Parliamentary Office of Science and Technology

postnote

March 2005 Number 238

CARBON CAPTURE AND STORAGE (CCS)

As part of the government's global strategy to address climate change, the 2003 Energy White Paper sets the target of a 60% reduction in UK emissions of the greenhouse gas carbon dioxide (CO_2) by 2050, to about 240Mt (million tonnes) per year from 550Mt in 2000.[1] Increased energy efficiency and use of renewable energy are the key mechanisms proposed to achieve this. However the White Paper suggests the continuing importance of fossil fuels to ensure security of electricity supplies. Using fossil fuels in a low-carbon economy requires their CO_2 emissions be reduced. This POSTnote discusses the potential of carbon capture and storage (CCS), a method of carbon sequestration[2], to reduce UK and global emissions, and also the costs, environmental impacts and public perceptions of CCS.

Background

CCS refers to the capture of CO_2 from emissions, followed by storage, thereby preventing it from entering the atmosphere. To be useful for climate change mitigation, storage should be for at least many hundreds of years until well past the end of the fossil fuel era.

Government policy

Applying CCS to UK power generation (especially coal) was framed as a promising way forward in the Energy White Paper which set up a number of follow-up projects. It has since been the subject of many government reports[3] and will be included in the forthcoming Department of Trade and Industry (DTI) Carbon Abatement Technology Strategy (Spring 2005). It has also had recent parliamentary attention.[4]

CCS in geological formations

There are several potential options for storing captured CO_2 (Box 1). The most viable and environmentally acceptable is geological storage. This POSTnote will therefore focus on this option. CCS in geological formations involves capturing CO_2 and then injecting it into rock layers. There are three main storage options:

- depleted or near-depleted oil and gas fields
- deep saline aquifers (porous rock layers containing salty water deep underground)
- unmineable coal seams.

As a form of 'Enhanced Oil Recovery' (EOR), CO_2 is already being pumped into near-depleted oilfields in the US and elsewhere to extend their lifetimes (Box 2). In Norway, Statoil has been re-injecting CO_2 co-produced with natural gas into a deep aquifer overlying its offshore Sleipner field, solely for storage. Since 1996, ~1Mt CO_2 per year has been stored here.

CCS involves three stages: CO_2 capture, transport and storage.

CO_2 capture

Carbon capture is best applied to large stationary sources such as power stations and industrial plants, where CO_2 can be separated from the flue gases at some stage of the process. In 2002, ~35% of UK CO_2 emissions were from energy industries compared with ~2% from the chemical industry.[5] Applying CO_2 capture to the UK's energy industries therefore has the greatest potential to reduce current emissions. The list of the 20 largest point sources in England and Wales in 2000, was made up of 16 power plants, three steel plants and one oil refinery.

There is a range of capture technologies at different stages of development. The most developed has been used in the petroleum and gas industry for almost a century and has already been applied to a few small power plants abroad producing CO_2 for EOR or industrial uses. In principle, subject to scale-up issues, this technology could be retrofitted to the UK's existing power stations as well as included in new build. All capture technologies consume energy and reduce the efficiency of the power station. Further research and development will lead to cost reductions and increased efficiency, although capture will inevitably add to process costs.

Box 1. Different CCS storage strategies
Suggested storage schemes have included, for example:

- in the deep ocean - there are uncertainties about how long CO_2 injected into the deep ocean will remain there and the potential impact on marine ecosystems.
- as a solid carbonate precipitate - although research continues, an energy efficient, cost effective and practical technology to process CO_2 to form carbonate on a large enough scale for climate change mitigation has yet to be developed.
- in geological structures (see main text)

CO_2 transport
CO_2 is captured as a gas. Its transport generally needs it to be compressed and/or cooled requiring energy input decreasing net CO_2 emission reduction. Bulk transport may be by tanker or pipeline. Tankers may have a role in smaller projects but for larger volumes pipelines are the only practical option. CO_2 transport by pipeline is an established commercial technology. Over 3000km of pipelines are currently used to transport several Mt of CO_2 per year for EOR in the US and Canada.

CO_2 storage in geological structures
Under most storage conditions in permeable rock CO_2 is buoyant and moves to the top of the rock layer. If the rock above offers an effective seal it is trapped and stored. There are also other processes that result in efficient long-term storage in geological structures. For example, permeable rocks commonly have their pore spaces filled with water in which injected CO_2 may dissolve and/or CO_2 may react chemically with water or minerals in the rock and be immobilised.

The key issue is the ability of geological structures to retain CO_2 over hundreds or thousands of years without it leaking out (called here 'tightness'). This is important in terms both of the inclusion of CCS in emissions trading and in any environmental impacts (see later sections). Technology for CO_2 storage in coal seams is at an early stage, but there is greater understanding of storage in oil and gas fields and saline aquifers. The oil and gas fields and aquifers in the UK sector of the North Sea have large storage potential (estimated ~20,000-260,000Mt CO_2).

Depleted oil and gas fields
Oil and gas have been 'stored' underground for millions of years demonstrating that buoyant fluids can certainly be retained in these structures over long timescales. While depleted oil and gas fields obviously had this 'tightness', the extraction process may have damaged it. This is mainly due to potential leakage through abandoned production and exploration wells, but the possibility that the rock structure itself may have been weakened has also been suggested. The effective capping of wells is a mature technology although it might need some optimising to seal CO_2.

Saline aquifers
Although saline aquifers do not have proven 'tightness', the Norwegian Sleipner project results are promising. CO_2 volumes estimated from monitoring measurements are consistent with the known injected volume.[6]

Given the length of storage required for climate change mitigation, demonstrations are still at an early stage. Further research is needed to establish the characteristics of successful storage structures and to understand the potential for large releases of CO_2 resulting from movements of the earth's crust in different parts of the world.

Box 2. North Sea Enhanced Oil Recovery (EOR)
EOR is a special case of CCS. CO_2 pumped into a near-depleted field dissolves in the oil, making it more mobile and easier to extract. This can lengthen the life of the field and is an established onshore technology, although not so far used offshore. Although some of the CO_2 returns to the surface with the oil, this is recaptured and added back to the CO_2 being injected. The Energy White Paper set up a consultation to establish how a UK EOR demonstration project might be initiated.[7] Oil producers considered EOR as proven technology and saw little value in a demonstration project other than stimulating further development of monitoring methods for stored CO_2. They also felt it might be hard to generalise from lessons at one field given the variety of conditions in the North Sea. Under present economic conditions oil producers did not see North Sea EOR as financially viable. However it was agreed that an EOR project would have other benefits as a lower-cost and legal (Box 3) initiation of CCS, including:

- to establish CCS technology and regulation – electricity suppliers considered that this would allow them to become 'informed buyers' of carbon capture technology
- to showcase UK CCS expertise
- to provide further opportunities to monitor and understand storage structure 'tightness'
- to get different concerned parties working together
- to increase public awareness.

Several EOR project scenarios have been discussed. Small-scale storage onshore is the lowest cost option but will not provide relevant experience if the future target is the North Sea. The cheapest CO_2 would be that separated from oil and gas anyway. However, to demonstrate the full potential of CCS to reduce UK emissions it would be necessary to include capture from a power station. Electricity suppliers were concerned about the different timescales for operating a carbon capture plant and EOR. To make investment in full-scale carbon capture feasible, they would need assurance of a long-term CO_2 market. Additional funding for North Sea EOR may be available through the EU to showcase European technology against competition from elsewhere.

Issues
The feasibility of each individual element of CCS technology has been demonstrated, but the integration and scale-up needed for routine application to large-scale power generation will require significant research and demonstration.[8] Along with obvious issues such as cost, issues such as environmental impacts and safety, public perceptions and incentives must also be considered.

Costs
Assessing the current and future cost of carbon emission reduction by CCS is complicated and depends on many factors. These include: the type of power station or other plant involved, the technology with which costs are compared, economies of scale, transport distances and, for EOR, future oil prices. It is generally agreed that the biggest cost element is capture but these costs should reduce with further research and development.

UK North Sea oil fields have significant estimated storage capacity in terms of EOR (~700Mt CO_2).[9] The UK's oil operations are nearing the end of their life and EOR could postpone decommissioning. Even if not commercially viable, North Sea EOR would be a cheaper way to initiate UK CCS (Box 2). In 2003, DTI estimated that, with current trends, CO_2 injection would need to start by 2008, to have an impact on the largest fields before existing infrastructure is dismantled. Recent increases in oil prices may push this date further into the future.

Estimated costs per tonne of CO_2 emissions reduced by CCS vary but range from about £30 to £90 without EOR.[3] If the CO_2 is used in EOR to recover more oil, these costs are reduced by an amount dependent on the oil price (£6-12/tCO_2 for oil at $20/bbl).[7] The cost of emission reduction using CCS are comparable with those of using offshore wind power or nuclear power.[3] Carbon emission reduction costs of about £50/tCO_2 have been estimated to add about 1-3p/kWh to the costs of electricity generation (estimates of the cost of generating electricity from fossil fuel fired base-load plants without carbon capture have been estimated as 2.2-3.2p/kWh[10]).

Environmental and safety issues
At low concentrations there are few environmental concerns about CO_2 beyond global warming. It is not poisonous but is more dense than air and can displace it, suffocating in high concentrations. There are concerns that CO_2 could be released during transport and injection or over time from geological storage.

CO_2 release would need to be carefully monitored for human and environmental safety. There are already expertise and industrial protocols associated with its handling. Even using pessimistic assumptions it has been estimated that it is unlikely that more than 0.03% of the CO_2 would be released during transport and injection.[3]

In many areas of the world CO_2 is released from the ground naturally. However seepage out of geological CCS projects into environments not adapted to CO_2 could lead to hazardous accumulations or have other detrimental effects. Dissolved in water CO_2 forms a weak acid, familiar as carbonated water, which could affect sea water or water in aquifers (with potential impacts on drinking water). It has been estimated that such leakage might release 0.004-2.4% of the CO_2 stored on a 1000-year timescale.[3] More understanding of long-term CO_2 retention and the potential impacts on marine and land environments of seepage is needed, maybe involving experimental deliberate releases.

Concerns have been raised as to who would undertake impartial monitoring of storage sites and have long-term responsibility and liability for them, especially once a particular project was complete. The need for intervention strategies in the event of unexpected CO_2 releases has also been highlighted. There have been suggestions that the government would need to establish a UK Carbon Dioxide Capture and Storage Authority analogous to the Coal Authority. Greenpeace has also voiced concerns about the potential impacts of the long-term activities monitoring subsurface CO_2, especially of seismic monitoring in the marine environment.

Public perception
CCS is not well-known by those not involved with the energy industry. This low level of awareness suggests that early success or failure will disproportionately influence attitudes. Preliminary work suggests public acceptability of CCS depends on levels of concern about climate change and how it is presented. For example, it is more acceptable when framed as part of a portfolio of measures and as an alternative to nuclear. If CCS were implemented on a large scale, studies recommend early and thorough public communication of the purpose and environmental risks of CCS relative to the alternatives.[11]

Box 3. Legal Issues

Offshore

There are three treaties designed to protect the marine environment relevant to offshore UK CCS in geological structures: the 1972 London Convention, the 1996 Protocol to it and the 1992 OSPAR Convention. These treaties refer to waste disposal into the water column or underlying 'subsoil' and did not consider the possibility of offshore CCS when they were drafted. An OSPAR review concluded that CCS is consistent with the convention if carried out by pipelines from land. Further reviews of CCS in the context of both the London and OSPAR conventions (the latter on environmental aspects) are under way. EOR is allowed under all three treaties as 'placement of matter for a purpose other than mere disposal'. Greenpeace has raised concerns that CCS must not undermine these legal mechanisms in the wider context.

Onshore

A recent assessment concluded that onshore CCS could be permitted under present legislation subject to detailed public scrutiny of specific projects. Further issues such as current and future EU directives and rights of owners whose property is underlain by projects could add complications.

Carbon accounting and incentives
It is unlikely industry will invest in deployment of CCS, even for EOR, under current market conditions. CCS might become more viable under schemes where value is attached to CO_2 emissions reduction. To be included in such schemes, an accepted methodology for carbon accounting in terms of CCS must be developed. Specific issues regarding CCS are:

- taking the whole process of CCS into account, including CO_2 emissions from energy expenditure and leakage at the plant and during transport and injection and unplanned emissions due to faults or breakdowns
- including verification of long-term CO_2 storage

- agreeing mechanisms for redress if stored CO_2 escapes.

It is generally agreed that the European Union Emissions Trading Scheme (EU ETS) for greenhouse gases could encourage investment in CCS. At present, CO_2 captured and stored may be subtracted from calculated emissions, subject to European Commission approval.

With agreed monitoring and reporting guidelines, the economic viability of CCS via the EU ETS will depend on the level at which emissions permits are traded. Since the start of trading in EU ETS carbon futures, the price (per tonne of CO_2) peaked at about €13 in mid-2003, and by the end of 2004, was about €8.5. This may not be sufficient to provide incentives for CCS investment in the UK, even with EOR. CO_2 storage at the Sleipner field was encouraged by Norway's carbon emission tax of about €40/tCO_2. US EOR projects have been encouraged by tax incentives.

The role of CCS as part of an integrated UK emissions reduction strategy

Carbon capture from industry is applicable only to the largest emission sources; but more than 20% of 1998 UK emissions were from the largest 25 industrial sources. If ~85% of CO_2 from these sources were captured and stored this would mean a 17% reduction in total UK emissions.[6] Thus if CCS were deployed straight away it could contribute significantly to achieving emission reduction targets. The first implementation of CCS technologies in the UK may be in conjunction with EOR in the North Sea (Box 2). Economic modelling studies based on the most cost-effective route to achieving the UK 2050 CO_2 emissions target suggest that CCS technology would be used anyway. Exactly when it is needed depends on future patterns of energy supply and demand and the success and acceptability of other options.

Long-term developments might include the application of CCS to power generation fuelled by sustainably grown biomass, thereby removing CO_2 from the atmosphere. CCS could also be applied to plants producing hydrogen or electricity to power a future low-carbon transport sector (~22% of 2002 UK CO_2 emissions).[12] The production of hydrogen from fossil fuels lends itself to carbon capture as a high purity CO_2 stream is produced.

In the wider debate on energy and climate change NGOs have expressed some concerns that CCS technology encourages continued reliance on fossil fuels and that investment in this area could draw funds away from research into renewable energy sources. However, subject to appropriate verification and monitoring, and weighed against the risks associated with doing nothing some NGOs are not totally averse to CCS as part of a portfolio of measures to tackle climate change, especially as an alternative to investment in nuclear power.

CCS and the developing world

Predicted increases in global energy demands and continued reliance on fossil fuels suggest related CO_2 emission increases of 62% by 2030. Two thirds of this growth is expected to be from developing countries, especially India and China. Coal is likely to be the preferred fuel for power generation. This increased demand will require many new plants which will operate for 40-60 years, strongly influencing future CO_2 emissions. It is not currently economically realistic to include CCS in new plants. However, building 'capture ready' plants (so CCS technology can be easily added in the future) could be encouraged. Several developing countries, including India and China, are already engaging with CCS through the Carbon Sequestration Leadership Forum. The Department for International Development (DFID) is tracking developments in CCS but has not yet provided direct funding for carbon capture and storage projects.

Overview

- Carbon capture and storage (CCS) in geological structures is technically feasible, although further development is needed to optimise it.
- CCS potentially offers carbon emissions reduction at costs similar to offshore wind and nuclear power.
- CCS offers a low-carbon way to use fossil fuels to ensure security of electricity supply.
- Enhanced oil recovery in the North Sea could reduce the cost of CCS and could also act as a showcase for UK technology and raise public awareness of CCS.
- Under present economic conditions CCS is not financially viable. Creating incentives for CCS forms part of the wider debate on economic strategies to reduce CO_2 emissions.
- CCS could play a key role in reducing future emissions from the developing world.

Endnotes

1 DTI White Paper, *Our Energy Future*, Feb 2003
2 Carbon sequestration is a more general term for carbon storage including that via natural biological processes. Carbon capture and storage tends to refer to the application of carbon abatement technologies to industrial CO_2 emissions.
3 For example, *Review of the feasibility of carbon dioxide capture and storage in the UK*, DTI, Sept 2003
4 For example, PM's Speech on Climate Change, 14 Sept 2004, Commons Hansard, 3 March 2005, Lords Hansard, 23 Feb 2005.
5 DEFRA, e-Digest Statistics about: The Global Atmosphere (www.defra.gov.uk).
6 Chadwick et al., Geol Soc London, Special Publication 233, 2004.
7 *Implementing a demonstration of enhanced oil recovery using carbon dioxide*, DTI, May 2004.
8 *Report of DTI International Technology Service Mission to the USA and Canada*, Feb 2002.
9 DTI's Improved Oil Recovery Research Seminar, 25 June 2002.
10 *The Cost of Generating Electricity*, Roy Acad Eng, March 2004
11 Tyndall Centre, Working Paper 44, Jan 2004.
12 POSTnote 186, *Prospects for a hydrogen economy*, Oct 2002.

POST is an office of both Houses of Parliament, charged with providing independent and balanced analysis of public policy issues that have a basis in science and technology. POST is grateful to the NERC for Tamsin Mather's secondment to Parliament to research this briefing note.

The Parliamentary Office of Science and Technology, 7 Millbank, London SW1P 3JA Tel 020 7219 2840

www.parliament.uk/post/home.htm