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CO_2 CAPTURE, TRANSPORT AND STORAGE

Carbon capture and storage (CCS) involves capturing carbon dioxide (CO_2) emitted from large sources such as fossil fuel power stations, transporting it, and then storing it in secure geological formations deep underground. These formations include depleted oil and gas fields, and natural underground reservoirs. This POSTnote details the main CCS technologies and considers their safety and legal issues. This is followed by an overview of global CCS projects as well as a discussion of UK and EU policy.

Background

CCS could potentially capture around 90% of the CO_2 emitted when fossil fuels such as coal are used. It would then be transported and stored safely underground so it cannot contribute to climate change. While the UK currently generates ~37% of its electricity from coal[1], the USA derives 50%, India 70% and China 80%. The International Energy Agency predicts a possible 70% global increase in the use of coal over the next 20 years. However, the UK has not built a coal power plant since Drax in 1974, and is committed to at least an 80% cut in greenhouse gas emissions by 2050 against a 1990 baseline. It should be noted that CCS can also be applied to gas-fired power plants, and on various CO_2 emitting sources such as oil refineries and cement, chemical or steel plants.

UK Policy

In April 2009 the Department of Energy and Climate Change (DECC) proposed that new coal plants built in the UK should have demonstration CCS facilities on at least 300 MWe (electricity output) of their capacity. For example, on approximately a quarter of the proposed 1600 MWe Kingsnorth plant. In addition, all other applications for power stations that emit CO_2 will have to be built with the ability to retrofit CCS in the future (see Box 1). If CCS is proven to be technically and commercially viable, all new coal fired power stations would have five years to fully retrofit the technology. A decision has yet to be made on whether existing coal plants will have to retrofit. Details of these proposals and the funding mechanism will form part of a DECC consultation to be released in summer 2009.

CO_2 Capture

There are three methods for capturing CO_2 from point-sources such as power stations: pre-combustion, oxyfuel-combustion, and post-combustion[2]. After the CO_2 is captured it needs to be transported and then injected into a suitable storage site. Capturing emissions from industrial facilities also requires separating out the CO_2, but such 'industrial separation' methods are not covered in this briefing[3].

Box 1. Carbon Capture Ready (CCR)

In April 2009, the government announced[4] that all new combustion power stations producing 300 MWe or above will have to be 'carbon capture ready' (CCR). This means UK proposals will have to:

- leave sufficient space to retrofit CCS technology, including the necessary pipework
- identify a practical offshore storage area
- plan a plausible transport route for the CO_2 from the power plant to the storage site
- carry out a technical assessment to ensure there are no foreseeable barriers to retrofitting CCS.

In addition, applicants are also required, under the EU Directive on the Geological Storage of CO_2 (Article 34), to carry out economic assessments on the feasibility of retrofitting CCS and on the transport of CO_2 to the storage area. However, due to economic and technical uncertainties surrounding CCS, 'capture readiness' cannot guarantee that retrofitting will take place, but does try to ensure that foreseeable barriers are removed.

Pre-combustion

In pre-combustion capture, carbon is extracted from the fuel before it is burnt. To do this, the fuel must first be 'gasified' by heating it in only small amounts of oxygen. This produces 'syngas', which is primarily a mixture of carbon monoxide and hydrogen. Steam is then added to convert the carbon monoxide to CO_2, producing additional hydrogen. The CO_2 can be chemically separated out, leaving hydrogen that can be used as a 'clean fuel' in a power plant, as a fuel for vehicles, or for other chemical processes. Only a few Integrated Gasification Combined Cycle (IGCC) coal plants exist as they are not yet an established technology (see POSTnote 253), all without CCS.

Oxyfuel-combustion

Capture of CO_2 through oxyfuel-combustion involves burning fossil fuels in almost pure oxygen rather than air. The oxygen is obtained by removing nitrogen and other gases from air (which is 79% nitrogen by volume). Burning the fuel in oxygen results in a flue gas of almost pure CO_2 and water vapour. The CO_2 can then be separated relatively easily from this mixture for transportation and storage.

Post-combustion

In post-combustion CCS, CO_2 is removed after the fuel has been burnt, just before the combustion products are released to the atmosphere. A chemical solvent is usually used to capture the CO_2 from the flue gas. Subsequent heating of this mixture allows the solvent to be recycled as it frees the CO_2 to be compressed, transported and injected into a storage site. This technology is particularly suited to retrofit applications, which is the main reason it was selected for the first UK based CCS competition (see page 4).

All these processes use energy, decreasing the efficiency of the power plant, as discussed in Box 2.

CO_2 Transport

CO_2 will not necessarily be stored close to where it is captured, so it will have to be transported – depending on the distance, this could be either by pipeline or ship[5] (this briefing will focus on the former as this is most relevant to the UK). With the right incentives in the UK, CCS facilities will initially cluster in industrial regions allowing infrastructure to be shared, thereby achieving the greatest emission reductions for the lowest cost and allowing future power plants and industry to take advantage of the infrastructure.

Pipeline Leaks

It is likely that CO_2 would be transported via a pipeline at high pressure (see Box 3). If a pipeline carrying CO_2 suffered a major fracture due to accident or failure, the CO_2 would rapidly expand and cool. In the case of pure CO_2, it is thought that this would initially form a 'vapour cloud' around the fracture, followed by the formation of solid CO_2 'snow'. However, impurities in the CO_2 could change the characteristics of this leak and introduce additional complexities affecting the nature of the release[6].

In the case of a pipeline constructed from steel containing a high level of carbon, the cooling effects of the leak could cause the area of the pipeline around the breach to become brittle, perhaps shattering and causing damage to the capture or injection equipment. Whilst it is thought that this would not affect stainless steel pipes, large scale experiments and modelling are needed to better understand the behaviour of leaks as well as their health and safety impacts.

Experience with CO_2 Transport

Millions of tonnes of CO_2 are already transported over thousands of km of pipeline. Much of this is in the USA for Enhanced Oil Recovery (EOR). EOR and Enhanced Gas Recovery involve injecting CO_2 into depleted reservoirs to assist in extracting some of the remaining oil or gas (see page 3). A 328 km pipeline has been taking supercritical CO_2 (see Box 3) from the USA to Canada for EOR since 2000. However, many of these pipelines are routed through low population areas, a situation that may not be possible in the UK. Existing oil and gas pipelines could be used or perhaps upgraded to transport CO_2, although this requires an analysis of the costs of pipeline decommissioning versus re-use.

Since 2008 Norway's Statoil has been transporting CO_2 (obtained from natural gas extraction) through a 160 km seabed pipeline from Hammerfest in north Norway back to the Snøhvit field under the Barents Sea from which the natural gas was originally obtained, but injecting it into a deeper geological formation.

Box 2. Energy Requirements of CO_2 Capture

All forms of CCS reduce the overall efficiency of electricity generation due to the need to compress, transport and inject the CO_2. Actually capturing CO_2 also requires energy to power the equipment, which brings down the overall output of the power plant[7]. The method of capture can also affect the efficiency of the power plant in various ways, meaning more fuel has to be used per unit of electricity in a CCS fitted power plant than in one without.

- **Pre-combustion capture**. The CO_2 is usually captured by a solvent. Energy is then required to extract the CO_2 from this so that the solvent can be re-used and the CO_2 compressed and transported. The hydrogen fuel that is produced has to be burnt at sub-optimal temperatures (compared with the 'syngas' that would be burned if CO_2 capture were not implemented) so as not to damage the turbine, which incurs a further efficiency penalty.
- **Oxyfuel combustion capture**. Cryogenic cooling technology is required to separate the nitrogen from the ambient air in order to obtain pure oxygen, although research is underway into 'membranes' that could separate the gases. Additionally, flue gas from the combustion products is re-routed back and mixed with the initial oxygen in order to reduce the temperature at which the fuel burns. This is to reduce it to a level that current turbine materials can tolerate, whether in new or existing plants.
- **Post-combustion capture** Energy is used in extracting the CO_2 from the chemical solvent that captures it, similar to pre-combustion capture. Additionally, unless the heat is sourced elsewhere, steam is diverted from power generation to solvent regeneration, incurring a further energy penalty.

These energy penalties reduce the efficiency of power plants fitted with CCS technology. However, efficiency losses should be less when power plants are designed that incorporate fully integrated CCS from the outset. Retrofitting CCS on existing power plants is more expensive in efficiency terms than applying CCS to new plants. Furthermore, advances in materials science could allow power plants to burn their fuel at higher, more efficient temperatures.

Natural CO_2 Leaks

CO_2 can also leak naturally to the surface from the ground through caves and lakes, especially in volcanic regions. This forms gas clouds at lower pressure, of greater volume and more slow moving than the high pressure CO_2 that would be encountered from a pipeline leak. These conditions give rise to a different set of hazards such as accumulation in ground depressions, as CO_2 is heavier than air. A high pressure CO_2 leak would rapidly draw in and mix with the surrounding air, making it more dilute. The conditions and some of the associated consequences of a natural CO_2 leak are not analogous to those envisioned in CO_2 transport.

CO_2 Storage

Once CO_2 has been captured and transported it needs to be stored safely and permanently. The emphasis in much of the world is on geological storage, the UK focus being underneath the North Sea[8]. The Energy Act 2008 (Chapter 32) was among the first pieces of legislation in the world to establish a regulatory framework for the licensing of CO_2 storage, as well as asserting the UK's right to store CO_2 offshore. The EU Directive on Geological Storage of CO_2 aims to provide a regulatory framework for CO_2 storage at scale. The Energy Technology Institute (ETI), an industry-government partnership that aims to identify and develop key energy technologies, is currently undertaking a desk-based study, the UK Storage Capacity Project, looking at CO_2 storage potential[9].

Box 3. High Pressure and Supercritical CO_2
In supporting government policy for the safe and efficient transport of CO_2 through pipelines, the Health and Safety Executive (HSE) is working with industry to address knowledge gaps on the behaviour of high pressure and 'supercritical' CO_2. While there is industrial experience of CO_2 pipelines outside of the UK, the HSE is concerned that worldwide experience of CO_2 pipelines is relatively low (compared to that of high pressure natural gas pipelines) to give assurance that there are not failure modes specific to CO_2. If CO_2 were to be transported at temperatures greater than 31°C and pressures above 74 bar the CO_2 would be 'supercritical' (this means that no matter how much pressure is applied the gas will not form a liquid, giving it special, but not unknown, characteristics). Transportation under such conditions is likely to be desirable as it would increase efficiency. However, pipelines in the UK will not necessarily transport CO_2 in its supercritical state. Temperatures in an underground pipeline are unlikely to reach those necessary for the CO_2 to become supercritical. In such a case, the CO_2 would be in the form of a high pressure liquid (called the 'dense phase'). As discussed under the section 'Pipeline Leaks', large scale experiments and modelling will provide greater understanding of the hazards and risks of supercritical and dense phase CO_2 transport.

Geological Storage
Geological storage involves injecting CO_2 underground at depths of around 800m or more. At such depths the CO_2 will be held at many times atmospheric pressure and temperature. Storage options include depleted oil and gas reservoirs, or deep saline aquifers (an underground layer of salt water bearing permeable rock). Recent investigation of saline aquifers in the waters offshore of Scotland has revealed up to 230 years worth of potential storage capacity based on current UK emissions[10], but little is known about these formations' detailed characteristics offshore. Through the North Sea Basin Task Force, Norway and the UK have commissioned a joint study to establish the role of the North Sea in the future of European CO_2 storage, to report by the end of the year.

Operational Storage
The Norwegian company Statoil has been injecting over a million tonnes of CO_2 per year (obtained during natural gas extraction) into the Utsira saline formation since 1996. Extensive CO_2 monitoring has not revealed any problems to date. Between early 2008 and March 2009 the deep underground Otway Basin in South East Australia has received 50,000 tonnes of CO_2, with extensive monitoring techniques showing no signs of leakage so far[11].

Oil and Gas Reservoirs and Enhanced Recovery
Depleted reservoirs have already been characterised by the oil and gas industry, and the rock that caps the formation has already been shown to keep oil and gas underground for millions of years[12]. CO_2 has been used for EOR in the USA since 1972, but there is only experience onshore. Since 2004, BP has been re-injecting 1.2 million tonnes of CO_2 per year from natural gas processing into a gas field at In Salah, Algeria. In Weyburn, Canada, over a million tonnes of CO_2 a year from a coal gasification chemical production plant (pre-combustion capture technology, although in this case non-power producing) in North Dakota, USA has been used for EOR since 2000. Emissions savings depend on whether CCS is applied to the combustion of the recovered oil or gas.

Storage Leaks
Once CO_2 is stored underground the geological formation must be monitored for leaks, which need to be minimised in order to avoid inducing further climate change. Monitoring will also be necessary for verification purposes under the EU Emissions Trading System (EU ETS). While the likelihood and extent of such leaks is thought to be highly unlikely and small[3], there are concerns about the effects of concentrated CO_2 on the local environment should a leak occur under the sea. As the CO_2 dissolved in the sea, it would cause a localised increase in acidity, which could adversely affect the marine ecosystem. The North Sea is fairly shallow, possessing very strong tidal mixing that would quickly dissipate a minor CO_2 leak.

Ecosystem Effects
Marine biologists at the Plymouth Marine Laboratories (PML) have created computer models to estimate the effects of CO_2 leaks on ocean ecosystems such as those in the North Sea. Unless the leak was catastrophic, simulations suggest that the impacts are unlikely to extend beyond the locality of the incident. The resulting increase in acidity would be restricted to a small volume for a limited time. The effects would not approach those that could arise from global ocean acidification as a result of unmitigated man-made CO_2 and other greenhouse gas emissions.

CCS Legislation and Regulation

CO_2 Pipeline Legislation
The HSE is considering whether to include CO_2 (for the purposes of CCS) as a 'dangerous fluid' in the Pipeline Safety Regulations due to the potential hazards of a CO_2 pipeline leak, including asphyxiation. This is being informed by comparing the risks associated with CO_2 hazards with those from natural gas pipelines.

Responsibility for Stored CO_2
The legislation and conditions surrounding the transfer of long-term liability from a CO_2 storage operator to a government are given in Article 18 of the EU Directive on the Geological Storage of CO_2. Once CO_2 injection is complete, responsibility remains with the operator while the site is sealed and the facility decommissioned. Then, when it has been established that, as far as can be determined, the stored CO_2 will remain contained indefinitely, the liability for the site will transfer from the operator. Once this is done, no further costs can be extracted from the former operator. As such, it is up to each Member State to ensure that potential operators make adequate provisions (such as financial security) in their storage permit applications to cover post-closure costs, liabilities and all other obligations. This financial security will be kept by the government post-closure, or upon the withdrawal of a CO_2 storage permit.

Environmental Law
Any damage to the environment - such as groundwater pollution caused by CO_2 leakage - would be covered by the EU Environmental Liabilities Directive (which focuses on habitats, water and land pollution). Under this an operator is liable for damage up to 30 years after an incident takes place, irrespective of the time the facility closes. In the UK, the Environment Agency is able to order companies to restore polluted environments through this directive, although it is unclear how this would apply to the sea.

Laws of the Sea
The London Protocol to the London Convention - an international framework governing dumping at sea - was amended in 2006 to allow "CO_2 from capture processes" to be stored under the seabed. This amendment came into force in 2007, but a further amendment is necessary to allow trans-border transport of CO_2. In 2007, the Convention for the Protection of the Marine Environment of the North-East Atlantic ("OSPAR Convention") was also amended to allow CO_2 storage in geological formations under the seabed. This amendment has yet to be ratified, and so is not in force.

Licensing and Leasing
The Crown Estate owns the rights for offshore CO_2 storage up to the 200 mile (320 km) continental shelf international boundary. Any licence for such activity would be obtained through DECC, while a land lease would be obtained from the Crown Estate. The government is currently developing a draft licensing structure, modelled on the current gas licensing structure.

International Regulation
EU regulation on the storage of CO_2 is currently rolling out among Member States, while Australia, Canada and the USA are also developing their own regulatory regimes and financial support mechanisms. When making major investments, such as in CCS technology, companies value legal certainty as well as a regulatory framework that is adaptable to changing circumstances.

CCS Demonstrations
CCS and transport has never been demonstrated at full scale for a power plant. Previous CCS development has tended to focus on various aspects of the technology (capture, transport, storage, monitoring), but demonstration projects are looking at fully integrating the processes into part of a power plant. The Scottish Centre for Carbon Storage have developed a world map showing a number of large commercial CCS tests or propositions in various locations[13]. The Swedish power company Vattenfall has built a small pilot oxyfuel combustion plant (30 MW) at Schwarze Pumpe in Germany. In 2008, it began capturing CO_2 from coal combustion (which generates steam for nearby industry) and plans to begin storing it once an appropriate site has been found and the necessary permits obtained. In April 2009, the French company Total began operation of the world's first retrofit oxyfuel capture power plant[14]. The aim is to store 150,000 tonnes of CO_2 over 2 years in the nearby depleted Rousse gas field. During and after this period the site will be monitored for leaks.

UK CCS Competition
The UK government's CCS competition was launched in November 2007. The focus is on post-combustion technology, followed by offshore storage, to be applied to at least 300MW (net electrical output) from a coal fired power station. Phase 1 ran until June 2008, and initially drew the involvement of: E.On; BP (who later withdrew); Scottish Power; Peel and Dong (joined by RWE). After an informal discussion stage, phase 2 will take a more detailed look at proposals, followed by formal negotiations and detailed planning in phase 3. The aim is to have a demonstration operating by 2014.

In addition to this competition, plans were announced in April 2009 to provide funding for up to three other coal CCS demonstrations (a mix of pre- and post-combustion). These would be funded through a levy on electricity prices.

EU Funding
The European Commission intends to support the construction of up to 10-12 CCS demonstration projects across Europe by 2015. As part of the revisions to the EU ETS agreed in December 2008, 300 million CO_2 emission allowances have been set aside to fund CCS and innovative renewable energy projects. The value of these CO_2 allowances has shown great variability: in the 18 months from May 2006 until December 2007 they fell from €30/tonne CO_2 to €0.03, and are at ~€15 in June 2009. It should, however, be noted that forward carbon prices for the 2008-2012 phase of the ETS are forecast to be higher and more stable[15]. Some of the money raised by these allowances could go to funding CCS projects in the UK.

In addition, the European Economic Recovery Programme lists 13 CCS projects across seven Member States that can apply for funding from a total provision of €1.05 billion[16]. As part of this, four UK-based coal projects have been selected to apply for money from a fund of €180 million. This money must be committed by the end of 2010, else the European Commission will invest it in renewables and efficiency projects. This is in addition to the 300 million EU-ETS allowances discussed above.

Overview
- The three main methods of CO_2 capture from power plants are called pre-combustion, oxyfuel-combustion, and post-combustion.
- The UK is looking to store captured CO_2 in geological formations underneath the North Sea.
- While there are safety concerns regarding CO_2 pipelines in the UK, there is some industrial experience of handling and transporting CO_2. The HSE and industry are working to ensure regulation leads to safe CO_2 capture and transportation.
- EU legislation on the geological storage of CO_2 has been agreed and is rolling out among Member States.
- The UK plans to fund up to four CCS demonstrations on coal power plants in the UK by 2020.

Endnotes
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The Parliamentary Office of Science and Technology, 7 Millbank, London, SW1P 3JA; Tel: 020 7219 2840; email: post@parliament.uk
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