REVIEW OF THE FEASIBILITY OF CARBON DIOXIDE CAPTURE AND STORAGE IN THE UK

CLEANER FOSSIL FUELS PROGRAMME

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Executive Summary

There is a broad consensus that climate change is occurring, and that it is linked to a build up of greenhouse gases (GHGs) in the atmosphere enhancing the natural "greenhouse effect". Carbon dioxide (CO_2) is the most significant of these GHGs and its main source is the combustion of fossil fuels. The UN Framework Convention on Climate Change (UN-FCCC) aims ultimately to achieve … *stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system*. Studies by the Intergovernmental Panel on Climate Change (IPCC) indicate that the likelihood of significant environmental and social damage increases significantly if CO_2 concentrations in the atmosphere exceed about 550ppm (roughly twice the present level). To stabilise CO_2 concentrations at or below this level over the next 100 years would require a global emissions reduction relative to the 'business as usual' trend of 50% to 60% by 2050 and 70% to 90% by 2100. The Royal Commission on Environmental Pollution supports this view and has recommended that the UK should aim for a 60% reduction in CO_2 emissions compared with current levels by 2050. The UK Government in its recent Energy White Paper has committed itself to this aim.

These are formidable targets since fossil fuels underpin the economic and social activities of both developed and developing countries, and with current trends this will continue for many decades to come. To change this trend without adverse effects on economic and social development will require a portfolio of measures including energy efficiency and switching to low to zero emission supply technologies. Carbon sequestration, involving the capture and storage of CO_2, would enable the continued use of fossil fuels, thus giving a longer timeframe to achieve a transition to fully sustainable energy sources and energy utilisation processes. Moreover, the retention of fossil fuels will contribute to the diversity and security of energy supplies.

The Energy White Paper recognised the longer-term strategic importance of Carbon dioxide Capture and Storage (CCS), as a potentially valuable contribution to the achievement of its target for a 60% reduction in greenhouse gas emissions by 2050. This study was announced by Brian Wilson MP, the then Minister for Industry and Energy, on 17 September 2002 with the following objectives:

- establish the technical feasibility of CO_2 capture and storage as a low carbon option
- define the potential technical, market, economic, public acceptability and legal barriers, and consider options for their solution
- establish the circumstances that could make the option competitive with other abatement measures
- consider the size of the potential contribution to UK abatement targets
- assess export opportunities for the technology
- define the role for Government in taking forward CO_2 capture and storage.

This report examines each of these factors and presents recommendations on the actions needed to take forward the development of CO_2 capture and storage in the UK context.

Key Findings

- Fossil fuels will, on current trends, continue to be a major source of energy for the UK and worldwide well into the timeframe when substantial reductions in greenhouse gas emissions are required. CCS enables the continued use of fossil fuels while making major cuts in greenhouse gas emissions, thus giving a longer timeframe to achieve a transition to fully sustainable energy sources and energy utilisation processes.

- The UK has access to substantial carbon dioxide storage capacity in the North Sea associated with deep saline aquifers and depleted oil and gas fields. The latter are important to the early implementation of CCS because they are accessible from existing production wells and their geology has been thoroughly characterised.

- Disposal into the water column of the sea was excluded from the review as this option is not appropriate to relatively shallow waters such as the North Sea.

- The timing for the deployment of CCS depends on the target rate of reduction in greenhouse gas emissions and the success of the full spectrum of measures including energy efficiency and renewable energy. With the 60% reduction target for CO_2 emissions by 2050, large-scale deployment of CCS may be needed for electricity generation and hydrogen production from about 2020, but earlier deployment could occur to tie in with the pattern of electricity plant replacement. In addition CCS in combination with Enhanced Oil Recovery (EOR) could be implemented from around 2010 (see below).

- Current costs for CCS are estimated to add 1.0-2.3p/kWh to the cost of electricity (0.2-1.0p/kWh with EOR) which compares favourably with other large-scale abatement options. Moreover, international research has identified an appreciable potential for these costs to be reduced through innovation.

- The above costs show that potential stakeholders (eg power producers, gas shippers and oil producers) will not implement EOR under current market conditions without additional financial incentives. These incentives will need to be substantial because, particularly with the oil producers, EOR will be assessed relative to other more attractive international investment opportunities. One potential option would be to gain credit for the CO_2 abated. The EU Emissions Trading Scheme may in principle offer a way to do this, through the proposed linking arrangement to project-based mechanisms, but greenhouse gas inventory methodologies must be established before CCS can be accepted into this or other measures compatible with the Kyoto Protocol. In any case, permit prices are unlikely to be sufficient for CCS including EOR in the near term. Consequently, alternative support measures will be needed to encourage any demonstration of CCS.

- Although not commercially competitive, storage of CO_2 in depleted oil reservoirs combined with EOR yields some financial return to offset partially the cost of capture and transportation. It therefore offers a lower cost option for a large-scale demonstration of CCS. However, EOR needs to be implemented before conventional oil production is terminated, and with many of the UK's oil fields at a mature stage of production, action would need to be initiated before about 2010.

- The current knowledge base is insufficient to support reliable assessments of the integrity of long-term geological storage. Further research is required to support the development of models to provide greater assurance on this issue. There is also a need for a greater knowledge base to support environmental impact assessments of the consequences of CO_2 releases to the terrestrial and marine environments.

- EOR is permitted, and sequestration from certain pipelines originating from land would appear not to be prohibited under the requirements of the London Convention/Protocol and OSPAR Convention governing disposal under the North Sea. However, these treaties preclude the use of existing offshore installations for sequestration without EOR. The process of amendment would probably take several years to secure, and would require international agreement.

- Irrespective of which methods are permitted, both the OSPAR and London provisions place responsibility on Contracting Parties (ie national governments) to establish strict regimes for authorisation and regulation of such activities, and to comply with treaty obligations to protect marine eco-systems.

- Given that the North Sea is bounded by another five countries (Norway, Denmark, Germany, The Netherlands and Belgium) storage of CO_2 cannot be treated as a UK issue alone. Co-operation with these countries will be important not only to reach agreement on CO_2 storage but also on the regulatory regime, which will need to be developed.

- At present CCS technology has attracted little media interest in the UK, and as a consequence there is little awareness amongst the general public of CCS as an option for CO_2 abatement. It is important that the facts about it be well understood and trust developed amongst the public and NGOs.

- At present there is no commercial electricity generation plant in the world using CO_2 separation and capture technologies. However, there is already a large international interest in the development and demonstration of CCS. The USA and Canada in particular are already fully committed to the development of these technologies. With the UK's strong industrial base in power engineering and oil and gas production it could win a substantial share of the potentially much larger global market for CCS technology.

- Cost reduction through innovation will be critical to the uptake and long-term viability of CCS technologies and there is considerable scope for international collaboration to spread this effort. The IEA GHG R&D Programme already plays a part in brokering international collaboration and could help extend such activities. The UK should continue to participate in work by the IPCC, and opportunities for developing further collaboration could be offered by the international Carbon Sequestration Leadership Forum, set up by the USA with membership including Australia, Brazil, Canada, China, Columbia, India, Italy, Japan, Mexico, Norway, Russia, the UK and the European Commission.

Recommendations

Recommendations for action cover:

- the near-term opportunity to demonstrate CCS at full scale through an EOR project
- the longer-term development and validation of CCS.

EOR

The Energy White Paper included a commitment to set up an urgent detailed implementation plan to establish what needs to be done to get an EOR demonstration project off the ground. Such a demonstration would extend to the full-scale capture and transport of CO_2, which, as discussed above, is an important step in the commercial development of CCS, and would provide a showcase for UK technology. Key issues to be addressed by this implementation plan are:

- What are the barriers (technical, economic, contractual, regulatory, etc.) affecting CO_2-based EOR in the North Sea?
- Would a demonstration project help reduce these barriers and uncertainties?
- Are there specific components of the CCS technology chain that are particularly uncertain and need further assessment?
- Would project-specific design and costing assessments help reduce these uncertainties?
- What needs to be done to define the most appropriate UK-based CCS/EOR demonstration project?
- What additional commercial incentives would be required to stimulate the take up of CO_2-based EOR in the North Sea?
- To what extent would CO_2 emissions credits enhance the prospects for EOR?
- Which international funding sources should be contacted to seek support for such a demonstration?
- What else could government do to reduce investment uncertainties?
- What else could government do to bring stakeholders together?

In line with the White Paper's commitment, this work should be completed by end 2003.

General Development of CCS

A broad strategy for progressive reductions in greenhouse gas emissions to meet the target of 60% reduction by 2050 would be expected to contain measures to improve energy efficiency and the uptake of renewable energy sources, with large-scale deployment of CCS being required from about 2020 onwards. However, two factors may lead to earlier deployment. Firstly EOR as discussed above, and secondly the normal replacement of capital stock in electricity generation, which may permit the construction of plant suited to carbon capture. This presents a major opportunity for the UK to create a world-leading low carbon energy design, construction and skills capability. To ensure the technology is available and cost effective when it is needed, more work is required to resolve the following:

- legal and regulatory issues
- environmental impact

- economic barriers and emissions trading
- acceptance in the context of international emissions inventory methodologies
- further development of the technologies, critically to reduce costs
- better understanding by the public of what CCS means for them.

It is recommended that a plan be developed to take this work forward covering each of the issues listed above. A set of work packages is recommended below.

Legal and Regulatory Issues

This entails the clarification or amendment of the London Convention/Protocol and OSPAR Convention. Key to this is the agreement of other Parties to the Conventions. While EOR is permitted, and there are legal arguments that suggest that sequestration by certain pipelines emanating from land will not be prohibited under these treaties, there is a clear obligation on Contracting Parties to establish strict regimes for authorisation and regulation of such activities. It is essential that these frameworks are established in collaboration with other such, and potential, Contracting Parties. The UK should take the lead to establish international collaboration on this subject.

Environmental Issues

A firm understanding of the environmental implications of CCS will need to be established before it can be fully deployed. This is important for supporting any changes to the Conventions controlling storage beneath the seabed, and for addressing concerns over inter-generational liabilities associated with long-term storage. Research is needed to determine the impact on ecosystems of any CO_2 leakage as well as on how the CO_2 behaves in storage. Work is already going on around the world on these issues (eg Norway's Sleipner Project and the Weyburn Project in Canada). It is recommended that DTI, in conjunction with Defra, evaluates existing research to determine if further work is needed either specifically for the UK or through international collaboration.

Economic Barriers and Emissions Trading Issues

A key to CCS becoming commercially viable is obtaining credits for its abatement of CO_2 emissions, thus providing a financial return to investors in the technology. To qualify under schemes designed to reward emissions abatement (eg the EU's Emissions Trading Scheme) internationally acceptable methods for monitoring, reporting and verification will have to be developed (see below).

Acceptance into the Emissions Inventory Estimates used in National Reporting and the Flexible Mechanisms

Ultimately the take-up and deployment of CCS technologies will depend on acceptance of their effectiveness and on how verifiable they are. This needs to be achieved firstly in the production and verification of national emissions inventories under the UN-FCCC and the Kyoto Protocol, and secondly at the entity level for emissions trading. The two requirements are of course linked and the following need to be addressed:

- agreed inventory methods to cover the operating period of a CCS technology
- agreed inventory methods to cover the continued sequestration of the CO_2 after

injection into the storage medium, including checking and verification

- establishment of a system for redress that could be applied within emissions trading schemes should any leakage of CO_2 occur.

Technology Development

The development of technology for CO_2 separation still has some way to go but it has become an area of considerable international activity including work in the USA, Canada, Japan, Australia and several European countries. Therefore, further development in the UK should be planned to take maximum advantage of opportunities for international collaboration, whilst fostering a competitive UK capability to design, manufacture and operate CCS systems. The ultimate goal should be a full-scale demonstration of CCS that will showcase UK technology and capabilities. It is recommended therefore that a new fossil fuel carbon management technology programme be developed to complement or possibly replace the existing Cleaner Coal Technology Programme, to include development activities for CO_2 capture and storage technologies.

Public Awareness

There is a role for government in helping to raise public awareness of CCS technologies. This should be done once the environmental issues are better understood and should involve bringing together technology developers and users with external stakeholders including local government, the regulatory authorities, national and regional media and NGOs. Dialogue with stakeholders should include exchange of information on progress with the technologies, the increasing knowledge base on the benefits and impacts of CCS and views on the location and options for their deployment.

Contents

1. Introduction

There is a broad consensus that climate change is occurring, and that it is linked to a build up of greenhouse gases (GHGs) in the atmosphere enhancing the natural "greenhouse effect". Carbon dioxide (CO_2) is the most significant of these GHGs and its main source is the combustion of fossil fuels. The UN Framework Convention on Climate Change (UN-FCCC) aims ultimately to achieve … *stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system*[1]. Studies by the Intergovernmental Panel on Climate Change (IPCC)[2] indicate that the likelihood of significant environmental and social damage increases significantly if average CO_2 concentrations in the atmosphere exceed about 550ppm (roughly twice the present level). To stabilise CO_2 concentrations at or below this level over the next 100 years would require a global emissions reduction relative to the 'business as usual' trend of 50% to 60% by 2050 and 70% to 90% by 2100. The Royal Commission on Environmental Pollution supports this view and has recommended that the UK should aim for a 60% reduction in CO_2 emissions compared with current levels by 2050. The UK Government in its recent Energy White Paper has committed itself to this aim[3].

These are formidable targets since fossil fuels underpin the economic and social activities of both developed and developing countries, and with current trends this will continue for many decades to come. To change this trend without adverse effects on economic and social development will require a portfolio of measures including energy efficiency and switching to low to zero emission supply technologies (eg renewable energy sources, carbon sequestration and nuclear power). Carbon sequestration, involving the capture and storage of CO_2, would enable the continued use of fossil fuels, thus giving a longer timeframe to achieve a transition to fully sustainable energy sources and energy utilisation processes. Moreover, the retention of fossil fuels will contribute to the diversity and security of energy supplies.

The Energy White Paper recognised the longer-term potential value and strategic importance of Carbon dioxide Capture and Storage (CCS), if feasible and economic, as a potentially valuable mechanism for contributing to the achievement of its target for a 60% reduction in greenhouse gas emissions by 2050.

This study was announced by Brian Wilson MP, the then Minister for Industry and Energy, on 17 September, 2002. The definition and scope for the study were published at the outset[4]. Briefly the objectives are to:

- establish the technical feasibility of CO_2 capture and storage as a low-carbon option
- define the potential technical, market, economic, public acceptability and legal barriers, and consider options for their solution
- establish the circumstances that could make the option competitive with other abatement measures
- consider the size of the potential contribution to UK abatement targets
- assess export opportunities for the technology
- define the role for Government in taking forward CO_2 capture and storage.

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[1] United Nations Framework Convention on Climate Change Article 2

[2] Special Report on Emissions Scenarios, Intergovernmental Panel on Climate Change, 1999.

[3] Energy White Paper: Our energy future – creating a low carbon economy (February, 2003) (http://www.dti.gov.uk/energy/whitepaper/index.shtml)

[4] The Feasibility of Carbon Capture and Storage in the UK – Project Definition and Scoping Paper (June 2002) (http://www.dti.gov.uk/energy/coal/cfft/co2capture)

The study was guided by an Advisory Group, membership and terms of reference for which are given in Annex 1[5].

The study examined a range of factors affecting the feasibility for CO_2 capture and storage, namely:

- Status of the Technology
  - technical options for CO_2 capture
  - technical options for CO_2 transport
  - technical options for CO_2 storage
  - UK and global potential for the technology.

- Economic and Social Factors
  - environmental risk
  - public awareness
  - economic assessment
  - legal issues.

- Strategic Position
  - role in UK GHG abatement
  - existing and prospective support mechanisms
  - overseas programmes and activities
  - export opportunities from the development of UK expertise.

This report discusses each of these factors before concluding with recommendations on the actions needed to take forward the development of CO_2 capture and storage in the UK context.

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[5] For EOR the study was guided by the work conducted through DTI's Sustainable Hydrocarbons Additional Recovery Programme (SHARP). This programme is managed by the Licensing and Consents Unit and is used to support its regulatory function of maximising economic recovery of hydrocarbons from the United Kingdom Continental Shelf (UKCS) and to promote new technology take up. CO_2 EOR is one of the enhanced recovery techniques evaluated through SHARP over several years and the results of this work are available to the public through its website www.dti-SHARP.com

2. Technology Status

2.1 Options for Carbon Dioxide Capture

CO_2 capture and storage (CCS) is best applied to large stationary sources, which offer economies of scale in construction and minimise the extent of the supporting transport network. In the year 2000 about 190MteCO_2 from the UK's total energy related emissions of 530MteCO_2 were produced in energy conversion plant. Furthermore, over 80% of the CO_2 from energy conversion was associated with electricity generation. A similar picture is found in other developed economies, and not surprisingly therefore, most current work on CCS has focused on its application to power generation and other large process plant such as oil refineries and coal gasification plant, and looking to the longer term, hydrogen production facilities. This review mainly considers electricity generation, although some of the capture processes are also applicable to hydrogen production.

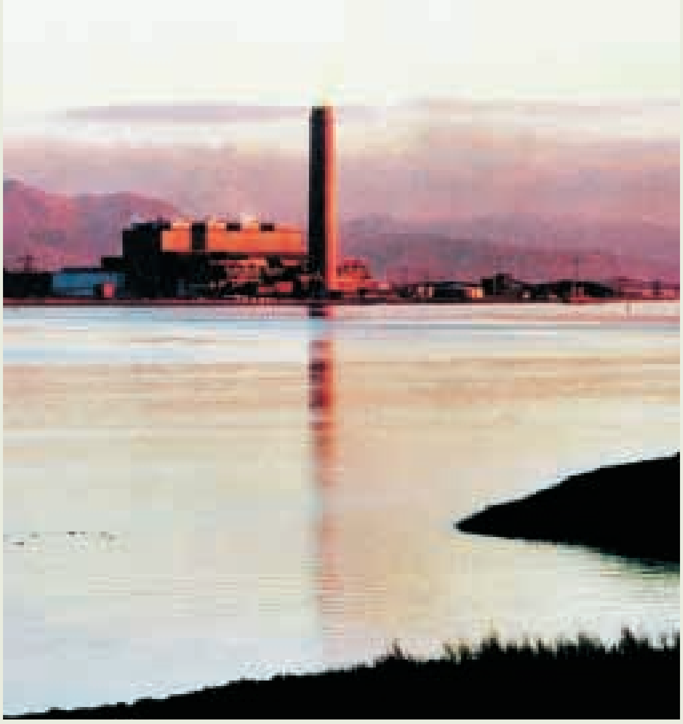
There are three generic process routes for capturing CO_2 from fossil fuel combustion plant:

- post-combustion capture
- pre-combustion capture
- oxyfuel combustion.

Each of these processes involves the separation of CO_2 from a gas stream. There are five main technologies available for doing this, with the choice depending on the state (ie concentration, pressure, volume) of the CO_2 to be captured:

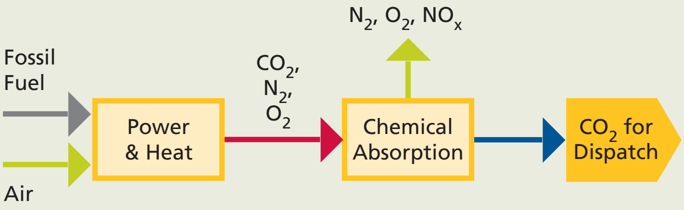
- chemical solvent scrubbing
- physical solvent scrubbing
- adsorption/desorption
- membrane separation
- cryogenic separation.

The UK's large coal-fired power stations typically release 5-10 million tonnes of carbon dioxide per year. (Courtesy of ScottishPower)



Post-combustion capture (Figure 1) involves the separation of CO_2 from flue gas. The preferred technique at present is to scrub the flue gas with a chemical solvent (usually an amine), which reacts to form a compound with the CO_2. The solvent is then heated to break down the compound and release the solvent and high purity CO_2. The flue gas needs to be cooled and, for coal- and oil-fired plant, treated to remove reactive impurities (eg sulphur and nitrogen oxides, particulate material) before scrubbing, otherwise these impurities will react preferentially with the solvent causing unacceptable rates of consumption and corrosion of the plant. With current processes a large amount of energy is needed to regenerate the solvent and to compress the CO_2 for transport, which significantly reduces the net electricity output of the plant.

Figure 1 Schematic diagram of the post-combustion capture process



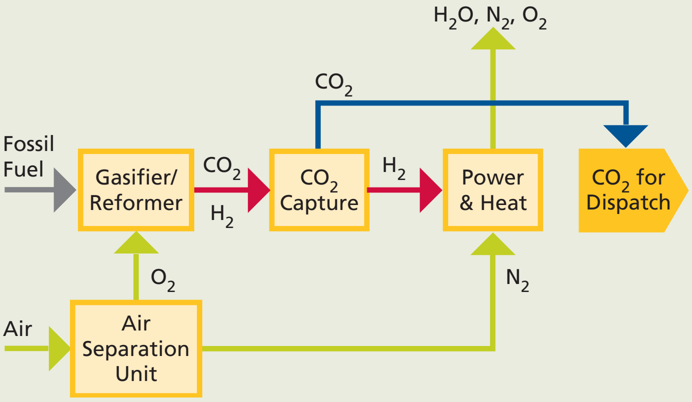
The alternative methods for separating CO_2 from flue gases are, at present, most effective with high CO_2 concentration gas streams at elevated pressures and therefore are more suited to pre-combustion and oxyfuel methods.

Amine scrubbing has been used for over 60 years for the removal of hydrogen sulphide and CO_2 from hydrocarbon gas streams. However most of this experience is with reducing gas streams rather than oxygen-containing flue gases, and at a smaller scale than for power plant. The largest operating unit, at Trona, California, captures 800teCO_2 per day; less than 10% of the capacity needed for a 500MW coal-fired power station[6].

There is potential for advances with amine technology that could increase solvent efficiency (thus reducing the size of scrubbing plant), reduce degradation and minimise the energy needed for regeneration. Also the energy penalty could be reduced through optimal integration of the capture plant within power station steam systems. Together these developments offer long-term opportunities for significant reductions in capture costs and improvements to electricity generation efficiency. Scaling up to full power plant size may present more plant-specific problems, however, requiring R&D before commercial deployment can go ahead[7].

Pre-combustion capture (Figure 2) involves reacting fuel with oxygen or air, and in some cases steam, to produce a gas consisting mainly of carbon monoxide and hydrogen. The carbon monoxide is then reacted with steam in a catalytic shift converter to produce more hydrogen and CO_2. The CO_2 is then separated and the hydrogen is used as fuel in a gas turbine combined cycle plant. The process can be applied to natural gas, oil or coal, but with the latter two fuels additional equipment is needed to remove impurities such as sulphur compounds and particulates.

Figure 2 Schematic diagram of the pre-combustion capture process



The advantage of pre-combustion separation over post-combustion is that it produces a smaller volume of gas for treatment, which is richer in CO_2 and at high pressure. This reduces the size of the gas separation plant thus reducing capital costs. Also the higher concentration of CO_2 enables less selective gas separation techniques to be used (eg physical solvents, adsorption/desorption) that require less energy to operate.

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[6] Capture and Storage of CO_2 – A status report on the technology (IEA Greenhouse Gas R&D Programme and the British Geological Survey, August, 2002) (http://www.dti.gov.uk/energy/coal/cfft/co2capture/ieapart1.pdf)

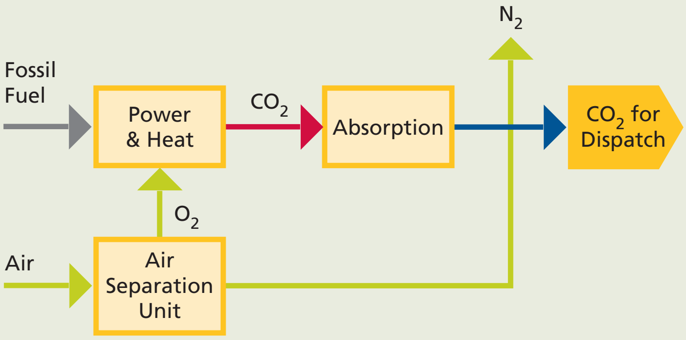
[7] Carbon Dioxide Capture and Storage, Report of DTI International Technology Service mission to the USA and Canada (DTI/APGTF, February 2003)

Most of the technology is proven for pre-combustion capture in ammonia plant, and is operating at utility-scale in the USA at the Great Plains Synfuels Plant. As with post-combustion capture, this route has substantial opportunities for cost savings and energy efficiency improvements through new technology development. One of the novel aspects is that the fuel gas feed to the gas turbine will be hydrogen, diluted with nitrogen or steam prior to combustion to reduce emissions of nitrogen oxides. It is expected to be possible to burn this gas mixture in current gas turbines with little modification. General Electric has conducted many tests and has a turbine running commercially on 62% hydrogen at the Schwarze Pumpe site in Germany.

In the longer term, hydrogen has significant future potential as an alternative fuel for transportation and for use in fuel cell plant. In fact in the USA one of the main motivators for developing IGCC technology, besides its use for power generation, is the production of hydrogen. Certainly hydrogen produced from fossil fuels, particularly from coal and natural gas, is the first stage for a 'hydrogen economy'.

Oxyfuel combustion (Figure 3) involves burning fuel in an oxygen/CO_2 mixture rather than air to produce a CO_2-rich flue gas. Generally the oxygen is derived from an air separation unit, and the oxygen/CO_2 mixture is produced by recirculating some flue gas to the combustor. The oxygen/CO_2 mixture is needed to control flame temperature, which would be too high if combustion took place in pure oxygen. Some novel processes seek to avoid the need for an air separation unit, which has a high energy demand. For example, chemical looping uses a metal oxidation reaction to separate oxygen, with subsequent reduction of the metal oxide to provide the oxygen needed to burn the fossil fuel. Oxyfuel combustion can be applied to boilers and gas turbines, although a different design of gas turbine would be needed to work with highly concentrated CO_2, which rules out retrofit to existing GTCC (Gas Turbine Combined Cycle) stations.

Figure 3 Schematic diagram of the oxyfuel combustion capture process



The advantage of oxyfuel combustion is that it produces a highly CO_2-enriched flue gas that in principle enables simple and low-cost CO_2 purification methods to be used. Also, because combustion occurs in a low-nitrogen environment, the formation of nitrogen oxides is greatly reduced. However, it has the disadvantage of requiring an air separation plant, which is expensive and requires a considerable amount of energy to operate. At present there is less operational experience with this option, and there are operational questions to be addressed before it can be taken to full commercial deployment. These issues include:

- uncertainties over boiler performance
- minimising air entrainment
- degree of flue gas clean up needed before CO_2 capture
- lower flue gas temperature may cause enhanced corrosion
- higher mill outlet temperatures may require changes to fuel feed systems.

All three of the above approaches could be applied to new plant or retrofitted to existing facilities. Taking account of the existing generation capacity, the more feasible options for the UK can be grouped as listed in Table 1.

New build has the advantage of allowing maximum integration of the capture facilities into the power generation plant, which will benefit overall generation efficiency. It also avoids any space limitations associated with fitting new equipment to an existing facility, and could permit the plant to be located closer to the storage facility thus reducing transport costs. Retrofit is likely to have lower capital cost, although this advantage is reduced if appreciable refurbishment is needed to extend the operating life of the plant. Also retrofitting to coal-fired plant could include additional investment in flue gas desulphurisation and nitrogen oxides control technologies.

An alternative with pulverised coal plant would be to undertake a more comprehensive refurbishment involving repowering with supercritical boilers. Although involving more capital investment, this would improve the generation efficiency of the plant, thus offsetting some of the energy losses associated with capture.

While there are a number of examples of industrial applications involving separation and capture of CO_2, including some at utility-scale, there are no commercial installations using this technology in the electricity generation sector. The USA and Canada have plans to build demonstration plant in the next few years. This suggests that this technology needs to be demonstrated satisfactorily before it can be considered to be commercially viable.

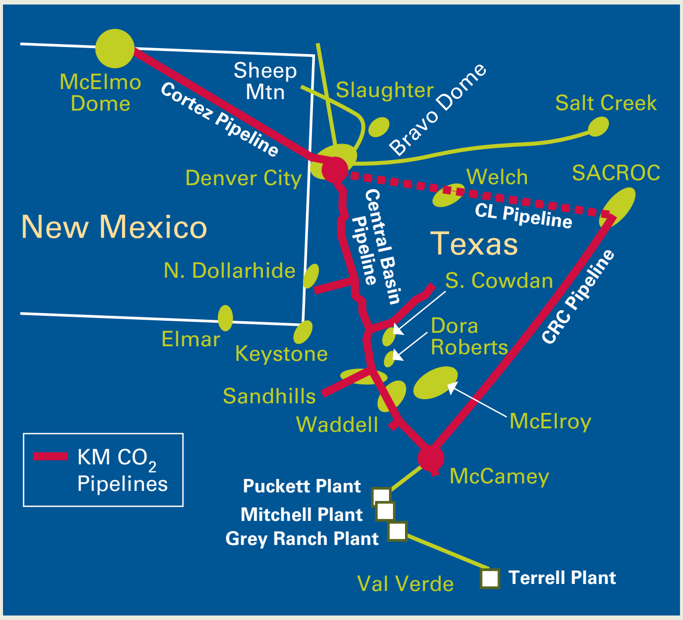
2.2 Options for Carbon Dioxide Transport

CO_2 is stored and transported in gaseous, liquid or solid forms. However, because the CO_2 captured from flue gases is in gaseous form, and large capital investments would be needed to construct the cryogenic plant needed for liquefaction or solidification, transportation is also likely to be undertaken in the gas phase (strictly speaking the supercritical dense phase). Furthermore, liquefaction or solidification would require appreciable energy input, which would impact on the overall energy balance of the process and thereby reduce its net abatement of CO_2.

Table 1 Possible carbon dioxide capture technologies that could be deployed in the UK's Power Generation Sector

Technology	Status	Type
Integrated gasification combined cycle (IGCC)	New	Pre-combustion capture
Gas turbine combined cycle with catalytic shift	New	Pre-combustion capture
Pulverised fuel (PF) with flue gas scrubbing	Retrofit	Post-combustion capture
PF + oxyfuel combustion + flue gas scrubbing	Retrofit	Oxyfuel combustion
PF + supercritical boiler + flue gas scrubbing	Retrofit/New	Post-combustion capture
PF + supercritical boiler + oxyfuel combustion + flue gas scrubbing	Retrofit/New	Oxyfuel combustion
GTCC with flue gas scrubbing	Retrofit	Post-combustion capture
GTCC with new coal gasifier to effectively produce an IGCC plant	Retrofit	Pre-combustion capture

Carbon dioxide pipelines and oil fields in West Texas and South East New Mexico deliver about 22 million tonnes of gas each year for enhanced oil recovery. (Courtesy of Kinder Morgan CO_2 Company L.P)



Bulk gaseous transport of CO_2 may be undertaken by tanker (road, rail or water) or by pipeline, but with the large volumes involved in a CCS scheme (10-30MteCO_2 per year), pipeline transport is the only practicable option. Tanker transport may have a role in smaller demonstration projects of the order of 100-200ktCO_2 per year.

Most experience of pipeline transport of CO_2 has been gained in the USA where the gas is used extensively for Enhanced Oil Recovery (EOR). For EOR in West Texas, CO_2 is derived from naturally occurring geological sources in New Mexico and Colorado, and from amine scrubbing at four natural gas processing plants. Around 22MteCO_2 is transported each year through a 3980km pipeline system to oilfields in the Permian Basin. More recently a 330km pipeline has been commissioned to carry CO_2 separated in the Great Plains Synfuels Plant in North Dakota to the Weyburn EOR operation in Saskatchewan. This pipeline can carry up to 2MteCO_2 per year[8].

This practical experience shows that CO_2 transport by pipeline is an established commercial technology. Factors requiring further consideration in an UK context are:

- safety requirements with the UK's greater population density (Section 3.1)
- planning and regulatory requirements.

2.3 Options for Carbon Dioxide Storage

Various methods have been proposed for storage or management of captured CO_2 including injection into geological formations, deposition into the water column on the deep ocean floor and conversion into solid minerals. This study has focused on geological storage because understanding of the processes is more advanced and it can be undertaken within the UK or its surrounding territorial waters. Disposal into the water column is not appropriate for relatively shallow waters such as the North Sea. Geological storage requires permeable rock strata that provide space for the gas to be stored. These strata must be sealed by rock which is impermeable to CO_2. There are three main options for geological storage.

- Depleted or near depleted oil and gas reservoirs. (This option may offer some financial return if the CO_2 can be injected as part of an EOR operation.)
- Deep saline aquifers.
- Unmineable coal seams.

2.3.1 Geological Storage Options

Oil reservoirs are a good option since prior to exploitation their seals have retained hydrocarbons over geological timescales.

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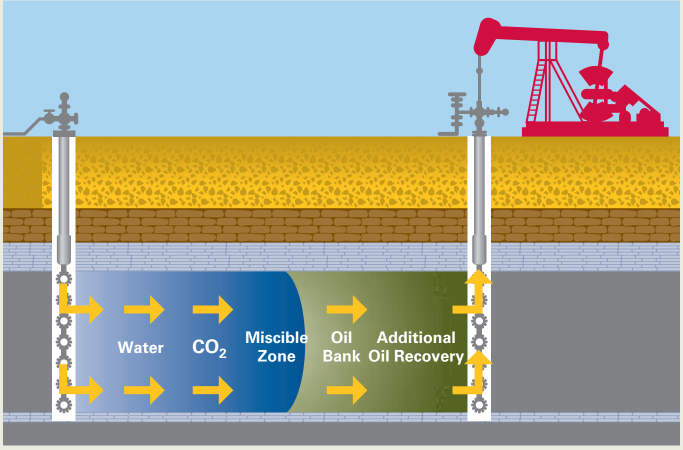
[8] Carbon Dioxide Capture and Storage, Report of DTI International Technology Service mission to the USA and Canada (DTI/APGTF, February 2003)

Also, they will have been extensively investigated and mapped during production thus providing essential knowledge for selecting suitable reservoirs and managing their utilisation. The capacity of an oil reservoir to store CO_2 is made up of the pore space vacated by the oil together with additional pore space occupied by "bottom waters" lying below the oil formation.

EOR may use CO_2 to mobilise some of the oil remaining in a reservoir after primary and secondary production is complete. It does this by dissolving in the oil thereby reducing the oil's effective viscosity and making it more mobile. The movement of the CO_2 front within the reservoir can then sweep the oil to the production wells. CO_2-based EOR is an established onshore procedure in North America but has not yet been undertaken offshore, although up to 15Mt per year of nitrogen is injected into the Cantarell oil field lying 60 miles off the Mexican coast. An EOR operation would store CO_2 in the pore space of the oil-containing rock. To utilise the storage space associated with underlying water it would be necessary to develop a new strategy, possibly with additional injection wells, after oil production is finished.

Carbon dioxide-Enhanced Oil Recovery with Water/Alternating Gas (WAG) injection sweeps additional oil to the recovery well. (Courtesy of Kinder Morgan CO_2 Company L.P)



Gas fields, like oil reservoirs, exist because they have seals that prior to exploitation prevented migration over long periods of time. Although CO_2 injection could help with some additional gas extraction from a field, the benefits are less than for EOR and storage would generally be considered when the field was largely depleted. A key factor is the operational record of the field. For example if the pore space has been filled by the ingress of water more energy will be needed to inject the CO_2 in order to overcome capillary forces. Operating records should be available to check on these factors when selecting candidate fields.

Deep saline aquifers present the largest potential capacity for storage of all the geological options. They could be used because they have little if any foreseeable value as a source of water for drinking or irrigation because of their depth and high dissolved mineral content. Two basic types occur – open and closed. Closed aquifers have defined boundaries produced by geological folding or faulting which considerably reduces the possibility for lateral movement and slow seepage of CO_2 into potable aquifers or to the surface. This makes them the preferred option for onshore storage, but their capacity is less than for open aquifers. Open aquifers are extensive flat or gently sloping formations of water bearing rock. Because they are open CO_2 can move laterally, but the slow rate of transport, combined with their size means that the gas will be confined for many centuries. Immobilisation of the CO_2 in both types of aquifer may come from its dissolution in the water remaining in the aquifer, which will reduce buoyancy effects, and by reaction with minerals to form solid compounds.

The world's first commercial-scale storage of CO_2 in aquifers was begun by Statoil in 1996 in conjunction with natural gas production from the Sleipner Field in the North Sea. Up to 1MteCO_2/yr have so far been injected into an aquifer formation about 800m below the seabed. Research is underway to monitor the containment and behaviour of the CO_2.

Unmineable coal seams offer a storage option because the CO_2 is preferentially adsorbed by the coal displacing previously adsorbed methane. In addition to offering storage for CO_2 there is potential to collect the desorbed methane thus gaining a financial return. A key factor in this form of storage is the permeability of the coal seam. Coal in NW Europe has relatively low permeability, which makes the process harder. Moreover, this could be exacerbated by the CO_2 causing swelling of the coal. These problems can be addressed by standard procedures such as hydro-fracturing (injecting water and sand at high pressure). This storage option is currently at the research stage.

2.3.2 Capacity for Storage

Global geological storage capacities have been estimated by the IEA Greenhouse Gas R&D Programme. These are:

depleted oil fields	125Gt of CO_2[9]
depleted gas fields	800Gt[10]
deep saline aquifers	400 to 10,000Gt[11]
unmineable coal seams	148Gt[12].

With current world CO_2 emissions of about 25Gt per year (6GtC/year) it is clear that CO_2 capture and storage has potential global significance for GHG abatement.

Estimates of the storage capacity of UK and other North Western European countries are listed in Table 2. As discussed above, current UK CO_2 emissions from large point sources that are suited for CO_2 capture are about 0.2Gt per year. Comparison with these capacities shows that CO_2 capture and storage could play a major role in UK GHG abatement.

Table 2 Capacity of CO_2 storage – estimates for the UK and North Sea[13]

Estimated Storage Capacity (Gt CO_2)	Depleted Oil Fields	Depleted Gas Fields	Deep Saline Aquifers	
			Closed	Open
North Sea				
Denmark	0.1	0.4	0	0
Netherlands	0	0.8	0	0
Norway	3.1	7.2	10.8	476
UK	2.6	4.9	8.6	240
Total	**5.8**	**13.3**	**19.4**	**716**

Notes
i) The potential for storage in deep unmineable coal seams has not been included in the table because this remains at the research stage.
ii) Estimates for the UK apply only to the North Sea with further potential in other areas including West of Shetland and the Irish Sea.

2.3.3 Enhanced Oil Recovery (EOR)

Enhanced Oil Recovery merits particular attention in the UK context because it represents an appreciable storage option for CO_2 while offering a financial return from the additional oil extracted from UK Continental Shelf reserves. The best currently available evaluation is by DTI's SHARP programme which has estimated an additional oil recovery potential from UK North Sea fields that are favourable for CO_2 EOR of between 950 and 2250 Million Standard Barrels of Oil (MMSTB) with an associated net CO_2 retention of about 700Mte[14]. This is less than the overall retention given in Table 2, which considers all UK fields (not all fields are suitable for EOR), and also the extra storage to be gained by displacing "bottom water".

[9/10] IEA Greenhouse Gas R&D Programme Report No PH3/22 (February, 2000)
[11] IEA Greenhouse Gas R&D Programme Report SR3, The disposal of CO_2 from fossil fuel fired power stations (June, 1994)
[12] IEA Greenhouse Gas R&D Programme Report No PH3/3 (August, 1998)
[13] Joule II Project No CT92-0031, The underground disposal of CO_2 (British Geological Survey, 1996)
[14] From SHARP study – Potential UKCS CO_2 retention capacity from IOR projects, Matthew Goodfield and Claire Woods, Presented to DTI IOR Research Dissemination Seminar, Aberdeen, June, 2002

Irrespective of the exact capacities involved, several factors complicate the implementation of EOR in the UK North Sea. Firstly, EOR needs to be implemented on a large number of oil fields of differing size and which are distributed over a large area of the North Sea. Secondly, the time at which EOR needs to start varies between fields depending on their maturity, and the duration of an EOR scheme can then vary from about 5 to 20 years. Finally, some of the injected CO_2 returns to the surface with the produced oil and needs to be separated and reinjected. As a result, while gross demand for CO_2 may increase over the course of EOR on a particular oil field, some of this demand is met with reinjected CO_2 and as a result net demand for additional CO_2 will decline with time.

CO_2 EOR may be implemented by two methods depending on the nature of the oil field; Water Alternating Gas (WAG) or Gravity Stabilised Gas Injection (GSGI). Figure 4 shows the cumulative net amount of CO_2 that could be used (and retained) in WAG EOR schemes assuming these could be implemented at any time up to the current Cessation of Production (COP) dates for the oil fields. Estimates suggest an annual CO_2 demand of about 15MteCO_2/yr averaged over 20 years. Figure 5 shows the estimated CO_2 demand profile for GSGI. The figure shows demand peaking at about 35Mt/yr in 2020. Overall these estimates suggest that total demand for CO_2 for EOR in UK North Sea oil fields could be about 10Mt/yr up to 2010, increasing to about 25 Mt/yr from 2010-2015 and reaching a peak of 35 to 40Mt/yr between 2015 and 2025[15]. Further demand could come from other North Sea regions (eg Norway).

It clearly would be expensive to set up separate CO_2 supply and transmission systems for individual oil fields. Drawing parallels with the use of CO_2 for EOR in North America it has been proposed that this position of multiple points of demand with varying demand profiles could best be met with a pipeline transmission and distribution system serving the whole North Sea[18]. This system would take CO_2 from sources in the UK, Denmark, Norway, etc. and deliver it to fields through a central "trunk" pipeline with spurs going to individual fields. Fields would be able to couple to the trunk pipeline when they were ready to move to EOR.

Figure 4 Remaining WAG EOR carbon dioxide retention assuming the window of opportunity closes at Cessation of Production (COP) dates[16]

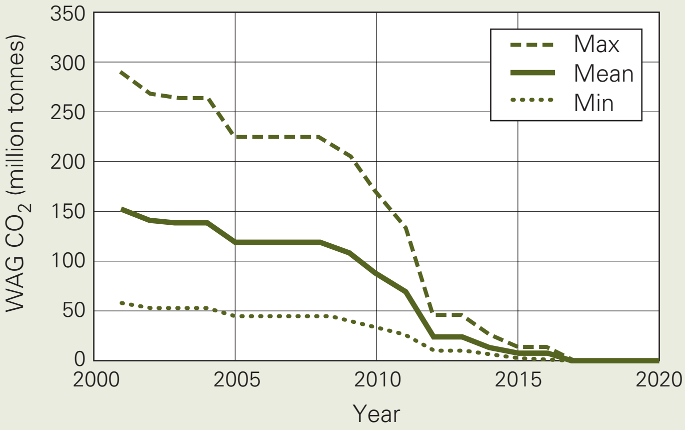
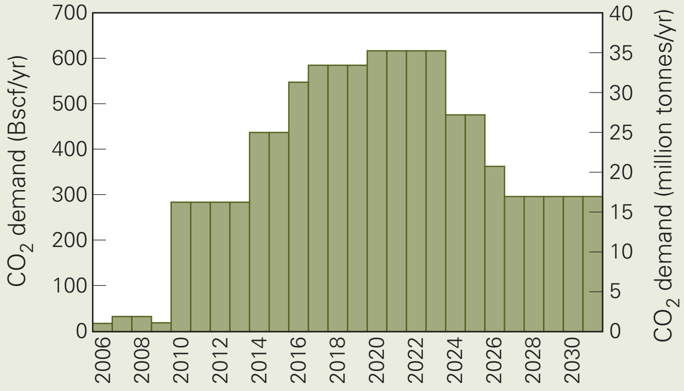


Figure 5 Illustrative carbon dioxide requirement profile for all potential GSGI EOR projects[17]



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[15] SHARP periodically updates its analysis to take account of significant changes in the estimated COP dates of key fields, therefore this data may be subject to change

[16/17] Joule II Project No CT92-0031, The underground disposal of CO_2 (British Geological Survey, 1996)

[18] CO_2 for EOR in the North Sea (CENS), presentation to the DTI Advisory Group on Carbon Capture and Storage, Kinder-Morgan Elsam

Figures 4 and 5 show that the total potential demand for CO_2 for EOR will decline over time. This is because EOR needs to be implemented before normal secondary production is terminated. Consequently as fields reach their COP date the option for EOR closes. This “window of opportunity” for EOR means that its implementation is set by oil production factors rather than the optimal time for deploying CCS as part of a strategy to reduce GHG emissions. However, the implementation of EOR would support the demonstration of full-scale CO_2 capture technology and would provide some of the long-term infrastructure needed to transport CO_2 to other geological storage media.

UK onshore oil fields could also use CO_2 for EOR, but the level of demand would be much less than for offshore. SHARP estimates for the total demand from the Wytch Farm (partly onshore), Humbley Grove, Storrington and Welton fields give an aggregate demand of less than 1MtCO_2 per year over 5-10 years[19].

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[19] SHARP programme — ECL Technology estimates for DTI Licensing and Consents Unit

3. Environmental, Economic and Social Factors

3.1 Environmental Risk Assessment

CO_2 is in common use in a range of applications including fire extinguishers, refrigeration and carbonated drinks. However, it is an acidic gas with asphyxiant properties, and consequently its capture and storage does present finite risks to human health and safety and to the natural and built environments. These risks are mainly linked to the possibility of CO_2 release from either the engineered system (ie capture and transportation plant) or from the geological storage site. Other potential risks being investigated are ground heave and induced seismicity arising in the locality of the storage site[20].

Significant releases from the engineered system are likely to take the form of sudden events of limited duration, which are associated with failures in pipelines, valves, etc, followed by dispersion and dilution into the atmosphere or sea. An assessment using generic data and conservative assumptions has shown that such events could present a risk to human health and safety, but that these risks should be manageable through established design, location, containment and monitoring measures. Using pessimistic assumptions it has been estimated that such failures would be unlikely to release more than 0.03% of the CO_2 transported for sequestration[21].

There is also potential for releases from the engineered system arising from controlled venting and slow leakage through valve seals, flanges, etc. Such releases would account for a small fraction of the CO_2 handled. Moreover they should not present risks to health and safety since slow leaks will be dispersed and diluted, and there are well established industrial practices for working in confined areas where there is potential for CO_2 accumulation. However, there is a need to monitor and quantify such releases, and the sudden events discussed above, in order to meet requirements for national GHG inventory reporting and as a prerequisite for acceptance under emissions trading schemes (see below).

In the longer term any risk from CCS will arise from releases of CO_2 from the geological storage site, which will be under pressure. This could take the form of a direct leak to the sea, possibly through the failure of a well closure, or slow migration either laterally or through the cap rock. At present there is a limited knowledge base to support assessments of these processes, which is being addressed with further research including monitoring studies. Events such as a well closure failure could lead to high leakage rates, although the circumstances of the leak, its detection and the time needed to respond are difficult to estimate over timescales of several hundred years. A judgement-based assessment has suggested that over the course of a 1000-year reservoir lifetime there is a high cumulative probability of such an occurrence with a resultant CO_2 release (probability weighted) in the range 1600 to 960,000 tonnes (ie of the order of 0.004 to 2.4% of the total amount sequestered). These values serve to illustrate the current high degree of uncertainty involved in assessing the long-term risk of releases, but that the level of release is likely to be a small fraction of the total quantity sequestered[22].

Migration and buoyancy-driven movements of CO_2 in the repository could lead to its eventual release through ingress into overlying aquifers that reach the surface or by penetration of the cap rock. Such slow release mechanisms are unlikely to return substantial amounts of CO_2 to the atmosphere provided the risks are

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[20] Carbon Dioxide Capture and Storage, Report of DTI International Technology Service mission to the USA and Canada (DTI/APGTF, February 2003)

[21] Risk Analysis of the geological sequestration of CO_2, Report to DTI CFT Programme by DNV Consulting, May 2003

[22] Carbon Dioxide Capture and Storage, Report of DTI International Technology Service mission to the USA and Canada (DTI/APGTF, February 2003)

minimised by careful selection of storage sites. There may also be indirect effects, for example the acidification by CO_2 in aquifers could mobilise heavy metals and, given sufficient migration and penetration, could theoretically compromise potable water supplies, although this risk is considered remote for offshore storage. The acidifying properties of any CO_2 leakage could also have impacts on marine ecosystems.

In conclusion, the long-term reliability of geological storage systems needs to be established. Although there are projects such as Weyburn and Sleipner there is still insufficient mechanistic knowledge of potential chemical and physical interactions between CO_2 and the storage medium, and the implications of these interactions for gas migration. This knowledge base is being increased by a range of ongoing R&D projects on such issues as:

- the geochemical interaction of CO_2 with cap rocks
- mineralisation reactions in aquifers that may tie up CO_2 permanently
- geomechanical effects of CO_2 injection such as the physical displacement of brines from saline aquifers
- natural analogues
- implications for seismicity including induced seismicity.

There is also a need for greater understanding of the impacts of CO_2 leakage for both marine and terrestrial ecosystems for which little systematic information or analysis is currently available, though they are potentially significant. DTI and Defra should consider what work could usefully be undertaken.

Additionally, reliable monitoring and verification will be vital if credits for CCS are to become eligible in national emissions inventories and trading schemes designed to reduce GHG emissions. There is a need to set out clearly what levels of leakage could be detected with present techniques, and what levels might be detectable in the future, and whether default assumptions about leakage rates from geological storage can be identified. Information should be supplied to the IPCC inventory programme so that it can contribute to the development of international methods. Demonstration projects could usefully contribute to this work, although it could take some time before methods are finalised.

The Norwegian Sleipner West gas field project, where 1MteCO_2/yr is separated from the well stream and re-injected under the seabed, presents an interesting case study. Norway's third national communication under the UNFCCC reports it as a successful CO_2 abatement measure, implicitly declaring a carbon credit.

3.2 Public Awareness

CCS is a new technology that is little known as a potential abatement option outside fossil fuel energy industries and research organisations. Nonetheless the deployment of CCS could have appreciable impacts on the general public; for example in terms of the construction and operation of separation plant and transport pipelines, the long-term choice of fuels and energy services and the cost of these services to the consumer.

Work is currently being undertaken by the Tyndall Centre through the use of focus groups that consider the global warming problem and how best this can be resolved. This is on-going work and not expected to report finally on its findings for another year or so. Results so far suggest that CCS would be seen as one of a number of acceptable solutions for the mitigation of GHG[23].

There is a role for Government in raising awareness of this option in terms of its benefits and drawbacks. This activity needs to progress in parallel with the development of technologies, to ensure that public concerns are taken into account and properly addressed.

3.3 Economic Assessment

The costs of implementing CCS in the UK have been examined in a scoping study commissioned as part of this review[24]. Costs for the capture, transport and storage phases were estimated for a range of case studies considering large-scale implementation (8MteCO_2 per year) and covering alternative capture technologies (new build and retrofit), alternative capture locations, and storage through EOR or injection into depleted UK offshore gas fields. The results given in Table 3 are central values based on generic cost data, and have an uncertainty of about +/- 30% reflecting site and plant-specific variations. The ranges given for transport costs reflect different locations for the capture plant.

The results show the overall cost of CCS to be of the order of £28-35/teCO_2 for EOR and £22-27/teCO_2 for storage in depleted gas reservoirs (nb these costs exclude the higher cost IGCC option from Table 3). Note that the overall cost ranges represent case study variations and cannot be derived by direct summation of the values in Table 3. Capture is the most expensive element of CCS although this also holds the greatest potential for innovation and cost reduction in the longer term. This is illustrated by the results for new build IGCC plant in Table 3 where the lower cost of £13/teCO_2 is derived from a new design that considerably reduces the energy losses associated with gas separation[25]. Storage involving EOR is more expensive to implement than injection into a depleted natural gas reservoir because it requires extra investment in injection and production wells and modifications to production platforms.

Table 3 Estimated gross costs for carbon dioxide capture, transport and storage in the UK North Sea oil and gas fields*

Capture	Cost (£/teCO_2)**
Coal PF Retrofit	19
GTCC Retrofit	14
New IGCC	13-34***
New GTCC	21
Pipeline transport for EOR	7-8
Pipeline transport for storage in depleted gas fields	4-6
Injection for EOR	7
Injection for gas field storage	1

Notes
* Capture costs estimated using a 10% discount rate and load factor of 80%.
** Capture costs estimated by subtracting the cost of electricity from the long-run marginal cost plant (assumed here to be gas-fired CCGT) from the cost at plants with CO_2 capture and attributing this cost difference to the CO_2 captured.
*** Costs based on two alternative design studies for IGCC plant.

EOR gives some financial return from the additional oil produced. Assuming an oil price of $20/barrel, an exchange rate of £1 = $1.6 and an average recovery of 2.7bbl/teCO_2 injected this was estimated to be equivalent to about £24/teCO_2, which reduces the overall cost of CCS through EOR to about £4-10/teCO_2.

Not all the CO_2 captured and placed in storage in CCS schemes can be counted as CO_2 emissions abated. This is because:

- The generation efficiency of a power plant with CO_2 capture is less than for a non-capture plant and hence more fuel is burnt, so producing more CO_2, to generate the same amount of electricity.

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[23] Evaluating the options for carbon sequestration, C. Gough, S Shackley and M Cannel, Tyndall Centre, technical Report 2, 2002
[24] Carbon Capture and Storage – A Win Win Option? (FES, April, 2003)
[25] Jacobs Consulting, Carbon capture and storage – the case for gasification, short assessment commissioned by the DTI Cleaner Fossil Fuel Programme, December, 2002

- Energy is used by gas compressors on the pipeline and injection facilities that results in additional CO_2 emissions.

If a comparison is made between two similar plants, one with capture and the other without, then the abatement of CO_2 emissions is about 60-80% of the quantity separated and committed to storage. This factor increases the cost of abatement compared with the cost of capture by about 25-65%.

The absolute cost of abatement is also sensitive to the choice of benchmark technology that is assumed to be replaced by the capture plant. For this review it was assumed that capture plant would replace or defer the deployment of natural gas-fired plants without capture. This does not affect the assessment of gas-fired plant with capture, but the abatement credited to coal-fired plants with capture is just 20-30% of the CO_2 actually captured. This is because the emissions of CO_2 per unit of electricity produced from a gas-fired plant are currently 45-50% of those from a coal-fired plant. Because of this the estimated abatement costs for coal-fired plants are higher than would be calculated from a straight comparison with existing coal-fired plant. Using gas-fired plant as the baseline the abatement costs with EOR were estimated to be £6-50/teCO_2, and for storage in depleted gas fields £34-93/teCO_2. Expressed as the additional cost of electricity these abatement cost ranges equate to 0.2-1.0p/kWh and 1.0-2.3p/kWh respectively.

The above economic assessment concentrates solely on CO_2 abatement, but CCS also delivers reduced emissions of sulphur and nitrogen oxides and of particulate material. Moreover, where CCS is associated with EOR there are additional benefits including:

- increased recovery of UK oil reserves (the direct economic benefit of this has been included in the estimates above)
- extended oil field (and UK offshore oil industry) life
- increased energy security
- a major investment in the North Sea giving a boost to the local economy and jobs during redevelopment period.

Nonetheless, the above results indicate that CCS, including CO_2-based EOR, is unlikely to be implemented without appreciable new financial incentives.

3.4 Market Barriers

In addition to the economic factors discussed above there are other market barriers to the implementation of EOR. These include:

- Organisation and division of risk.
- Technical uncertainty.
- Market uncertainty.

Organisation and division of risk – The organisation of CO_2 capture with EOR requires collaboration between power producers, gas shippers, oil producers and government over a 20-30 year timescale. Projects will require considerable “up front” capital investment, but this is not divided evenly across the stakeholders. Investment for the power producers in CO_2 capture plant is highest, particularly if they decide on new plant rather than retrofit options. Investments needed to modify offshore infrastructure for CO_2 EOR may also be very large. It is likely that some mechanism for distributing risk more evenly between stakeholders will be needed before projects can go ahead.

Government has been included in the list of stakeholders because the full-scale implementation of CO_2-based EOR is likely to depend on the payment of some form of credit for the emissions abated (eg emissions trading). The other stakeholders would need to be confident that this arrangement would be maintained for the full 20-25 year lifetime of capture and EOR plant for them to take the investment risk.

Technical uncertainty – The economics of capture and storage are vulnerable to uncertainties concerning the technical performance and cost of key elements of the system. Most important are the yield of oil from EOR schemes, the costs to modify offshore infrastructure, the capital cost of capture plant and their reliability. Early capture and storage initiatives could focus on oil fields that are well suited for CO_2-based EOR and on capture technology that has least uncertainty over costs and performance. Nonetheless there will be a reluctance to take this risk unless the returns are sufficient to justify it.

Commercial uncertainty – The economics of capture and storage are sensitive to market prices, particularly for oil, but also for gas and coal. A standard approach for dealing with this would be for the oil producers to require projects to yield a positive return at a conservative oil price (e.g. $16/bbl) and with a higher investment test discount rate. These measures would considerably increase the economic gap reported in Section 3.3.

Furthermore, CO_2 capture plant are designed to operate for over 20 years, and their cost effectiveness depends on capital recovery over a long period. In contrast EOR on an individual oil field may last only 5-10 years. Therefore, the power generation company may be reluctant to invest in capture plant unless there is a mechanism in place to create a fairly firm long-term market for CO_2.

3.5 Legal Position

The storage or disposal of materials in the North Sea is controlled by three treaties designed to protect the marine environment from the dumping of matter. These are the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matters 1972 (the London Convention), the 1996 Protocol to that convention, and the Convention for the Protection of the Marine Environment of the North East Atlantic 1992 (the OSPAR Convention). The 1996 Protocol will supersede the London Convention between those Parties that ratify the Protocol, but it is not yet in force. However, the UK has ratified the Protocol, and UK policy is to apply its requirements. In order to meet its international obligations the UK would seek to adhere to whichever of these treaties was the most stringent.

The Sleipner Project injects about 1 million tonnes of carbon dioxide each year into a sub-seabed aquifer thereby avoiding its inclusion in Norways greenhouse gas emissions inventory. (Courtesy of Statoil)

The London Convention only refers to disposal into the water column of the sea and therefore would not apply to CO_2 storage below the seabed. However, the 1996 Protocol and OSPAR Convention extend control to the underlying subsoil. While a literal interpretation of "subsoil" suggests that the treaties would be limited to the shallow broken rock contacting the water column, a purposive approach is required when interpreting international agreements. Since the purpose of the treaties is to protect the marine environment from pollution, the extension of the 1996 Protocol and OSPAR to subsoil must be assumed to be aimed at potentially polluting activities carried out below the water column. As sub-seabed storage has a small but finite potential to release CO_2 into the sea at some later date, then legally the 1996 Protocol and OSPAR will be deemed to apply to sub-seabed CO_2 storage, even though the host geological formations are substantially deeper than what would in general be considered to be subsoil.

The requirements of the 1996 Protocol and OSPAR allow CO_2 storage through EOR since both permit "placement of matter for a purpose other than mere disposal". However, the injection of CO_2 into the seabed from offshore installations purely for storage would be regarded as disposal and therefore in general would not be permitted under these treaties. It could be argued that the treaties did not envisage CCS when they were drafted, indeed they have no mechanism to consider the issue that failure to implement CCS could result in higher atmospheric concentrations of CO_2 and therefore arguably greater damage to the marine environment. Nonetheless they will need to be amended in some way to enable storage using existing offshore facilities to go ahead. This will require international agreement and support, and, if obtained could take some years to move forward.

The 1996 Protocol would appear not to prohibit storage in a "seabed repository accessible only from land", which would appear to leave open the option of direct injection through a pipeline. The UK's assessment of the position under OSPAR is that injection of CO_2 for storage from pipelines emanating from land, without the use of an offshore platform, is not prohibited. Also, in respect of OSPAR, it is considered that the use of purpose built platforms, to take gas from a pipeline emanating from land to apply a pressure boost before injection, is not prohibited. However, OSPAR will assess these issues later this year and it cannot be guaranteed that the outcome of the assessment will reflect these views.

Irrespective of which storage methods are/are not caught by the treaties, all these treaties place responsibility on Contracting Parties (ie national governments) to establish strict regimes for authorisation and regulation of such activities and to ensure that the overriding objectives of the treaties are achieved. Since this is a new activity for regulation, the UK could provide a useful lead in helping to develop appropriate control systems that could be implemented by all Parties to the treaties. Internally there is also a need to determine the controlling authority for CCS in the UK.

With regard to onshore storage, a recent assessment has concluded that this could be permitted under present legislation subject to detailed public scrutiny of the specific proposal[26]. Future EU directives on groundwater protection, as currently envisaged, could increase the difficulty of getting such schemes approved. Furthermore, protecting the rights of surface landowners, whose property would be underlain by any storage scheme, could present problems due to the likely fragmentation of ownership over the area into which the CO_2 could disperse.

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[26] Carbon Dioxide Capture, Utilisation and Storage – Legal Issues – a report produced for the Coal Authority and DTI (DLA, Ocxtober 2002) (http://www.dti.gov.uk/energy/coal/cfft/co2capture)

4. Strategic Position

4.1 Role in UK Greenhouse Gas Abatement

The Energy White Paper 'Our Energy Future – Creating a Low Carbon Economy' accepted the recommendation from the Royal Commission on Environmental Pollution that the UK should put itself on a path towards a reduction in CO_2 emissions of some 60% from current levels by 2050. This was supported by studies examining the costs of alternative technology options for making large-scale reductions in CO_2 emissions in the medium to long term. These studies estimated abatement costs for the technologies, which were presented in the Supplementary Annexes to the White Paper[27], and are reproduced in Table 4. These data predate the economic assessment described in Section 3.3 above, but the results of this assessment have been included for comparison. Overall the results highlight the uncertainties associated with forecasting longer-term technology performance. Nonetheless they serve to illustrate that CCS has costs that are comparable with, and in many cases competitive with other large-scale supply side abatement options, including offshore wind, energy crops and nuclear power.

The Energy White Paper – Our energy future – creating a low carbon economy, put the UK on a path to a 60% reduction in carbon dioxide emissions by 2050.

The deployment of CCS technologies has been investigated as part of the systems analysis studies undertaken in support of the White Paper[28]. This work further demonstrated the potential importance of CCS by showing that it could be needed on a large scale both for electricity generation and the production of hydrogen for use in road transport, provided that the legality of sub-sea storage can be established and concerns over long-term leakage to the atmosphere properly addressed. In the case of electricity generation the technology used was natural gas-fired GTCC, while the hydrogen production was also from natural gas through a steam reforming and shift conversion process. In most cases these technologies were needed after 2020, although both the timing and size of deployment depended on the scenario for future energy prices and demand, as well as assumptions about other factors such as the availability of nuclear power, rate of innovation, rate of improvement in energy efficiency and possible limitations on natural gas supplies. This modelling work did not include lower cost EOR storage options, which may have led to earlier deployment. Neither did it include the low cost IGCC capture design discussed in Section 3.3 above.

Irrespective of the exact timing of large-scale deployment it is important that CCS technology is developed and optimised in terms of cost and performance for when it is needed. Additionally, infrastructures need to be put in place to transport CO_2 and possibly hydrogen. The slow rate of capital stock turnover and the high investment costs of CCS mean that development needs to start now if this technology is to make a significant contribution to the 2050 target.

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[27] Energy White Paper: Our energy future – creating a low carbon economy (February, 2003) (http://www.dti.gov.uk/energy/whitepaper/index.shtml)

[28] Options for a Low Carbon Future Phase 2 (FES, February 2003)

Table 4 Comparison of the carbon dioxide abatement costs for various technologies[29,30]

Technology	**Abatement Cost estimates for 2020/25 (£/teCO$_2$)***	
	Low	**High**
IAG Estimates		
Energy Efficiency**		
Domestic	-30	5
Services	-70	5
Industry	-20	10
Electricity Generation		
Onshore Wind	0	15
Offshore Wind	0	30
Municipal Waste	-15	20
Landfill Gas	-15	20
Energy Crops	30	70
Nuclear	20	55
GTCC + capture	20	30
FES/MARKAL Estimates		
Electricity Generation		
Onshore Wind	-10	35
Offshore Wind	45	130
Energy Crops	40	50
Nuclear	30	50
Wave	30	120
Tidal	70	190
Photovoltaics	600	870
Retrofit Supercritical Coal + capture	45	55
GTCC + capture	50	55
New Coal + capture	125	150
Road Transport		
Hybrid ICE	100	115
Hydrogen fuel cell	130	150
Biodiesel	80	100
Department for Transport Data		
Hybrids	40	110
Fuel Cell Vehicle (Hydrogen from natural gas)	150	1490
Fuel Cell Vehicle (Hydrogen from renewables)	85	325
Biofuels (5% blend)	60	185
Results from Present Review		
CCS with EOR	6	50
CCS with storage	34	93

Notes
* Values converted from the original DTI data which were in £/tC.
** Estimates for 2050.

4.2 Support Mechanisms for CCS

CCS is not a fully economic proposition at present, even with the off-setting revenue from EOR. It is therefore necessary to consider what incentives might be available should a large-scale demonstration of the technology be required. It is important to note that this position is not unique to the UK. Both the USA and Canada have put fiscal measures in place to support and encourage CO$_2$-based EOR including reduced production taxes and enhanced capital allowances. Moreover, the Sleipner CO$_2$ sequestration project currently underway in the Norwegian North Sea was encouraged by a carbon emissions tax (currently up to 315NOK/teCO$_2$ or approximately £26/teCO$_2$).

With regard to EOR per se, the North American approach is to incentivise action through adapting the fiscal regime. This would not seem appropriate for the UK's North Sea oil (and gas) production, since the fiscal regime is designed to be non-distortionary, inasmuch as capital expenditure is allowed immediate relief against tax, leaving post-tax rates of return equal to pre-tax rates of return. CO$_2$-EOR would have access to the incentives generally available for North Sea investments including the 100% capital allowances for North Sea investments which can be set against Petroleum Revenue Tax, Ring Fence Corporation Tax and the recently introduced Supplementary Charge. This enhanced, first year writing-down allowance delays payment of taxes on profits, currently totalling 70% for fields consented before March 1993 and 40% for newer fields. However, these incentives only apply to the offshore investment and not to the capture plant and onshore pipelines[31] and

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[29] Energy White Paper – Supplementary Annexes (www.dti.gov.uk/energy/whitepaper/annexes.pdf)

[30] By 2010/11, the DTI estimates that the Renewables Obligation will cost £85/teCO$_2$ (New & Renewable Energy – Prospects for the 21st Century, DTI, August 2001)

[31] http://www.og.dti.gov.uk/upstream/taxation/index.htm

are unlikely to be sufficient to stimulate action. It would be difficult to identify incremental costs and benefits associated with production involving EOR, which is what would be required to treat it differently from other activities, and equally hard to justify against the objective of maximising economic recovery of UK hydrocarbon resources.

Existing measures addressing GHG abatement that could in principle be extended to included CCS are (a) exemption from the Climate Change Levy (CCL), and (b) inclusion in the European Emissions Trading Scheme.

The CCL is presently 0.43p/kWh to industrial electricity users. If CCS electricity generation technologies were exempt from the levy, as good quality CHP and renewable energy sources are at present, this support would be comparable to the estimated 0.2-1.0p/kWh funding needed to make EOR viable. However, CCL levy exemption is less than the 1.0-2.3p/kWh needed to support storage without EOR, for example in depleted gas reservoirs.

The Energy White Paper indicated the Government's intention to make carbon emissions trading a central plank of future GHG abatement policies. This will be achieved through participation in the EU Emissions Trading Scheme, which is expected to begin in 2005 and will include the electricity industry. The White Paper acknowledges the need to have a coherent approach and indicates that the linkages between trading and other mechanisms will need to be examined. The benefit of carbon trading to CCS will depend on the value at which permits trade. From data in the economic assessment described in Section 3.3 permits would need to trade at around £6-50/teCO_2 for EOR to be viable and £34-93/teCO_2 for storage in depleted gas fields. Modelling carried out for the European Commission suggests the EU could achieve its Kyoto Protocol 8% target with a marginal abatement cost of €20/teCO_2 (£13/teCO_2)[32]. However, permit prices may be lower due to the participation of new Member States that have lower cost abatement options.

For inclusion as an abatement measure via emissions trading or any other route it is important that an acceptable monitoring, reporting and verification mechanism is developed for CCS. Three issues need to be addressed:

- Development of inventory methods that take account of CO_2 emissions from the capture plant, operating emissions in the gas transportation and injection systems and unplanned emissions due to faults or breakdowns.
- Development of inventory methods including verification to confirm the continued long-term storage of the CO_2 in the geological medium.
- Agreement over mechanisms for redress should CO_2 escape from storage.

Looking beyond the UK and Europe there is potential to support CCS through the other flexible mechanisms under the Kyoto Protocol (ie Joint Implementation and the Clean Development Mechanism). To benefit from these mechanisms, as with emissions trading, CCS will need to be supported by internationally accepted standards for inventory assessment and verification together with a mechanism for compensation should the CO_2 leak back into the atmosphere in the longer term.

Overall, it is clear that potential stakeholders (eg power producers, gas shippers and oil producers) will not implement CCS, including

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[32] Blok, K., de Jager, D. and Hendricks, C. (2001) *Economic evaluation of sectoral emission reduction objectives for climate change*, ECOFYS Energy and Environment, Netherlands; AEA Technology, UK; National Technical University of Athens, Greece

EOR, under current market conditions without additional financial incentives. These incentives will need to be substantial because, particularly with the oil producers, EOR will be assessed relative to other more attractive investment opportunities. Although market base mechanisms may support deployment in the long term, they will not be sufficient in the near term to support a CCS demonstration. Therefore alternative support measures need to be considered.

4.3 International Activity

Interest in the deployment of CCS as one element of a low-carbon energy system is not confined to the UK. Research and development activities are being actively pursued in other countries with a high dependence on fossil fuels, notably the USA, Australia, Canada and Japan as well as a number of countries in Europe. A recent mission made under the auspices of the Advanced Power Generation Technology Forum has highlighted the intense effort being made to take CCS forward in North America[33].

The Dakota Gasification Company's Great Plains Synfuel Plant that is supplying around 2 million tonnes of carbon dioxide per year for enhanced oil recovery in Canada's Weyburn oil field.

Although the USA has not ratified the Kyoto Protocol it acknowledges the need to tackle climate change and to develop carbon management strategies and technologies including CO_2 capture and sequestration. This work is being undertaken as part of the President's coal research initiative – the Clean Coal Power Initiative (CCPI), and through the US Department of Energy's Carbon Sequestration Programme. CCPI is a ten-year cost-sharing programme between government and industry, with a government input of $2 billion, which is targeted on the development of emerging coal power generation technologies including near-zero emission technologies, sequestration and hydrogen production. The programme aims to take technologies to the demonstration stage and the US DOE has announced a $1 billion pre-commercial demonstration of an advanced pre-combustion capture system to be built by 2006.

The Carbon Sequestration Programme covers separation technologies, geological storage, terrestrial/ocean storage and novel sequestration systems. The programme, with a budget of $32 million for 2002, has the goal of developing, to the point of commercial deployment, systems for GHG capture and sequestration from fossil fuel conversion processes that result in a cost increase of less than 10% for energy services. One objective of the programme is to facilitate an international showcase demonstration of an integrated $100MW_e$ power/sequestration project to be started in 2004.

The USA is also participating in and giving financial support to a number of international activities including the BP-led CO_2 Capture Project; the Weyburn CO_2 Monitoring and Storage Project; the Canadian Clean Power

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[33] Carbon Dioxide Capture and Storage, Report of DTI International Technology Service mission to the USA and Canada (DTI/APGTF, February 2003)

Coalition (see below); the ZECA Corporation (formerly Zero Emission Coal Alliance) project to develop a zero emission power plant and the monitoring activities at the Sleipner West oil field in the Norwegian North Sea. Recently the USA took the initiative to set up the Carbon Sequestration Leadership Forum with membership including Australia, Brazil, Canada, China, Columbia, India, Italy, Japan, Mexico, Norway, Russia, the UK and the European Commission[34]. This forum is intended to facilitate the development of improved, cost-effective technologies for CO_2 capture, transport and long-term storage, to help make these CCS technologies broadly available internationally, and to identify and address the wider issues relating to CCS.

Canada has ratified the Kyoto Protocol, accepting a legally binding target to reduce GHG emissions by 6% below 1990 levels by 2008-2012. This is a considerable commitment that is estimated to require an emission reduction of about 200MteCO_2/yr compared with "business as usual" trends. Canada's Climate Change Plan envisages CCS making a contribution to this target through EOR, with further future potential from enhanced coalbed methane extraction and sequestration in deep aquifers.

Work to develop CCS in Canada is being led by the CANMET Energy Technology Centre (CETC), which undertakes the analysis of policy options to support CCS as well as supporting public/private partnership developments through the provision of funding or test facilities. Also through the CETC, Canada is participating in a number of major international collaborative projects including those listed above.

The pilot-scale facility at the Boundary Dam power plant in Canada, which is used to test key components for carbon dioxide capture.

A notable example of the public/private partnership approach is the Canadian Clean Power Coalition (CCPC). The main aim of CCPC is to promote the construction of two full-scale demonstrations of CO_2 capture. At the time of the DTI's mission in November 2002 it was planned that the first of these should involve retrofitting capture technology to an existing coal-fired station and the second the construction of a completely new IGCC plant.

Outside North America, major programmes have been underway for some years in Japan, Australia and several European countries. These cover capture technologies and storage/disposal options. Because of the unstable geological conditions in Japan much effort has been put into understanding the long-term effectiveness and environmental impacts of deep ocean disposal methods.

To date, the size of investment in CCS R&D in Europe has been small in comparison with North America and Japan. However, there are countries in addition to the UK with active R&D programmes, including The Netherlands,

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[34] South Africa is also considering membership and The Netherlands is expected to be invited to join

Sweden, Italy, Norway and Germany. There is considerable potential for further collaboration between these countries.

The Norwegian Government has announced its intention to establish a framework to develop "CO_2-free" gas-fired power plant. Further research, a cooperation programme with industry, tax exemptions and an investigation of the environmental status are important elements of the government's policy. For 2002, the Government allocated NOK 65 million (£5.4M) to R&D related to CO_2-free technologies. Several Norwegian companies are currently involved in technology R&D for gas-fired power plant with CO_2 separation and sequestration.

The IPCC is preparing a Special Report on carbon capture and storage, to be completed in 2005, which will assess the information available internationally on such issues as potential risks, environmental impacts, costs, verification and inventory methods. UK authors and UK-based organisations are contributing to this study. The IPCC is also initiating a full revision, to be completed by 2006, of the inventory guidelines which underpin international reporting under the UN-FCCC, and the Kyoto Protocol.

5. Conclusions and Recommendations

5.1 Conclusions

The level of CO_2 abatement needed worldwide to stabilise atmospheric GHG concentrations is extremely challenging. The Energy White Paper aims to put the UK on a path to reducing CO_2 emissions by 60% by 2050, in line with the Royal Commission on Environmental Pollution's recommendation, and this would need to be matched by all developed countries to have a real impact. Moreover, with continuing economic growth, developing countries will also need to reduce their emissions substantially from "business as usual" trends for stabilisation to be attained. Such a major change in emissions trends will require radical changes in the way we supply and use energy. Energy efficiency and renewable energy sources are clearly central to this objective, but as time moves on and the required cuts become more severe other options may well be needed. Certainly at this early stage on the path to a much lower carbon world economy it would be prudent to develop and retain a portfolio of emissions abatement options. Against this background the review has concluded:

- Fossil fuels will, on current trends, continue to be a major source of energy for the UK and worldwide well into the timeframe when substantial reductions in GHG emissions are required.

- CO_2 capture and storage is potentially a major UK and global option for CO_2 emissions abatement. Moreover, CCS enables the continued use of fossil fuels, thus giving a longer timeframe to achieve a transition to fully sustainable energy sources and energy utilisation processes.

- The UK has access to substantial CO_2 storage capacity in the North Sea associated with deep saline aquifers and depleted oil and gas fields. The latter are particularly important to the early implementation of CCS because they are accessible from existing production wells and their geology has been thoroughly characterised.

- Disposal into the water column of the sea was excluded from the review as this option is not appropriate to relatively shallow waters such as the North Sea.

- The timing for the deployment of CCS depends on the target rate of reduction in GHG emissions and the success of the full spectrum of measures including energy efficiency and renewable energy. With the 60% reduction target for CO_2 emissions by 2050, large-scale deployment of CCS may be needed for electricity generation and hydrogen production from about 2020, but earlier deployment could occur to tie in with the pattern of electricity plant replacement. Cost reduction will be critical if CCS technologies are to be widely deployed, therefore much research and preparatory work is needed before this date, and full-scale demonstration is vital to prove the technology.

- For the UK, estimates of the present cost of CO_2 abatement by sequestration in depleted gas reservoirs are of the order of £34-93/teCO_2. EOR is more cost effective with net costs of the order of £6-50/teCO_2. Expressed as the additional cost of electricity these abatement costs equate to 1.0-2.3p/kWh and 0.2-1.0p/kWh respectively. These costs compare favourably with other large-scale abatement options and could be reduced appreciably through innovation.

- The above costs show that potential stakeholders (eg power producers, gas shippers and oil producers) will not implement CCS, including EOR, commercially under current market conditions without additional financial incentives. These incentives will need to be substantial because EOR will be assessed relative to other more attractive investment opportunities, particularly by oil producers. One potential long-term option would be to gain credit for the CO_2 abated. The EU Emissions Trading Scheme in principle offers a way to do this (through the proposed linking arrangement to project-based mechanisms), but GHG inventory methods including monitoring, reporting and verification methods must be developed and agreed before CCS can be accepted into this or other such measures compatible with the Kyoto Protocol. Inventory methods will be needed in any event for countries to count CCS towards commitments under the Kyoto Protocol or the UN-FCCC. In any case permit prices are unlikely to be sufficient for CCS including EOR in the near term. Consequently, alternative support measures will be needed to encourage any demonstration of CCS.

- Although not commercially competitive, storage of CO_2 in depleted oil reservoirs combined with EOR yields some financial return to offset partially the cost of capture and transportation. It therefore offers a lower-cost option for a large-scale demonstration of CCS. However, EOR needs to be implemented before conventional oil production is terminated, and with many of the UK's oil fields at a mature stage of production, action would need to be initiated before about 2010.

- The risks of CO_2 leakage from the engineered systems for capture, transportation and injection should be manageable through established design, location, containment and monitoring measures.

- The current knowledge base is insufficient to support reliable assessments of the integrity of long-term storage. Further research is required to support the development of models to provide greater assurance on this issue. There is also a need for a greater knowledge base to support environmental impact assessments of the consequences of CO_2 releases to the terrestrial and marine environments. This should cover slow long-term releases and large-scale, short duration events such as well cap failures.

- EOR is permitted, and sequestration from certain pipelines originating from land would not appear to be prohibited under the requirements of the regimes under the London Convention/Protocol and OSPAR conventions governing disposal under the North Sea. However, these treaties preclude the use of existing offshore installations for sequestration without EOR. Since the treaties did not envisage CO_2 capture and storage the distinctions within them cannot be used as a guide as to what is acceptable in current circumstances, therefore it would be reasonable to promote amendments to the treaties in the light of CCS. The process of amendment would probably take several years to complete, and would require international agreement.

- Irrespective of which storage methods are not caught by the treaties, both the OSPAR and London provisions place responsibility on Contracting Parties (ie national governments) to establish strict regimes for authorisation and regulation of such activities.

- Given that the North Sea is bounded by five other countries (Norway, Denmark, Germany, The Netherlands and Belgium) storage of CO_2 cannot be treated as a UK issue alone. Co-operation with these counties will be important not only to reach agreement on CO_2 storage but also on the regulatory regimes which will need to be developed.

- EOR is the leading option for demonstrating CCS in the UK not only on cost grounds, but also because it is permitted under the current London and OSPAR regimes, and there are well established frameworks to regulate activities related to oil and gas production offshore.

- At present there is little awareness amongst the general public of CCS technology as an option for CO_2 abatement. It is important that the facts about it are well understood and trust is developed with the public and NGOs.

- At the moment there are no commercial electricity generation plants in the world using CO_2 separation and capture technologies. The US Government is just launching its FutureGen project to demonstrate CCS, which it envisages will cost around $1bn with the US DOE contributing 80% of the cost. Its Vision 21 concept envisages CCS being viable some time after 2015.

- There is already a large international interest in the development and demonstration of CCS. The USA and Canada are fully committed to the development of these technologies and significant programmes are also underway in Japan, Australia and several European Countries. With the UK's strong industrial base in power engineering and oil and gas production it could win a substantial share of the potentially much larger global market for carbon capture and storage technology.

- There is considerable scope for international collaboration both in research and development and in the funding of full-scale demonstration projects. The IEA GHG R&D Programme already plays a part in facilitating international collaboration (for example, Sleipner and Weyburn monitoring projects) and could help extend such activities. The UK should continue to participate in work by the IPCC, and the international Carbon Sequestration Leadership Forum, set up by the USA with membership including Australia, Brazil, Canada, China, Columbia, India, Italy, Japan, Mexico, Norway, Russia, the UK and the European Commission, could offer opportunities for developing further collaboration[35].

5.2 Recommendations

In view of the above conclusions it is recommended that:

5.2.1 EOR

The Energy White Paper included a commitment to set up an urgent detailed implementation plan to establish what needs to be done to get an EOR demonstration project off the ground. Such a demonstration would extend to the full-scale capture and transport of CO_2, which, as discussed above, is an important step in the commercial development of CCS, and would provide a showcase for UK expertise and technology. Key issues to be addressed by this implementation plan are:

- What are the barriers (technical, economic, contractual, regulatory, etc.) affecting CO_2-based EOR in the North Sea?

- Would a demonstration project help reduce these barriers and uncertainties?

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[35] South Africa is also considering membership and The Netherlands is expected to be invited to join

- Are there specific components of the CCS technology chain that are particularly uncertain and need further assessment?
- Would project-specific design and costing assessments help reduce these uncertainties?
- What needs to be done to define the most appropriate UK-based CCS/EOR demonstration project?
- What additional commercial incentives will be required to stimulate the take up of CO_2-based EOR in the North Sea?
- To what extent would CO_2 emissions credits enhance the prospects for EOR?
- Which international funding sources should be contacted to seek support for such a demonstration?
- What else could government do to reduce investment uncertainties?
- What else could government do to bring stakeholders together?

In line with the White Paper's commitment this work should be completed by end 2003.

5.2.2 Sequestration

A broad strategy for progressive reductions in GHG emissions to meet the target of 60% reduction by 2050 would be expected to contain measures to improve energy efficiency and the uptake of renewable energy sources, with large-scale deployment of CCS being required from about 2020 onwards. However, two factors may lead to substantially earlier deployment. Firstly EOR as discussed above, and secondly the normal replacement of capital stock in electricity generation, which may permit the construction of plant suited for carbon capture. This presents a major opportunity for the UK to create a world-leading low-carbon energy design, construction and skills capability. To ensure the technology is available and cost-effective when it is needed more work is required to resolve the following:

- legal and regulatory issues
- environmental impact
- economic barriers and carbon trading
- acceptance into the International Emissions Inventory
- further development of the technologies, critically to reduce costs
- better understanding by the public of what CCS means for them.

It is recommended that a plan be developed to take this work forward covering each of the issues listed above. A set of work packages is recommended below.

Legal and Regulatory Issues

- This entails the clarification or amendment of the London Convention/Protocol and OSPAR Convention. Key to this is the agreement of other Contracting Parties to the treaties. While there are legal arguments that suggest that EOR is permitted, and sequestration by certain pipelines emanating from land will not be prohibited under these treaties, there is a clear obligation on such Contracting Parties to establish strict regimes for authorisation and regulation of such activities. It is essential that these frameworks are established in collaboration with other such, and potential, Contracting Parties. It is expected that this could take several years to resolve. The UK should take the lead with this work with the aim of presenting recommendations to the 2004 ministerial meetings covering these treaties.

- Work should address the regulatory requirements, particularly for transport and storage. It would be of benefit if regulations for storage were developed in collaboration with other countries around the North Sea rim.

Environmental Issues

A firm understanding of the environmental implications of CCS will need to be established before it can be fully deployed. This is important for supporting any changes to the Conventions controlling storage beneath the seabed, and for addressing concerns over the inter-generational liabilities associated with long-term storage. Research is needed to determine the impact on ecosystems of any CO_2 leakage as well as on how the CO_2 behaves in storage. Work is already going on around the world on these issues (eg Norway's Sleipner Project and the Weyburn Project in Canada). It is recommended that DTI, in conjunction with Defra, evaluates existing research to determine if further work is needed either specifically for the UK or through international collaboration.

Economic Barriers and Emissions Trading Issues

Apart from the reduction of investment and operating costs, which can be considered as part of the technology's development, a key to CCS becoming commercially viable is to obtain credits for the abatement of CO_2 emissions, thus providing a financial return for investors in the technology. To qualify under schemes designed to reward emissions abatement (eg the EU's Emissions Trading Scheme) internationally acceptable methods for monitoring, reporting and verification will have to be developed (see below).

Acceptance into the Emissions Inventory Estimates used in National Reporting and the Flexible Mechanisms

Take up and deployment of CCS technologies will depend on acceptance of their effectiveness. This needs to be achieved in two areas; first the production and verification of national emissions inventories submitted to the UN-FCCC and the Kyoto Protocol, and second at the entity level for the purposes of emissions trading. The requirements are of course connected and need to address;

- standard inventory methods to cover the operating period of a CCS technology
- standard inventory methods including monitoring and verification of the continued sequestration of the CO_2 after injection into the storage medium
- establishment of a system for redress applicable to emissions trading schemes should some leakage of CO_2 occur.

Accordingly the UK should take actions to:

- Work with international partners to develop proposals for the inclusion of CCS within the IPCC methodology for estimating national emissions inventories.
- Investigate what work is currently going on to develop monitoring methods which have the potential to provide assurance of the continued storage of CO_2.

- Examine with international partners what system of redress is needed to cover the possible leakage of CO_2 from the storage site. This work should consider any lessons to be learned from the approaches taken in considering the long-term effectiveness of sinks such as afforestation, and the treatment of Norway's Sleipner sequestration project.

- The above actions should include representation and participation in the team currently preparing a Special Report on CCS technologies for the IPCC.

Technology Development

The development of technology for CO_2 separation still has some way to go but it has become an area of considerable international activity including work in the USA, Canada, Japan, Australia and several European countries. Therefore, further development in the UK should be planned to take maximum advantage of opportunities for international collaboration, whilst fostering a competitive UK capability to design, manufacture and operate CCS systems. The ultimate goal should be a full-scale demonstration of CCS that will showcase UK technology and capabilities. It is recommended therefore that a new fossil fuel carbon management technology programme be developed to complement or replace the existing Cleaner Coal Technology Programme to include development of CO_2 separation and capture technologies. This would cover:

- Detailed engineering design studies and costing should be undertaken for the CO_2 capture technologies relevant to UK industry. These may cover new IGCC and GTCC plant and new/refurbished PF plant with supercritical boilers, oxy-firing and CO_2 scrubbing facilities, or other novel options, but the final selection will be guided by discussions with Industry. These studies should be based on actual site options with the purpose of reducing economic uncertainty and guiding the choice of technology for any subsequent demonstration.

- There is a need for further development and optimisation of key components in established capture processes and in new emerging options (eg scrubbers, high efficiency boilers, sorbents, membranes, etc). Projects on these topics should be developed in collaboration with Industry as part of the new programme. This work also needs to be coordinated with work sponsored by the research councils.

- Building on the DTI's successful international technology service mission to the USA and Canada a more active approach should be taken to broker international collaboration. The US-led international Carbon Sequestration Leadership Forum represents one such opportunity, and other opportunities should be pursued at both international (eg IEA, IPCC, industry-led consortia), national and project levels.

Public Awareness

There is a role for government in helping to raise public awareness of CCS technologies. This should be done once the environmental issues are better understood and should involve bringing together technology developers and users with external stakeholders including local government, the regulatory authorities, national and regional media and NGOs. Dialogue with stakeholders should include exchange of information on progress with the technologies, the increasing knowledge base on the benefits and impacts of CCS and views on the location and options for their deployment.

Annex 1

CO_2 Capture and Storage Feasibility Study Advisory Group

Terms of Reference and Membership

1. To provide advice to the DTI study team on the issues surrounding the feasibility of:

   (i) capturing CO_2 emissions

   (ii) transporting CO_2

   (iii) using CO_2 for enhanced oil recovery

   (iv) sequestering CO_2 in the geological formations for long-term storage.

The issues surrounding CO_2 capture and storage as a whole should also be assessed.

2. To comment on the papers and other products produced as a result of the study.

3. To ensure the study team is aware of other developments which would affect the outcome of the study's conclusions.

4. Membership of the Advisory Group:

   Iain Todd (Chairman) – Director, Renewable Energy Industry Development, DTI

   Brian Morris – Deputy Director, Cleaner Fossil Fuels Unit, DTI

   David Crockford – CCT R&D Programme, DTI

   Richard Penn – Senior Economist, DTI

   George Marsh – Advisor, DTI

   Tissa Jayasekera – Licensing and Consents Unit (formerly Oil & Gas Directorate), DTI

   Jim Penman – Defra

   David Vincent – Carbon Trust

   Jeff Chapman – Trade Partners UK

   Ray Burleigh – Trade Partners UK

   Philip Sharman – DTI/ITP

   Nick Riley – British Geological Survey

   Paul Freund – IEA Greenhouse Gas R&D Programme

   Nick Otter – Alstom

   John Curran – TXU

   John Mitchell – Scottish & Southern Power

   Tony Epsie – BP

   Keith Burnard – Future Energy Solutions AEAT

   Nigel Devereux – DTI Energy White Paper Team

   Ken Fergusson – Combustion Engineering Association

   Brian Ricketts – UK Coal

   David Hanstock – Progressive Energy

   Jolyon Thomson – Defra (co-opted to cover legal issues)

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DTI/Pub URN 03/1261