are pleased that the Minister appeared to acknowledge this, but it is essential that the Government makes an explicit commitment to serve as the long term guarantor, and makes it very soon. Industry will not proceed with CCS projects in the absence of such a commitment.** We are also working on the assumption that insurance for CCS will be available as part of normal business practice.

185 Ev 94

186 Q 105

187 Q 139

188 Ev 187

189 Q 314

## *Decommissioning of North Sea infrastructure*

108. The DTI estimates that the UK North Sea contains around 1.5 billion barrels of oil which could be recovered using $CO_2$-EOR.[190] If this is not produced by EOR during the next 10-20 years, these assets could be stranded, with no prospect of production. The time constraint arises because decommissioning of the North Sea oil and gas fields has already started and will increase in rapidity and scope over the next 5-10 years.[191] The East of England Energy Group (EEEGR) has recently conducted a study to examine the possibility of reusing the North Sea infrastructure, including for the purposes of CCS and EOR. EEEGR told us: "Over the last 40 years, the international oil and gas industry has invested some £170 billion in the infrastructure needed to develop the UK's hydrocarbon resources in the UKCS", including "11,000 km of pipeline, installed at an estimated cost of £11 billion".[192]

109. BP also told us that "recycling the North Sea pipeline infrastructure could play an important part in enabling cost effective access to these reservoirs", noting that "the UK's window of opportunity to gain material benefit from CCS technology will close as that infrastructure is removed".[193] Dr Nick Riley from the BGS commented in oral evidence on the "considerable costs in decommissioning" and argued: "it is just crazy not to consider reusing that infrastructure for carbon management in the future". However, the Snohvit CCS project in Norway does not depend on reusing existing equipment and pipes, reflecting the fact that if other incentives are available, the cost of new infrastructure may not be a deal breaker. We return to the issue of incentives in chapter 6.

110. According to EEEGR,

> "As UK oil and gas production declines resulting in the decommissioning of offshore facilities, it is generally accepted that many of the offshore platforms have limited alternative uses and will be removed; this may not be the case for the pipelines. Many of these will remain in situ, with a potential lifespan of 200–300 years. Research undertaken by Cambridge and Cranfield Universities for EEEGR has confirmed that there is no technical reason why these pipelines cannot be reused to transport dry $CO_2$".[194]

One of the obstacles to reuse of the pipeline network is the fact that "Current legislation - principally the 1998 Petroleum Act - does not consider the use of North Sea infrastructure in general and pipelines in particular for anything other than hydrocarbon production and the DTI's structures and procedures reflect this legal requirement".[195] Moreover, "current legislation provides a disincentive for reuse for $CO_2$ storage, due to ownership and liability issues attributed to a change of use".[196] **The Government must take steps to enable and**

190 DTI, *Our energy future–creating a low carbon economy*, Energy White Paper, February 2003, p 90.

191 www.dti.gov.uk/energy/eid/offshore_decom.shtml

192 Ev 180

193 Ev 137

194 Ev 180

195 Ev 181

196 Ev 181

**promote the reuse of existing North Sea infrastructure for the purposes of EOR and CCS. The window of opportunity for the pipelines and platforms is time-bound so rapid action is required.** This action should include ensuring that reuse of pipelines for $CO_2$ transportation is permissible under the OSPAR and London Conventions/Protocol.

## *A Carbon Capture and Storage Authority*

111. It became apparent during the course of the inquiry that a number of different parts of Government have an interest in, and/or expertise of relevance to, CCS. The DTI has led much of the work on CCS through its Cleaner Fossil Fuels Programme and has responsibilities for energy and the hydrocarbon industry. DEFRA is the lead Department for climate change and multilateral environmental agreements (such as the OSPAR and London Convention). George Marsh, a DTI adviser, highlighted a role for the Health and Safety Executive (HSE) in pipeline regulation: "As far as the engineering aspect of carbon capture and storage is concerned, in other words the power plant, the pipeline and the operation of the platform, the regulatory standards for safety exist and are operated through the Health & Safety Executive".[197] E.ON UK also noted that "existing implementation of the EU ETS already involves the EA [Environment Agency], DEFRA and the DTI".[198]

112. In oral evidence, Dr Gibbins from UKCCSC, proposed a solution to streamline the regulation of CCS: "It has been the thought of the UK Carbon Capture and Storage Consortium that it would be useful to have a carbon capture and storage authority which is an independent, national body that assesses the risks, monitors the appropriate operation of a storage scheme and, in the longer term, assumes responsibility, not without payment, but I think that is the way we have to move ahead".[199] We subsequently put the idea to a number of other witnesses, most of whom were supportive of the concept. Air Products told us: "We would actively support the establishment of a Carbon Capture and Storage Authority", while Nick Otter from Alstom Power described it as "a good idea".[200, 201]

113. **At present, multiple Government Departments and agencies, including the DTI, DEFRA, Environment Agency and the Health and Safety Executive, have expertise and functions that would be required for the regulation and monitoring of CCS. In the absence of a Department of Energy, we propose the establishment of a CCS Authority to bring together all the relevant functions. We believe that a single body in this area could make regulation more transparent, thus building public confidence, as well as minimising bureaucracy for companies engaging in CCS projects. In order to ensure that these objectives are met, it is essential that all the relevant onshore and offshore functions be subsumed into the CCS Authority, leaving no residual responsibilities in other Departments, and that the Authority has a clearly defined line of accountability to a single Secretary of State.**

197 Q 307

198 Ev 199

199 Q 101

200 Ev 199

201 Ev 202

114. The CCS Authority would fulfil all the key regulatory functions pertaining to CCS. The initial priorities for a CCS Authority would include taking a lead in the establishment of: a clear legal framework for onshore and offshore $CO_2$ storage; planning and regulatory guidelines for granting consent for CCS projects; clear requirements for monitoring and inspection of $CO_2$ storage sites; and an appropriate process of transferring liability from the private sector to the Government once the injection phase is complete. The CCS Authority could also play an important role in advising Government on the development of incentive frameworks to promote investment in CCS (see chapter 6). In addition, an early task for the CCS Authority would be to review the 1998 Petroleum Act to examine whether and how it should be amended to facilitate CCS (paragraph 110). Once the relevant regulatory and market frameworks were in place, the CCS Authority would then take responsibility for implementation, including monitoring and verification. **In view of the wide range of tasks required to put in place the necessary regulatory frameworks for CCS, and the urgency with which they need to be undertaken, the Government should not delay in taking steps to establish the CCS Authority. Indeed, the Energy Review provides an ideal opportunity to set this process in motion.** Clearly, the process of establishing the Authority must not lead to any delays in granting approval for the first demonstration projects.

# 6 Costs and Incentives

## Costs

115. Most of the cost penalty associated with CCS comes from the capture process. Approximately 75% of the present cost of CCS in full scale plants derives from the $CO_2$ capture process. Transport costs depend on the amount being transported, the distance between the site of capture and that of storage and on whether existing infrastructure can be utilised. The costs of injection and storage are a relatively small component of the overall cost and are not expected to be prohibitive. Although it may seem superficially appealing to bypass the expensive capture step and directly inject the flue gas into the storage site, this would require extremely large and expensive pipelines and would not be desirable for a number of reasons. For example, it would use up the storage capacity at a much faster rate. Also, a relatively pure stream of $CO_2$ is required to minimise pipeline corrosion and the presence of pollutants could have unpredictable effects on the interaction of the gas with the storage site and other potential environmental implications. It would also change the regulatory framework with which the process would need to conform.

116. A wide range of costs have been cited in association with electricity generated using CCS. This largely reflects the array of factors that need to be taken into account, such as the technology chosen for the base case scenario, site-specific issues, national circumstances, oil and gas prices and the predicted benefits of economies of scale.

117. According to the Royal Academy of Engineering, the typical additional cost of CCS is about 1–2.5 pence per kilowatt-hour (p/kWh).[202] UKCCSC also estimates additional costs required to produce electricity from CCS to be in the range of 1–3 p/kWh.[203] The IPCC report states that application of CCS to electricity generation would increase costs by approximately $0.01 to 0.05 per kWh, depending on the fuel, specific technology, location and national circumstances.[204] At current exchange rates, this equates to approximately 0.5–2.8 p/kWh.

118. In view of the different approaches adopted to the calculation of costs associated with CCS, we have produced a standardised set of cost data based on common assumptions defined by us (see Annex B). The data represent the average of the figures submitted by DTI, E.ON, BP, Progressive Energy and the UK Carbon Capture and Storage Consortium.

202 Ev 77

203 Ev 149

204 IPCC, *Special Report on Carbon Dioxide Capture and Storage*, Autumn 2005.

**Table 1: Cost of electricity generation with CCS**

| | Without CCS | With CCS |
|---|---|---|
| Coal | 2.6p/kWh | 3.7p/kWh |
| Gas (£4/GJ cost) | 3.4p/kWh | 4.3 or 5.7p/kWh |

*Source: average of cost data presented by 5 sources in response to questions aimed at producing data on a standard basis.*

119. The data on gas power generation with CCS from three of the sources suggest an average cost of 4.3p/kWh, whilst two sources suggest an average of 5.7p/kWh. The reason for the difference is not clear and could not be established on the basis of the information available. Otherwise there is good agreement between most of the information provided by these 5 sources. In summary, the data suggest that under the conditions specified:

- use of CCS with coal (irrespective of whether it is post-combustion or pre-combustion capture) leads to a cost of generation of about 3.7p/kWh compared with a cost without CCS of 2.6p/kWh;
- electricity generation with CCS from gas costs about 5.0p/kWh (this is the average of the range 4.3 to 5.7p/kWh) at £4/GJ gas price compared with a cost without CCS of 3.4p/kWh;
- at a lower gas price (£3/GJ), which may be more representative of planning assumptions today, the cost of electricity generation with CCS is probably about 4.3p/kWh (but the data were insufficient to be confident in the precise number).

Another way of measuring cost which is often discussed in the literature is to express the extra cost of a plant using CCS in relation to the amount of $CO_2$ emissions avoided. For coal plant, the cost of avoided emissions compared with the plant which would be built today is £17/t $CO_2$ avoided. For gas plant, the corresponding cost would be about £40/t $CO_2$ avoided – the higher cost of avoidance in this case in part reflects the smaller amount of $CO_2$ produced by such plant.

120. **Overall, the data collected in this inquiry indicate that the cost of electricity generated using CCS is 1–2 p/kWh more than without. Taking into account the uncertainties associated with these calculations, the data suggest that there is no clear 'winner' between gas- or coal-fired plant fitted with CCS. It would also appear that an increased gas wholesale price has only a weak effect on cost data.**

121. Futhermore, the cost of electricity generation using CCS seems to be comparable with, or less than, published costs from other carbon abatement or low carbon technologies such as nuclear and renewables. E.ON UK, for example, gave a range of 3.9–5.1 p/kWh for electricity generated from coal using CCS compared to 2.5–4.0 p/kWh for nuclear, 4.2–5.2 for onshore wind and 6.2–8.4 pkWh for offshore wind.[205] [206] Others have estimated the cost

205 Excluding the cost of back-up power for wind.

206 Ev 81

of electricity from nuclear fission to be higher.[207] George Marsh, the DTI's adviser on carbon abatement technologies, acknowledged the competitiveness of CCS in his evidence:

> "You are not going to abate carbon free […] when you aim to abate carbon at the right sort of level and there is a market-based instrument to deliver rewards for abating that carbon, then [CCS] technology, to the best of our knowledge, with the data we have got at the moment, looks to be a competitive technology".[208]

Dr Marsh's crucial point about the need for an appropriate investment framework is addressed in paragraphs 128–147.

## *Infrastructure*

122. CCS and, in particular, transport of $CO_2$ between capture and storage sites requires a considerable amount of new infrastructure. The cost of laying new pipeline is a function of its length but also depends on factors such as the terrain: according to the IPCC Special Report, onshore pipeline costs may increase by 50–100% (or more) when the pipeline route is congested and heavily populated.[209] Costs also increase if the pipelines have to pass through mountainous areas or overcome obstacles such as rivers and major roads. Offshore pipelines are frequently up to 70% more expensive than onshore ones, usually having to operate at higher pressures and lower temperatures.[210]

123. It seems unreasonable to expect any one industrial project to bear the cost of installing large scale pipelines. The memorandum from BNFL stated that "Large-scale transportation of $CO_2$ would require an extensive pipe work infrastructure, on the same size and scale as that used today for the large-scale natural gas supply network".[211] BNFL also argued that it was "unlikely that large sections of the existing natural gas transmission system will become available for $CO_2$ transportation use from clean coal plant until natural gas is no longer used for power production and industrial heating".[212]

124. Dr Freund noted that transport infrastructure had significant cost implications for early projects : "The cost of pipelines for single capture/storage projects will tend to distort the cost […] To avoid this it will probably be necessary to transport 10Mt/y or more […] which may be more than one individual project could justify".[213] He therefore called for Government to provide "incentives for establishing a $CO_2$ infrastructure", using the analogy of transmission systems for electricity and gas: "The common good makes a commanding logic to establishing such infrastructure by use of government support, more so than subsidising an individual plant or storage project".[214] BP noted in its memorandum that the "significant" cost of $CO_2$ transport can "be offset if the re-use of existing

207 E.g. Performance and Innovation Unit, *The Economics of Nuclear Power*, Cabinet Office, 2001 and Massachusetts Institute of Technology, *The Future of Nuclear Power: an interdisciplinary MIT study*, July 2003.

208 Q 48

209 IPCC, *Special Report on Carbon Dioxide Capture and Storage*, Autumn 2005.

210 As above.

211 Ev 122

212 Ev 122

213 Ev 66

214 Ev 66

infrastructure is possible and encouraged”.[215] **It seems unreasonable to expect industry to bear the full costs of the infrastructure required for CCS, particularly in the case of the first demonstration projects. The Government must make sure that this is not a deal breaker for the first demonstration projects.**

### *Opportunities for cost reduction*

125. Part of the cost of CCS reflects the loss of energy efficiency associated with the capture process. Much of the evidence comments on the need to improve the energy efficiency of plant if CCS is to become viable. The Royal Academy of Engineering highlighted the need to characterise better, and reduce, the efficiency loss associated with CCS: “The overall loss in efficiency is about 30% but this estimate is subject to debate, and should be the area in which much of the R&D effort should be directed”.[216]

126. George Marsh, a DTI adviser, argued that “there is a technical potential to reduce [CCS] costs by the order of 50 per cent”.[217] Gardiner Hill from BP, who has been heavily involved in the Carbon Capture Project (CCP) initiative to reduce the costs of capture had a similarly optimistic view.[218] Nick Otter from Alstom also noted that cost reduction was likely to emerge as a result of learning and economies of scale, using the analogy of Flue Gas Desulphurisation [FGD] technology which is fitted to plant to reduce toxic sulphur dioxide emissions:

> “over a 10-year period the cost of FGD went down by a factor of 4. That is due to market penetration; that is not technological development; that is just the market driving the costs down as you get the benefit of scale. I can imagine that happening with $CO_2$ capture”.[219]

**It seems reasonable to expect that new technological developments and benefits derived from increasing experience and economies of scale could collectively lead to significant reductions in the costs associated with CCS.**

127. The cost to the operator might also be offset by income from EOR and, in the future, by carbon credits for reductions in emissions. Additional benefits or costs could arise from other Government support, fiscal or regulatory measures. These are the focus of the next section.

## Market incentives

128. One of the most striking conclusions of the evidence we received was that there are no inherent technological barriers to CCS and industry is ready and willing to launch demonstration projects. The sole obstacle, therefore, is the lack of a policy and incentive framework to provide industry with confidence that it will have a potential means of

215 Ev 138

216 Ev 76

217 Q 329

218 Q 163

219 Q 162

recouping costs in the long term. Provision of the framework is the responsibility of the Government. Brian Morris, Head of Carbon Abatement Technologies at the DTI, acknowledged this in oral evidence:

> "We recognise that there is a need for some sort of incentive. We also recognise that carbon trading in itself is not enough and that there needs to be some sort of way to bridge the gap. How we bridge that gap is difficult to say at this point".[220]

**There are no fundamental barriers to the development and deployment of CCS in the UK, apart from the lack of a suitable long term policy framework to provide industry with the incentives and confidence it requires to make the substantial investments entailed in CCS projects. The Government must put this framework in place as quickly as possible–it is already at risk of holding back UK industry.**

129. We were pleased to hear Malcolm Wicks, the Energy Minister, support the idea of a framework that incentivises $CO_2$ emissions reductions rather than any particular technology. He told us:

> "in principle, there is a case for moving towards the famous level playing field whereby, essentially, government sets challenges and targets in terms of emissions and climate change. […] However, within that it is technology neutral".[221]

The Minister rightly pointed out that "as we move towards that, there is a case for incentivising and helping fund certain technologies", for example through the Renewables Obligation (see paragraph 139).[222] The Minister also made it clear who held the purse strings, telling us: "fiscal and tax matters are best left to the Treasury and I am not going to trespass in that territory".[223] **In the longer term, the Government should seek to provide a level playing field for all carbon abatement technologies.** This does not exist at present and there is, moreover, little prospect of it emerging in the near future. **A technology neutral incentive framework would better reflect the overall objective, which is to reduce $CO_2$ emissions. It would also be more efficient to let the market decide which technologies provide the best solutions to meet this challenge.**

130. It is argued by some that since everyone will reap the benefits of climate change mitigation, industry should not be expected to foot the bill. Rio Tinto told us: "Everyone, including future generations, will benefit from a stable climate. Industry on its own cannot be expected to bear the full cost of developing and demonstrating new technologies".[224] Sussex Energy Group also asserted that "There is a strong rationale for UK government support for CCS technologies because the market value of carbon emissions is well below their full social cost, and the full economic benefits of innovation cannot be captured by private innovators".[225] Dr Douglas Parr from Greenpeace took a different stance, arguing that "We've given tax breaks to companies for getting oil and gas out of the ground, we

220 Q 30

221 Q 345

222 Q 345

223 Q 282

224 Ev 96

225 Ev 152

shouldn't subsidise them to put the subsequent pollution back underground".[226] **We acknowledge the need for Government support during the early stages of technology development. Ultimately, however, a market-based mechanism that puts a price on carbon is the best way to incentivise industry to invest in CCS and other carbon abatement technologies.** Possible approaches to incentivising industry are discussed further below.

## *EU-ETS*

131. The EU-Emissions Trading Scheme (EU-ETS) was introduced to enable the EU countries to meet their $CO_2$ emissions reductions targets under the Kyoto Protocol. The EU-ETS was established by Directive 2003/87/EC in October 2003 and transposed into UK national legislation via the Greenhouse Gas Emissions Trading Scheme 2003. The EU-ETS covers roughly 12,000 industrial plants across the EU's 25 Member States, accounting for around 46% of Europe's total $CO_2$ emissions. The EU-ETS comprises, in the first instance, two phases: Phase I runs from 2005–2007 and Phase II from 2008–2012 (to coincide with the first Kyoto Commitment Period). Further phases are expected thereafter but no firm commitments have been made.[227]

132. The scheme is based on a system of allowances, whereby each allowance entitles the holder to emit one tonne of carbon dioxide per year. The total number of allowances granted to each Member State is capped to reflect that country's Kyoto commitment (e.g. for the UK, this is a 12.5% reduction). National governments then allocate allowances to companies (free of charge). Since the total number of allowances available is restricted, companies emitting more $CO_2$ than their allowances permit are forced to either reduce their emissions or purchase extra allowances. Conversely, companies which reduce their emissions below the level permitted by their allowances have the opportunity to sell their allowances. Thus the EU-ETS creates both an incentive to reduce emissions and a market for carbon. This kind of scheme is sometimes referred to as a 'cap and trade' system.

133. The EU-ETS received widespread support from a range of witnesses in this inquiry. Many witnesses felt that a market-based mechanism was the best way of delivering the level playing field referred to in paragraph 129. E.ON UK's Director of New Business, Colin Scoins, told us for instance: "we need a market in carbon. That is what will drive the technology and its deployment".[228] However, at present CCS is not recognised within the EU-ETS. Although the European Commission guidelines for the monitoring and reporting of emissions from installations covered by the EU-ETS published in 2004 did not include specific guidance on the monitoring and reporting of emissions from CCS projects, they did allow for the inclusion of CCS in the EU-ETS subject to approval of interim guidelines from the Commission.

134. We asked the Government what the prospects were for including CCS in Phase II of the EU-ETS. The DTI responded that following work by an EU Ad Hoc Group of Experts,

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226 Ministers back carbon dumping, *The Guardian*, 15 June 2005.

227 Further information on the EU-ETS is available on the DEFRA website: http://www.defra.gov.uk/environment/climatechange/trading/index.htm.

228 Q 171

recommendations have been made to the Director General Environment (DG ENV) and the European Commission and further work on EOR and the EU-ETS is being commissioned. The DTI also told us: "We understand that DG ENV wishes to include consideration of the issue of CCS and the ETS in the European Climate Change Programme, and to use the CCS working group's meeting next year to develop policy recommendations (reporting later in 2006)".[229] In addition, Brian Morris assured us in oral evidence: "We have already been discussing this with the Commission and we have been told that, provided the correct regulatory regime is in place, there is no reason why [CCS] cannot qualify for carbon credits in the next phase of the Emissions Trading Scheme".[230]

135. Despite supporting the EU-ETS in principle, witnesses' enthusiasm for the EU-ETS was tempered by two main factors. The first was the low carbon price achieved so far within the scheme. The second was the lack of visibility beyond Phase II of the EU-ETS, exacerbated by uncertainty over the details of Phase II itself (including whether CCS will be recognised). These concerns were summarised by BP, who told us that although "a properly functioning Emissions Trading System would be of enormous benefit to CCS projects", the "specific European system is currently insufficient, even if the rules were to be clarified, because it fails to provide a framework of sufficient duration and the current (and indeed, forecast) level of carbon price is inadequate to encourage business to invest the very large sums required".[231]

136. In oral evidence on 7 December, industry witnesses told us that they needed visibility "15 years beyond 2012" and a minimum carbon price of around £20 to £40 per tonne during this period.[232] BP suggested that even this carbon price would not suffice, asserting that £40 per tonne would be at the lower end of what was required for BP to break even on CCS projects. Dr Jon Gibbins, leader of UKCCSC, argued in oral evidence 16 November that there was a role for Government in underwriting the price of carbon in order to provide industry with the long term visibility and minimum carbon price they need.[233] **The EU-ETS has the potential to provide the requisite incentive framework to stimulate investment in CCS and other carbon abatement technologies in the long term. At present, however, the scheme delivers neither the long term visibility nor a sufficiently high carbon price to fulfil this function.**

137. Interestingly, the environmental NGOs argued that a properly functioning EU-ETS would provide the best incentive framework to stimulate CCS investment and proposed that tightening the emissions cap was the best way of boosting the carbon price. Green Alliance concluded that "a robust EU Emissions Trading Scheme and a tight national cap on emissions should be used to support the development of Carbon Capture and Storage", noting that "Key characteristics of the scheme must be a carbon price that is high enough to drive development, and a long-term market that is secure enough to attract investment in low-carbon technologies".[234] Greenpeace and Friends of the Earth also asserted in oral

229 Ev 184

230 Q 54

231 Ev 140

232 Qq 177-181

233 Q 95

234 Ev 178

evidence that the best incentive for CCS was the EU-ETS in conjunction with a tighter cap on emissions.[235] **Government should redouble its efforts to ensure that CCS is included in the next Phase of the EU-ETS and to get agreement for limits beyond 2012. Government should also make the case for a substantial tightening of the emissions cap in the next round in order to stimulate a higher carbon price.**

138. We do not consider it reasonable that Government should underwrite the carbon price or unilaterally tighten the UK emissions cap in the meantime. There is, therefore, a need to put in place interim measures to provide a means of incentivising CCS investment until the EU-ETS is able to deliver this function.

### *Decarbonised Electricity Certificates*

139. BP has called for Government to introduce Decarbonised Electricity Certificates (DECs), analogous to Renewables Obligation Certificates, as a stopgap until the EU-ETS can provide the necessary framework to incentivise CCS. Renewables Obligation Certificates are issued to generators who comply with the Renewables Obligation to generate 15% of electricity from renewable sources by 2015. They can be traded to allow electricity suppliers to meet their targets at the lowest cost. Helen Fleming, Head of the Treasury's Competition and Economic Regulation Team, told us:

> "An obligation is certainly one of the options that we considered in relation to carbon capture and storage. It is not necessarily going to be the right answer for it. In particular, because renewable generation is not exposed to basic fuel price volatility as you would burning gas or coal, a CAT subsidy scheme might not be the best in terms of revenue certainty for a developer".[236]

Green Alliance also considered the possibility of a DEC-like subsidy but asserted that drawbacks would include "disrupting investor confidence in the RO [Renewables Obligation] market; the possibility that carbon-neutral projects could claim some of the subsidy currently distributed to renewable technologies" as well as the fact that it would "add further complexity to an already complex market".[237] In oral evidence, other companies also made it clear that they did not support BP's proposal for DECs on the grounds that "you should not be trying to incentivise technology, but you should be trying to incentivise the reduction in carbon emissions".[238]

### *Other instruments*

140. On our visit to E.ON UK, we heard that it would be in favour of the Government introducing capital grants which could be bid for competitively as one means of getting the first demonstration projects off the ground. BP, by contrast, told us: "We do not think a capital grant is sufficient because we need some sort of long-term commitment […] in

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235 Q 225

236 Q 54

237 Ev 178

238 Q 187

place so that these projects will remain economic over their entire life”.[239] **Competitive capital grants may be needed to encourage the first demonstration projects but they are not a substitute for developing a long term incentive framework.**

141. Prior to the introduction of the Renewables Obligation, the main instrument used by Government to encourage the growth of renewable energy technologies was the Non-Fossil Fuel Obligation (NFFO).[240] NFFO provided generators with premium payments over a fixed period for electricity generated using renewables. Originally, NFFO was introduced to support the nuclear industry. The money needed to support the industry was raised through imposing a levy on electricity bills, known as the Fossil Fuel Levy. Green Alliance raised the possibility that the “fossil fuel levy mechanism, which is currently dormant, could be revived to provide a long-term funding stream for zero carbon technologies”.[241] This has the potential to generate a substantial amount of income. However, a recent report claimed that of the £321M raised for the NFFO fund, only £60M has been spent on capital grants for renewable energy, with most of the rest having been diverted to the Treasury.[242] **It is unacceptable that income from the Non-Fossil Fuel Obligation is not being used to support the renewable energy industry. We recommend that revenues generated through levies imposed in the name of ‘green’ energy be used in a manner consistent with that objective.**

142. Another alternative to the market-based framework provided by the EU-ETS would be to introduce a carbon tax. This would form a direct payment to Government, based on the carbon content of the fuel being consumed. Our predecessor Committee called in its 2003 Report, *Towards a Non-Carbon Fuel Economy: Research, Development and Demonstration*, for the “replacement of the Climate Change Levy and the Renewables Obligation with a unified Carbon and Renewable Energy Tax to be levied on the electricity generators”.[243]

143. In 2001, the Government introduced a Climate Change Levy, essentially a tax on energy used in the non-domestic sector (industry, commerce, and the public sector) aimed at encouraging these sectors to improve energy efficiency and reduce emissions of greenhouse gases.[244] The revenue generated by the Levy is recycled back to businesses in the form of lower National Insurance contributions. The Levy rates vary depending on the fuel used and certain sources, such as renewables, are exempt. Progressive Energy pointed out that “High quality CHP [Combined Heat and Power] is supported by being given enhanced capital allowances and eligibility for Levy Exemption Certificates under the Climate Change Levy”.[245] According to Progressive Energy, “Giving IGCC [with CCS] the same treatment as CHP has the same rationale” and would “overcome any barriers associated with perceived technology risk by investors.[246] We note that this suggestion has

239 Q 192

240 www.dti.gov.uk/renewables/renew_2.2.6.htm

241 Ev 178

242 Treasury hijacks funds meant for green causes, *The Independent*, 17 January 2006.

243 HC [2002–03] 55–I, paragraph 217.

244 http://www.defra.gov.uk/environment/ccl/

245 Ev 130

246 Ev 130

not received widespread backing and are doubtful that the Climate Change Levy would be able to deliver the degree of support that other major companies have argued is necessary to promote investment in CCS.

144. It is also worth noting that some of the evidence we received argued for specific incentives to promote EOR. Fiscal incentives have been used to good effect to stimulate EOR in the US. The costs of offshore EOR are greater than for onshore projects and we heard that, without such incentives, EOR was unlikely to be viable in the North Sea. The Institution of Chemical Engineers suggested that Government should "Encourage the use of CCS technologies for EOR through financial incentives, such as a reduction in royalty payments on recovered oil, as is being considered in Norway".[247] Air Products Plc also called on Government to undertake a "review of the tax treatment for oil produced by tertiary means using $CO_2$ enhanced oil recovery techniques".[248] However, BP told the Committee during its visit to Sunbury that the economic benefits of EOR were nowhere near sufficient to offset the costs of the DF1 project and, moreover, indicated that EOR-specific incentives would not significantly influence its investment decisions.

145. A complicated mix of incentives have been used to stimulate investment in different forms of low carbon energy generation in the UK. **There is now a pressing need for a policy that will provide the level of financing and long term framework necessary to persuade industry to start investing significantly in CCS. Since the Government is currently conducting extensive reviews of its climate change programme and energy policy, it is not feasible for us to determine which specific policy instrument would best meet these needs – the choice would depend on the approaches being taken to incentivise or support other technologies, such as renewables and nuclear energy. It is clear to us that urgent action is required. Doing nothing while waiting for the EU-ETS to come good, or postponing a decision on the policy beyond summer 2006 when the Energy Review reports, would have disastrous consequences for the UK's competitiveness in this area.** The Government should also ensure that incentives are in place which will encourage development and deployment of CCS in industries other than power generation, such as steel and cement production and oil refining.

146. **In the longer term, as well as working towards an effective EU-ETS, the Government should continue to make the case for a global framework for trading carbon.** Ideally, this would eventually include China and India (as well as industrialised countries such as the US and Australia which have not ratified the Kyoto Protocol). **In the meantime, the Government should also support efforts to enable CCS to qualify for the Joint Implementation and the Clean Development Mechanism, which were established by the Kyoto Protocol to allow investment in emissions reduction projects in developing countries and economies in transition.** Under these mechanisms, the reductions in emissions resulting from such projects could then be credited to the investor and used towards meeting their targets.

147. In addition, we believe that there may be an argument for the Government to consider introducing a mechanism which would take into account the environmental credentials of

247 Ev 121

248 Ev 126

its trading partners. This could, for example, take the form of preferentially purchasing goods from countries which have taken demonstrable steps to reduce their greenhouse gas emissions. Any such measures would obviously need to be designed in a way that takes into consideration the UK's existing commitments to free trade.

# 7 Role of CCS in the UK's Future Energy Portfolio

## Energy Review

148. One of the key tasks for the Energy Review is to consider the relative roles of fossil fuels, nuclear energy and renewable technologies in the UK's future energy mix. The availability or otherwise of CCS technology must play a vital part in influencing this balance. This chapter explores the relationship between CCS and renewables and CCS and nuclear energy, as well as considering timescales for decision making.

149. The timing of the Energy Review is striking, not least because it comes so soon after the 2003 Energy White Paper. In an article in The Observer, Energy Minister Malcolm Wicks described the factors that, in his view, rendered today's situation "a very different world from just three years ago":

> "Faster-than-expected North Sea decline, global oil prices rising by 50 per cent in just three years, hardening of the scientific consensus around climate change and, with 30 per cent of the UK's generating capacity set to close by 2020, critical investment decisions on new capacity fast approaching".[249]

The Minister drew particular attention to the UK's increasing dependence on imported gas, commenting that "We would be more exposed to the risk both of natural disasters like [Hurricane] Katrina and political instability in distant producer countries. And the chances of us achieving our ambitious 2050 carbon emission targets would be seriously threatened".[250] We accept that there have been significant developments of relevance to energy policy in the last three years, but we also believe that many of these could have been anticipated in 2003. **The Government's decision to launch another Energy Review less than three years after the publication of the last Energy White Paper in 2003 must been seen as a tacit acknowledgment that the previous White Paper did not foresee some of the key issues.** The scope for CCS to contribute to securing UK energy supply is discussed in paragraph 156.

150. **In view of the complexity of energy policy and the wide-ranging remit of the Energy Review, we were surprised at the short time—barely six months—allocated for consultation and analysis of the evidence.** The Minister acknowledged that this represented an "enormous challenge" but assured us that the allocated time would be sufficient to address all the key questions—we look forward to an announcement later this year.[251] At the launch of the Energy Review Consultation Document in January 2006, the Government announced that it had asked the Health and Safety Executive (HSE) to "report on some specific potential health and safety risks arising from recent and potential energy developments and on the HSE's approach to ensure that risks arising from these are

249 Malcolm Wicks MP, Grasping the nuclear nettle, *The Observer*, 4 December 2005.

250 As above.

251 Q 352

sensibly managed by industry".[252] The HSE has been given 18 months to report. **We are concerned that the review being undertaken by the Health and Safety Executive may be used by the Government as an excuse for delaying concrete decisions about commitments to CCS. This would be a major setback for the UK's progress in this area and must not be allowed to happen.**

### *CCS and renewables*

151. One of the factors underlying the conditionality of environmentalists' support for CCS is the concern that it will, in the words of the Environment Agency, "unnecessarily prolong our dependence on fossil fuels, which is counterproductive for the environment overall" and "distract effort from more cost-effective, immediate and proven solutions".[253] Doug Parr, the Greenpeace chief scientist, made a similar point: "the pursuit of this technology [CCS] is a distraction from the real priorities of implementing renewable energy and energy efficiency technologies which are available right now".[254]

152. Numerous other witnesses argued that these concerns were overridden by the fact that fossil fuels would be an inevitable and essential part of the energy mix for the foreseeable future (both in the UK and abroad) and CCS could limit the damage inflicted through burning them. Rodney Allam from Air Products commented: "We certainly cannot sustain our economy or our way of life without burning fossil fuels, which are providing 70 per cent of our total energy requirements in this country and similar amounts in other countries".[255] Jim Penman from DEFRA also told us: "The thing to bear in mind is that fossil fuels are going to be used in future probably whatever happens", emphasising that "This is not a zero-sum game and [CCS] is a classic transition technology".[256] The Minister Malcolm Wicks said that he had a "lot of sympathy" for those concerned about CCS encouraging reliance on fossil fuels at a time when the world should be moving away from burning them. However, he then went on to say that opposing CCS on this basis was "ideology gone mad".[257] Whilst we wouldn't necessarily endorse the Minister's choice of words, we support the sentiment. **The availability of CCS should not become an excuse to deepen the world's dependence on fossil fuels as energy sources. Nevertheless, it is clear that neither the UK nor most other countries are yet willing or able to exclude fossil fuels from their energy mix and, this being the case, CCS can play a crucial damage limitation role during the transition to alternative energy sources such as renewables.**

153. Another argument that has been made to justify preferential investment in renewables is that CCS only decreases the increase in emissions resulting from fossil fuel combustion (albeit by around 85%) rather than eliminating them altogether. However, others have pointed out that CCS has the potential to produce negative net emissions. This could be

252 DTI, *Our Energy Challenge: securing clean, affordable energy for the long-term*, Energy Review Consultation Document, January 2006.

253 Ev 94

254 Ministers back carbon dumping, *The Guardian*, 15 June 2005.

255 Q 109

256 Q 12

257 Q 261

achieved by fitting biomass-fired plant with CCS. Energy generation from biomass is considered to be carbon neutral (due to the $CO_2$ absorbed from the atmosphere as the biomass grows), therefore adding CCS would, in effect, remove $CO_2$ from the atmosphere. This possibility was highlighted by, amongst others, UKCCSC:

> "Large scale biomass conversion with CCS, probably through co-utilisation of biomass with coal, would also remove $CO_2$ from the air, as well as providing energy. This could be used as an offset for emissions from air and marine transport, where carbon-based liquid fuels have obvious technical advantages".[258]

It should be noted that recent reports have drawn attention to the limitations of biomass, even suggesting that in some circumstances it may cause more harm than good to the environment overall (e.g. due to negative impacts relating to land use).[259] **The possibility of removing $CO_2$ from the atmosphere by fitting biomass-fired plant with CCS is highly appealing but further research is needed to ensure that this approach will deliver the expected environmental benefits.**

154. It is also important to consider the overall scale of reductions that could be generated by CCS and renewables in the near term. Dr Riley from the BGS commented that the avoidance of $CO_2$ emissions that would be provided by BP's Miller project (1.3 million tonnes $CO_2$ per annum) would be "about the same [$CO_2$ emissions] avoidance as all the entire wind farm installed capacity we have at the moment for the UK".[260] In fact, this may be a slight overestimate but it is certainly true that, if successful, the scale of emissions reductions that the DF1 project would deliver would be comparable to the reductions achieved by all the onshore wind farms in the UK in 2005. Thus, CCS could play a vital role in helping the UK get back on track to meet its 2050 target to reduce $CO_2$ emissions by 60% compared with 1990 levels.

155. **CCS has the potential to make a dramatic impact on carbon dioxide emissions in a short space of time and, given current performance, it will be hard for the UK to meet its 2050 target on emissions reductions without CCS. However, CCS must not be regarded as a substitute for developing renewable forms of electricity generation or implementing energy efficiency measures.** These will still be essential, particularly for the longer term. Irrespective of the role played by CCS, the availability of, for example, market-ready mass scale tidal or wave energy technology would be of enormous value and investment in these technologies must continue.

### *CCS, nuclear energy and security of supply*

156. One of the main purposes of the Energy Review is to explore the possibility of new nuclear build.[261] Dr Jon Gibbins argued that CCS had far more to offer than nuclear in terms of reducing $CO_2$ emissions:

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258 Ev 146

259 European Environment Agency, *How much biomass can Europe use without harming the environment?*, EEA Briefing 02, 2005.

260 Q 69

261 DTI, *Our Energy Challenge: securing clean, affordable energy for the long-term*, Energy Review Consultation Document, January 2006.

> "The problem of climate change is largely a problem of carbon being emitted from burning fossil fuels. Carbon capture and storage is the only option that directly addresses that. We are not having climate change problems because we do not have enough nuclear; we are having climate change problems because we have too much carbon dioxide coming from fossil fuels".[262]

Others have backed CCS precisely because it offers an alternative to nuclear energy and, as such, is perceived to be the lesser of two evils. Friends of the Earth, for instance, asserts that CCS is "a far preferable approach to the possible alternative of nuclear power, which is also put forward by some groups as a bridging technology".[263]

157. It is frequently asserted that nuclear energy is key to securing and diversifying UK energy supply. We were interested to hear analogous arguments put forward for CCS. Brian Morris, for example, told us that CCS "gives you an opportunity for diversity of supply" by enabling the use of coal, gas, oil or biofuel mixtures sourced from a range of geographical and political origins.[264] Kenneth Fergusson, President of the Combustion Engineering Association, has also argued that underground gasification of unmineable coal seams in conjunction with CCS could provide the UK with substantial amounts of low carbon energy from a domestic fuel source.[265] However, substantial additional research and development is likely to be needed to ensure that underground gasification is reliable and commercially viable. Others pointed out that EOR could prolong the life of the North Sea oil fields.[266] Gardiner Hill from BP argued that CCS "has the potential to extend the useful aspects of the North Sea" through creating employment and opportunities for EOR, thus adding to the diversity and enhancing security of energy supply for the UK.[267] **CCS can contribute to security of supply by enabling the UK to utilise a range of fuels from diverse sources and suppliers, without impairing progress towards $CO_2$ emissions targets.**

158. The Government's Chief Scientific Adviser has repeatedly argued that the UK will need "every tool in the bag" in order to meet its energy and climate change mitigation objectives.[268] It remains to be seen, however, whether the Government will be able to provide a framework to persuade industry to invest in renewables, nuclear **and** CCS. Professor Gordon MacKerron, Director of Sussex University Energy Group and chair of the Committee for Radioactive Waste Management, has raised the possibility that a Government commitment to nuclear could deter gas and renewable energy suppliers from investing which could, if not all the expected nuclear plant was built (as has happened in the past), leave the UK with an energy shortfall.[269] According to Professor MacKerron, even if new nuclear build was approved and commissioned, the first power from a new reactor

262 Q 62

263 *Carbon capture supported–but more needed on emissions cuts*, Friends of the Earth press release, June 14 2005.

264 Q11

265 Ev 174

266 Ev 139

267 Q 108

268 E.g. *Climate target 'a bit optimistic'*, BBC News, 20 November 2005.

269 Gordon MacKerron, Who puts up the cash, *The Observer*, 4 December 2005.

would not be produced before 2018 or, "more likely", 2020.[270] The Secretary of State for the Environment, Food and Rural Affairs, Margaret Beckett, has also been reported as saying that any new nuclear build would not be producing energy by 2020.[271] By contrast, both BP and Progressive Energy have stated that they are capable of building industrial scale demonstration plants using CCS starting today, with the first electricity being produced within four years.[272] This would seem to support the argument that early build and demonstration of CCS plant in the UK could lead to $CO_2$ emissions reductions more rapidly than investment in nuclear. Demonstration of CCS could also deliver the additional benefit of providing an entry point for reducing the far more substantial emissions from China and India.

159. In informal discussions, one of the major UK energy suppliers admitted that one of the most difficult questions facing the company was whether CCS and nuclear could be pursued in parallel, presumably due to the levels of investment and expertise required for each. It is also worth noting that most of the costings for both nuclear and gas- or coal-fired plant fitted with CCS assume that the plant will be base-load generation plant.[273] There is a finite demand for base-load plant on the grid (in the order of 15–20 GW) so it would probably not be possible for both types of plant to operate as such. This means that either CCS-fitted plant or nuclear would need to bear the additional penalty of running at lower levels of generation, which could impact on their commercial viability. The Government must take these limitations into account when considering the respective roles of nuclear and CCS in the UK's future energy mix.

## Timescales

160. The UK is faced with a significant opportunity to take a lead in demonstrating CCS technology and, as discussed in chapter four, the rewards on offer could be considerable in both domestic and global terms. However, time is of the essence if the UK wishes to capitalise on this opportunity. This reflects the fact that:

- The greatest benefits would be derived by the UK if it takes a lead in demonstrating CCS technology;
- Export opportunities depend on full scale demonstrations of technology in the UK. These need to start now, to provide industry with the confidence to make medium term decisions (e.g. industry decisions are required by 2010 for plant to come on-line by 2015);
- Industry needs a long term price signal, as well as an indication of the framework for strategic regulation and ownership, before serious investment will occur;
- Decommissioning of the UK electricity generation fleet is underway, and will reach 30% by 2020;

270 As above.

271 The Monday Interview: Margaret Beckett: "Somebody clearly wants my job. But you wonder if these people are living in the real world", *The Independent*, 28 November 2005.

272 Ev 148

273 A base load power plant provides a steady flow of power regardless of total power demand by the grid.

- Decommissioning of the North Sea oil and gas fields is underway and the infrastructure is being removed;

- There is a need to prove that the amount of stored $CO_2$ can be verified and that there is no significant risk of leakage, both of which will take time to do; and

- There is an increasing sense of urgency over the need to meet emissions targets as a result of emerging scientific evidence on climate change and ocean acidification.[274]

161. We were therefore disappointed to discover that the Government considered CCS to be a technology primarily of long term significance. Brian Morris, the DTI's Head of Carbon Abatement Technologies said in oral evidence:

> "I would even go as far as to say that one would tend to think about this technology as being beyond 2020 and, as I think you will see in the Carbon Abatement Technology strategy, we think of this technology as being something beyond that time. It is not really a technology that could apply up to 2020."[275]

The Energy Minister, Malcolm Wicks, also repeatedly referred to the fact that CCS was at a very early stage and, when asked about timescales, was less than ambitious: "I would very much hope that into the next decade we would have seen a major demonstration project, the most likely one is the Miller field BP project and after that I would hope there would be other fundamental developments, but it is too early to be entirely confident about that".[276] **We are disappointed by the Government's repeated assertion that CCS technologies are at a very early stage and are concerned that this is being used as an excuse for inaction. If the Government were to demonstrate the ambition and determination that we believe is merited, the UK could significantly progress the status of CCS technology and perceptions of its viability.** Brian Morris rightly stated that "We have got to be doing the work today to enable [CCS] technologies to be there by 2020".[277] **Regrettably, the Government's actions to date do not reflect the urgency of the situation. We trust that this will be rectified during the forthcoming Energy Review.**

162. In oral evidence, the Minister told us: "One thing I have learned, if I needed to learn it, is that in energy policy, where we have got targets on emissions which go up to 2050 and where we need to make judgments now which will influence energy policy and therefore climate change maybe for much of this century […] we need long-term certainty and industry need long-term certainty".[278] We are heartened to hear this and hope that the Minister will now put his lesson into practice. **One of the top priorities for the Government must be to develop the long term and coherent energy policy which has been sorely lacking to date. It is essential that, following the Climate Change Programme Review, Energy Review and Stern Review, the Government puts in place a stable incentive framework that will enable industry to find the most cost effective technological solutions to meet the UK's energy and climate change objectives.**

274 POSTnote 245.

275 Q 2

276 Q 234

277 Q 12

278 Q 252

# 8 Conclusion

163. The available evidence indicates that CCS could and should make a valuable contribution to reducing $CO_2$ emissions and safeguarding energy security in the UK. It also appears likely that CCS technology could play a key role in mitigating $CO_2$ emissions internationally and, more specifically, from China's and India's ever growing fleet of coal-fired power stations, providing that it can be deployed sufficiently rapidly. In order to meet this timescale, the development of CCS technology needs to be pursued with greater vigour than has been the case to date. In particular, multiple full scale demonstration projects are urgently needed and the UK should take advantage of the fact that it is especially well placed to take a lead in demonstrating offshore EOR and $CO_2$ storage. The costs of CCS are comparable with—and have the potential to be lower than—other low carbon electricity generating techniques. Although renewable technologies for energy generation will be essential, especially in the medium to long term, the capacity of CCS to make a large contribution to reducing $CO_2$ emissions in a short space of time could make it a very valuable tool for climate change mitigation.

164. There appear to be no insurmountable regulatory hurdles to CCS in the UK, although the Government needs to do its best to accelerate progress towards clarification of the relevant multinational environmental agreements, as well as putting in place an appropriate domestic regulatory regime. Capture readiness should also be made a requirement for statutory licensing of any new plant, both to facilitate the process of subsequent fitting of capture technology in the UK and to prove the concept for export to China and other countries.

165. Given sufficient impetus by the Government, UK industry could deploy CCS technology in a full scale test by 2009. However, UK industry is awaiting a financial framework and policy signal from Government to give the initial projects the go ahead. The Energy Review must provide these.

# Conclusions and recommendations

## Background

### Climate change policy

1. It is indisputable that—in the absence of CCS—fossil fuel consumption in countries such as China and India will have a profound and potentially catastrophic impact on global atmospheric CO2 levels, eclipsing any reductions made by the UK and others. (Paragraph 18)

## Technology

### Capture technologies

2. Although it is clearly important that pre-combustion, post-combustion and oxyfuel capture technologies be developed, we believe that for new plant pre-combustion capture offers a significant advantage, in a carbon constrained world, as a potential source of hydrogen. As the technology develops, the Government should take into account the potential strategic importance of polygeneration systems based on pre-combustion capture technology and consider the case for putting in place incentives to promote the use of this technology in new build plant. (Paragraph 32)

3. In our view, no convincing case has yet been made for retrofitting of the UK's ageing fleet of coal-fired power stations with capture technology. Combining retrofitting with boiler and turbine replacement may provide a means of overcoming the loss in efficiency associated with current capture technology, but it remains to be seen whether this will prove economic for the majority of UK coal-fired plant. (Paragraph 35)

4. We recommend that Government makes capture readiness a requirement for statutory licensing of all new fossil fuel plant. This would compel the developer to demonstrate that consideration has been given in the planning and design of the plant to facilitating subsequent addition of suitable carbon dioxide capture technology, as and when it becomes available and economic. (Paragraph 38)

5. Although in the near term CCS is most likely to be employed in the power sector, it has the potential to be applied to a range of industrial processes, as well as in the building and transport sectors. We recommend that the Government support for CCS research includes applications in these sectors. (Paragraph 39)

### Storage

6. The UK is fortunate in being very well endowed with potential CO2 storage sites, many of which have been thoroughly characterised. This provides the UK with a competitive advantage in terms of access to potential CO2 storage sites, both for its own use and to demonstrate UK geological skills to the rest of the world. (Paragraph 44)

7. Oil and gas fields have, in general, been better characterised than saline aquifers so may be more suitable for immediate development. Nevertheless, the best way of furthering understanding of storage of CO2 in aquifers, which provide very substantial storage potential in the longer term, is through large scale demonstration projects. (Paragraph 45)

8. The UK's geological expertise through the hydrocarbon industry and British Geological Survey is recognised to be amongst the best in the world. This expertise should be leveraged to facilitate and promote UK demonstrations of CCS and, ultimately, uptake of CCS internationally. (Paragraph 46)

9. On the basis of current information, coal seems unlikely to be a major storage option for the UK, at best being of small scale and local significance. (Paragraph 49)

10. It is clear that storage in geological formations, providing that it can be done safely and securely, is the most desirable and competitive way of storing CO2 of the currently available options. (Paragraph 50)

## RD&D and international competitiveness

### Demonstration projects

11. Most of the component technologies of CCS are not novel: the key outstanding requirement is to integrate them within full-scale demonstration projects involving different elements of the technology and operating under different conditions (including offshore). (Paragraph 54)

12. The BP-led DF1 project could be a crucial opportunity to test the viability of linked systems of onshore gas conversion, power generation and offshore CO2 storage in the North Sea. (Paragraph 57)

13. We are encouraged by the number of companies considering investing in UK CCS demonstration projects. Industry evidently believes that CCS technology is sufficiently advanced to proceed with full scale demonstrations. What is needed now to complement this positive response from industry is a commensurate effort from the Government. (Paragraph 58)

### Government RD&D funding

14. The additional £10 million provided for demonstration of carbon abatement technologies in the pre-budget report is welcome but the piecemeal allocation of funding suggests a worrying lack of strategic vision in Government decision making. (Paragraph 60)

15. Government can play an essential role in 'pump priming' the initial demonstration projects. In order to do this effectively, Government support in the order of hundreds of millions of pounds needs to be forthcoming over the next five years. (Paragraph 61)

## Skills

**16.** Once again, we find the Government erring on the side of complacency over the continued supply of skilled scientists and engineers. In view of the strategic significance of energy policy at this time, failure to take active steps to build and safeguard the UK skills base in this area will prove costly. (Paragraph 63)

## International co-operation

**17.** The Government must do its utmost to work together with both the private sector and academia to give the UK the best chance of hosting any major EU-funded CCS demonstration project. (Paragraph 64)

**18.** The increasing co-operation between the UK and Norway on CCS is sensible, but the UK should also learn from the Norwegian Government's approach of backing its words with action and investment. (Paragraph 66)

**19.** The UK and EU bilateral agreements to co-operate in the development of CCS technology with China are to be welcomed. However, the timescales envisaged and sums allocated in no way reflect the urgency with which CCS technology needs to be demonstrated and deployed if it is to be able to play a significant role in mitigating climate change. Efforts to engage China and India in this area are to be encouraged, but we doubt whether Memoranda of Understanding in themselves represent an effective way of expediting the development of carbon abatement technologies, or of promoting their uptake by these countries. (Paragraph 68)

**20.** The DTI and DEFRA should ensure that there is strong co-ordination between their activities in promoting CCS RD&D in China and India and those undertaken by the FCO and DFID in these countries. (Paragraph 69)

**21.** The major obstacle to the adoption of CCS technologies by countries such as India and China is still the lack of value attached to carbon internationally. (Paragraph 70)

## A leadership role for the UK?

**22.** The UK is well positioned to take an international leadership role in demonstrating the viability of CCS. British leadership in the use of CCS technology will both yield returns from domestic carbon reduction and provide a strong indication to other major polluters of the potential of CCS to reduce global emissions. (Paragraph 73)

**23.** Export opportunities for UK companies are likely to derive from intellectual property and licensing of CCS technology. (Paragraph 74)

**24.** If the UK is serious about making an impact on China and India, the most useful thing it could do would be to get full scale demonstrations of several different types of CCS technology up and running domestically as soon as possible. This would prove the viability of the technologies and give UK companies comparative advantage in terms of experience and know how. In the absence of such demonstrations, the idea of major export opportunities for UK companies is unrealistic. (Paragraph 77)

25. A major refurbishment of a UK coal-fired power station combined with retrofitting of CCS technology could afford a very valuable opportunity to demonstrate the post-combustion capture technology required to retrofit Chinese coal-fired plant, as well as providing useful experience of combined retrofit and upgrade of a UK plant. (Paragraph 78)

## Risks and Regulation

### Risks

26. Experience to date has demonstrated that, over the timescales studied, $CO_2$ can be safely stored in both depleted oil and gas fields and aquifers. Current and future large scale demonstration projects will play a key role in building the evidence base for, and public confidence in, geological storage of $CO_2$. (Paragraph 79)

27. The main source of leakage from $CO_2$ storage sites is likely to be via boreholes, although it is expected that any breach of the borehole seal could be remediated quickly. Further R&D to develop cements and sealants optimised for $CO_2$ storage would nevertheless be valuable. (Paragraph 85)

28. We recommend that the Government works both with other interested parties within the UK and, over the longer term, internationally, in order to develop a standardised methodology for site characterisation. More generally, there is a need for codes of practice to be developed to ensure good design and management of $CO_2$ storage facilities. (Paragraph 87)

29. Further research is needed to improve the tools for site selection and subsequent monitoring and verification of $CO_2$ stored in geological formations. Although companies will be expected to take steps to improve monitoring and verification in the projects that they sponsor, the Government must take primary responsibility for commissioning research in this area in view of its significance for public safety and confidence in the technology. We recommend that the Government makes this an RD&D priority. (Paragraph 89)

30. Providing that the pipelines are designed and routes are selected in such as a way as to minimise risk, transportation of $CO_2$ by pipeline between capture and storage sites should not pose any greater threat to human health or the environment than natural gas transport and may indeed be lower. (Paragraph 91)

31. Overall, the evidence suggests that for well-chosen sites the risk of leakage of $CO_2$ from geological storage reservoirs or pipelines is low. The risks associated with storage of $CO_2$ would be further mitigated by thorough site characterisation and management, monitoring and verification of storage sites. (Paragraph 92)

32. Clear and transparent information about CCS at an early stage will be crucial for securing public acceptance. The Government must therefore adopt a pro-active approach to communication. (Paragraph 95)

33. The Government has done little so far to engage the public in a dialogue about CCS technology. We accept that it is early days for the technology but previous experience

has emphasised the value of early engagement. The evidence we have seen does not support the view that the Minister's confident and relaxed attitude towards the Government's performance on this issue is justified, and this is a source of concern. (Paragraph 97)

**34.** The first demonstration projects will need to give careful consideration to public engagement—early successes or failures are likely to have a disproportionate impact on subsequent public attitudes. (Paragraph 98)

**35.** Environmental NGOs can make a major contribution to ensuring that public debate about CCS is conducted in a responsible way. Their suggestion that they do not have influence over public opinion was perplexing and unconvincing. We call on the NGOs and the Government to work collaboratively to inform public perceptions of the risks and benefits associated with CCS. (Paragraph 99)

## Regulatory framework

**36.** EOR can provide a useful stepping stone to CCS by enabling early proving of offshore $CO_2$ injection without contravening the multinational environmental agreements governing the disposal of waste in marine environments. (Paragraph 102)

**37.** It is commendable that the Government has taken a lead in international negotiations to amend the London Convention/Protocol to ensure that CCS projects are permissible. Whilst we appreciate that it may take time to secure international agreement, it is vital that the UK does its utmost to expedite this process: industry needs to have one hundred per cent confidence that multinational environmental agreements are not going to serve as barriers to future deployment of CCS technology. In addition, we urge the Government to take steps to clarify the legality of the various types of CCS project to ensure that uncertainty and ambiguity in this area does not hinder the progress of CCS demonstration projects in or around the UK unnecessarily. (Paragraph 105)

**38.** The private sector should take responsibility for $CO_2$ during the injection phase of any CCS project but we believe that Government will have to take responsibility for the stored $CO_2$ thereafter. We are pleased that the Minister appeared to acknowledge this, but it is essential that the Government makes an explicit commitment to serve as the long term guarantor, and makes it very soon. Industry will not proceed with CCS projects in the absence of such a commitment. (Paragraph 107)

**39.** The Government must take steps to enable and promote the reuse of existing North Sea infrastructure for the purposes of EOR and CCS. The window of opportunity for the pipelines and platforms is time-bound so rapid action is required. (Paragraph 110)

**40.** At present, multiple Government Departments and agencies, including the DTI, DEFRA, Environment Agency and the Health and Safety Executive, have expertise and functions that would be required for the regulation and monitoring of CCS. In the absence of a Department of Energy, we propose the establishment of a CCS Authority to bring together all the relevant functions. We believe that a single body in this area could make regulation more transparent, thus building public confidence, as well as minimising bureaucracy for companies engaging in CCS projects. In order to ensure that these objectives are met, it is essential that all the relevant onshore and offshore functions be subsumed into the CCS Authority, leaving no residual responsibilities in other Departments, and that the Authority has a clearly defined line of accountability to a single Secretary of State. (Paragraph 113)

**41.** In view of the wide range of tasks required to put in place the necessary regulatory frameworks for CCS, and the urgency with which they need to be undertaken, the Government should not delay in taking steps to establish the CCS Authority. Indeed, the Energy Review provides an ideal opportunity to set this process in motion. (Paragraph 114)

## Costs and Incentives

### Costs

**42.** Overall, the data collected in this inquiry indicate that the cost of electricity generated using CCS is 1–2 p/kWh more than without. Taking into account the uncertainties associated with these calculations, the data suggest that there is no clear 'winner' between gas- or coal-fired plant fitted with CCS. It would also appear that an increased gas wholesale price has only a weak effect on cost data. (Paragraph 120)

**43.** It seems unreasonable to expect industry to bear the full costs of the infrastructure required for CCS, particularly in the case of the first demonstration projects. The Government must make sure that this is not a deal breaker for the first demonstration projects. (Paragraph 124)

**44.** It seems reasonable to expect that new technological developments and benefits derived from increasing experience and economies of scale could collectively lead to significant reductions in the costs associated with CCS. (Paragraph 126)

### Market incentives

**45.** There are no fundamental barriers to the development and deployment of CCS in the UK, apart from the lack of a suitable long term policy framework to provide industry with the incentives and confidence it requires to make the substantial investments entailed in CCS projects. The Government must put this framework in place as quickly as possible–it is already at risk of holding back UK industry. (Paragraph 128)

**46.** In the longer term, the Government should seek to provide a level playing field for all carbon abatement technologies. A technology neutral incentive framework would better reflect the overall objective, which is to reduce $CO_2$ emissions. It would also be more efficient to let the market decide which technologies provide the best solutions to meet this challenge. (Paragraph 129)

**47.** We acknowledge the need for Government support during the early stages of technology development.. Ultimately, however, a market-based mechanism that puts a price on carbon is the best way to incentivise industry to invest in CCS and other carbon abatement technologies. (Paragraph 130)

**48.** The EU-ETS has the potential to provide the requisite incentive framework to stimulate investment in CCS and other carbon abatement technologies in the long term. At present, however, the scheme delivers neither the long term visibility nor a sufficiently high carbon price to fulfil this function. (Paragraph 136)

**49.** Government should redouble its efforts to ensure that CCS is included in the next Phase of the EU-ETS and to get agreement for limits beyond 2012. Government should also make the case for a substantial tightening of the emissions cap in the next round in order to stimulate a higher carbon price. (Paragraph 137)

**50.** Competitive capital grants may be needed to encourage the first demonstration projects but they are not a substitute for developing a long term incentive framework. (Paragraph 140)

**51.** It is unacceptable that income from the Non-Fossil Fuel Obligation is not being used to support the renewable energy industry. We recommend that revenues generated through levies imposed in the name of 'green' energy be used in a manner consistent with that objective. (Paragraph 141)

**52.** There is now a pressing need for a policy that will provide the level of financing and long term framework necessary to persuade industry to start investing significantly in CCS. Since the Government is currently conducting extensive reviews of its climate change programme and energy policy, it is not feasible for us to determine which specific policy instrument would best meet these needs – the choice would depend on the approaches being taken to incentivise or support other technologies, such as renewables and nuclear energy. It is clear to us that urgent action is required. Doing nothing while waiting for the EU-ETS to come good, or postponing a decision on the policy beyond summer 2006 when the Energy Review reports, would have disastrous consequences for the UK's competitiveness in this area. (Paragraph 145)

**53.** In the longer term, as well as working towards an effective EU-ETS, the Government should continue to make the case for a global framework for trading carbon. (Paragraph 146)

**54.** In the meantime, the Government should also support efforts to enable CCS to qualify for the Joint Implementation and the Clean Development Mechanism, which were established by the Kyoto Protocol to allow investment in emissions reduction projects in developing countries and economies in transition. (Paragraph 146)

## Role of CCS in the UK's Future Energy Portfolio

### Energy Review

**55.** The Government's decision to launch another Energy Review less than three years after the publication of the last Energy White Paper in 2003 must been seen as a tacit acknowledgment that the previous White Paper did not foresee some of the key issues. (Paragraph 149)

**56.** In view of the complexity of energy policy and the wide-ranging remit of the Energy Review, we were surprised at the short time—barely six months—allocated for consultation and analysis of the evidence. (Paragraph 150)

**57.** We are concerned that the review being undertaken by the Health and Safety Executive may be used by the Government as an excuse for delaying concrete decisions about commitments to CCS. This would be a major setback for the UK's progress in this area and must not be allowed to happen. (Paragraph 150)

**58.** The availability of CCS should not become an excuse to deepen the world's dependence on fossil fuels as energy sources. Nevertheless, it is clear that neither the UK nor most other countries are yet willing or able to exclude fossil fuels from their energy mix and, this being the case, CCS can play a crucial damage limitation role during the transition to alternative energy sources such as renewables. (Paragraph 152)

**59.** The possibility of removing $CO_2$ from the atmosphere by fitting biomass-fired plant with CCS is highly appealing but further research is needed to ensure that this approach will deliver the expected environmental benefits. (Paragraph 153)

**60.** CCS has the potential to make a dramatic impact on carbon dioxide emissions in a short space of time and, given current performance, it will be hard for the UK to meet its 2050 target on emissions reductions without CCS. However, CCS must not be regarded as a substitute for developing renewable forms of electricity generation or implementing energy efficiency measures. (Paragraph 155)

**61.** CCS can contribute to security of supply by enabling the UK to utilise a range of fuels from diverse sources and suppliers, without impairing progress towards $CO_2$ emissions targets. (Paragraph 157)

**62.** We are disappointed by the Government's repeated assertion that CCS technologies are at a very early stage and are concerned that this is being used as an excuse for inaction. If the Government were to demonstrate the ambition and determination that we believe is merited, the UK could significantly progress the status of CCS technology and perceptions of its viability. (Paragraph 161)

**63.** Regrettably, the Government's actions to date do not reflect the urgency of the situation. We trust that this will be rectified during the forthcoming Energy Review. (Paragraph 161)

**64.** One of the top priorities for the Government must be to develop the long term and coherent energy policy which has been sorely lacking to date. It is essential that, following the Climate Change Programme Review, Energy Review and Stern Review, the Government puts in place a stable incentive framework that will enable industry to find the most cost effective technological solutions to meet the UK's energy and climate change objectives. (Paragraph 162)

# Acronym List

| | |
|---|---|
| BGS | British Geological Survey |
| CAT | Carbon Abatement Technology |
| CCP | Carbon Capture Project |
| CCS | Carbon Capture and Storage |
| $CO_2$ | Carbon Dioxide |
| DEFRA | Department for Environment, Food and Rural Affairs |
| DF1 | Decarbonised Fuels 1 Project |
| DTI | Department of Trade and Industry |
| EOR | Enhanced Oil Recovery |
| ETS | Emissions Trading Scheme |
| $H_2$ | Hydrogen |
| IGCC | Integrated Combined Cycle Gasification (power plant) |
| PF | Pulverised fuel (power plant) |
| UKCCSC | UK Carbon Capture and Storage Consortium |
| UKCS | UK Continental Shelf |

# Annex A

## *$CO_2$ capture technology: summary of experience*

The main $CO_2$ capture processes currently in use are solvent scrubbing and membrane separation. These processes are based on established chemical engineering experience; they are used to clean up natural gas, to separate $H_2$ from $CO_2$ in ammonia and hydrogen manufacture. They provide $CO_2$ for the food industry, for making urea (a fertiliser) and for Enhanced Oil Recovery (EOR).

Reports of the numbers of such plant in use include:

- 334 physical solvent scrubbing plants in use in 1997;
- 294 chemical solvent (amine) scrubbing plants were recognised in one survey of US installations; the total number worldwide probably amounts to thousands;
- in addition, a smaller number of membrane units remove $CO_2$ from natural gas.

The typical size of these $CO_2$ capture plant is much smaller than would be necessary for CCS. Few of the current applications of $CO_2$ capture are at the scale of operation which would be required for a plant designed to mitigate climate change, for the simple reason that currently there is no commercial need to separate gases at that scale. The largest are synthetic fuels plants (making transport fuels or synthetic natural gas) which separate substantial amounts of $CO_2$ from the synthesis gases, in the same way as would be done in pre-combustion capture power plants. For example, the Dakota Gasification plant separates 3.3Mt/y of $CO_2$ using physical solvent scrubbing – this is equivalent to the rate at which $CO_2$ would be captured in a modern power plant. $CO_2$ is also separated in hydrogen and ammonia production plants at rates up to 3500 t/d (1.3 Mt/year).

Chemical solvent capture is used in the food and chemicals industries to capture $CO_2$ amounts between 2000 and 200,000 t/y of $CO_2$, including in a few power plant; in other words a 10-fold scale-up would be required for post-combustion capture in power plant. Three processes are available commercially (i.e., the ABB Lummus Crest process, Fluor Daniel's Econamine process, Mitsubishi Heavy Industry's KS-1 process). All of these have been installed in plant separating tens of thousands of tonnes of $CO_2$ per year. Scale-up would involve using extra separation columns, or increasing the diameter of the columns, which will not be a major obstacle.

Existing applications of chemical solvent scrubbing are mainly in reducing atmospheres; in the post-combustion capture application, there would be an oxidising atmosphere for the separation, which could have an effect on the durability of the chemical solvents, so the manufacturers introduce additives to minimise oxidation of the solvent. On the other hand, pre-combustion capture would involve separation under conditions very similar to those found in hydrogen production plants today so durability of the solvent should be no different from current experience.

Compression of $CO_2$ to supercritical conditions is usually considered as part of the capture system. Industrial gas compression experience is available to design and manufacture compressors for $CO_2$ but the large scale of these machines and the conditions of operation mean this is a specialised design task; there are only a few compressor manufacturers worldwide able to provide suitable machines. The largest system currently in use is at the Dakota Gasification plant where 2 internally-geared centrifugal compressors supply $CO_2$ to the pipeline to the Weyburn oil field. A third compressor has recently been ordered to expand the supply. In other oil fields, reciprocating compressors are used for similar duties.

# Annex B

## *Criteria used for calculation of the cost of generating electricity*

1. That the plant would be a new build, constructed today to meet the Large Combustion Plant Directive (2001/80/EC). It is assumed the costs would be representative of series-ordered plant.

2. The mode of operation of the plant would be base load, 8000 operational hours each year.

3. Capital costs are on engineering procurement and construction (EPC) basis.

4. Fuel specified as coal or gas. Base-case fuel prices would be 1.4 £/GJ coal (net calorific value) and 4.0 £/GJ gas (also illustrating sensitivity to 3.0 and 5.0 £/GJ gas if possible).

5. A net output of the plant delivered to the UK grid of 800MW.

6. Delivery pressure for $CO_2$ would be 110 bar, pipeline quality.

7. Discount rate of 10% real and project (investment) lifetime of 25 years.

8. $CO_2$ transportation and storage facilities – it is assumed that one 800MW power plant would share the transport and storage facilities with others; it is suggested that a representative basis for offshore geological storage assuming a new construction is 10Mt/y of $CO_2$ transported and injected (which would serve several power stations).

# Formal minutes

Wednesday 1 February 2006

Members present:

Mr Phil Willis, in the Chair

Mr Robert Flello
Dr Evan Harris
Mr Brooks Newmark
Dr Brian Iddon
Bob Spink
Dr Desmond Turner

Draft Report (Meeting UK Energy and Climate Needs: The Role of Carbon Capture and Storage), proposed by the Chairman, brought up and read.

*Ordered*, That the Chairman's draft Report be read a second time, paragraph by paragraph.

Paragraphs 1 to 165 read and agreed to.

Summary read and agreed to.

*Resolved*, That the Report be the First Report of the Committee to the House.

*Ordered*, That the Appendices to the Minutes of Evidence taken before the Committee be reported to the House.

*Ordered*, That the Chairman do make the Report to the House.

*Ordered*, That embargoed copies of the Report be made available, in accordance with the provisions of Standing Order No. 134.

[Adjourned till Wednesday 8 February at Nine o'clock.

# Witnesses

# Written Evidence

## Reports from the Science and Technology Committee

### Session 2005-06

| | | |
|---|---|---|
| First Special Report | Forensic Science on Trial: Government Response to the Committee's Seventh Report of Session 2004-05 | HC 427 |
| Second Special Report | Strategic Science Provision in English Universities: Government Response to the Committee's Eighth Report of Session 2004-05 | HC 428 |

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