EI response to HM Treasury - May 2006
Carbon capture and storage: a consultation on barriers to commercial deployment

Introduction

The Energy Institute (EI) is the leading professional membership body and learned society dedicated to the international energy industry. It has a membership of 12,000 individuals and 300 organisations and provides an independent focal point for the energy community, bringing together industry, academia and government. The EI's purpose is to promote the safe, environmentally responsible and efficient supply and use of energy in all its forms and applications. In fulfilling its purpose the EI can address a wide range of topics in detail, from upstream and downstream hydrocarbons and other primary fuels and renewables, through power generation, transmission and distribution to sustainable development, demand side management and energy efficiency.

As a charitable body incorporated by Royal Charter and with membership across the full range of energy sectors, it is not appropriate for the EI to promote specific technologies or options. Instead we seek to assist the policy process by helping clarify the key issues and by improving the evidence base on which decisions will be made. The EI welcomes this consultation on barriers to commercial deployment of carbon capture and storage (CCS), and is pleased to make the following submission. It is structured around the questions posed in the consultation document.

Summary of conclusions

The key barrier to commercial deployment of CCS in the UK and elsewhere can be summarised as uncertainty. Widespread deployment of CCS requires that first-of-kind projects go ahead at an early stage so that the lessons learned can be used to reduce technical risk to an acceptable level for subsequent commercial projects to be developed. The current uncertainties in regulatory and policy frameworks are not ideal for development and could present a barrier to project development if there is not sufficient clarity and certainty to ensure investor confidence.

A full lifecycle analysis of any CCS project and its CO_2 savings should include any CO_2 produced in generating the energy required for transport and storage processes and not captured. Carbon capture plants based on pre-combustion capture generate hydrogen which can then be used to generate electricity, which could be used as part of a hydrogen economy and therefore should also be considered as part of the lifecycle analysis.

In the longer term, hydrogen produced at plant operating carbon capture combined with the use of hybrids powered by decarbonised electricity, could allow significant CO_2 reductions in the transport sector. CCS schemes can also significantly reduce CO_2 emissions from power generation and energy-intensive industry. Decarbonised electricity and hydrogen could also be used to reduce emissions in the building sector.

The true costs of CCS projects cannot be estimated accurately without appropriate experience on real projects. Costs will be subject to changes due to learning, particularly in the early stages of deployment, and can change significantly with fuel prices, and general changes in engineering, procurement and construction costs.

CO_2 transport options are limited to pipeline or ship transport due to the volumes of CO_2 involved. Transport costs will vary between projects depending on many factors, including the volume of CO_2 and the distance between the capture plant and the storage site. It is important to consider whether schemes should be encouraged to develop a more coherent general infrastructure which could be used in the hope of reducing overall costs in the long term.

The UK is home to a skilled community who are suitably qualified and experienced to design and develop CO_2 storage projects successfully and who are likely to welcome the opportunity to extend the working life of the North Sea. If the North Sea fields are decommissioned before CO_2 storage is implemented in the UK Continental Shelf then it is likely that these skills will be lost since workers may move to other areas. It seems likely that there could be skills gaps that should be addressed as a priority to ensure that these do not become a barrier to the development of CCS in the UK.

The legality of most offshore storage options is not clear under international treaties to protect the marine environment. In addition, the development of appropriate regulatory frameworks, environmental legislation and the EU ETS must be reviewed to reduce risk and uncertainty for CCS projects, providing a more stable and predictable environment. The Government's current work in this area is noted and encouraged.

The general public are likely to find CCS acceptable as part of a portfolio of technologies to reduce CO_2 emissions. Particular concerns raised can be best addressed by providing accurate, understandable information explaining the expected environmental impacts of CCS schemes and their potential role within a wider energy policy.

It is possible that significant volumes of new build plant will be designed and built before capture technology has become fully commercial in terms of technical risk and economic viability. Therefore, fossil-fired power plants should be designed and built with retrofit of carbon capture in mind so plant operators will have the option of adding capture if and when the market conditions indicate that this would be favourable.

It is important to choose the right instrument to meet each particular objective. For CCS schemes, this will require a detailed understanding of the different technologies involved at each stage of the scheme as well as appropriate analysis to determine how technology choice might affect the particular objectives of CCS projects for various stakeholders including Government, investors, and project operators. Government should consider mechanisms that provide appropriate long term signals whilst maintaining the flexibility required to ensure development as understanding of the technology and commercial viability of CCS improves.

Key barriers to commercial deployment of CCS

The key barrier to commercial deployment of CCS in the UK and elsewhere can be summarised as uncertainty. Commercial deployment of CCS can be seen as a two-stage process with further development work, including first-of-kind projects, required to facilitate widespread use of CCS in the UK or overseas in the next decade and beyond. Each of these phases has different uncertainties and Government should recognise the key differences between them in developing any strategy to support commercial deployment of CCS in the UK and overseas.

As noted in the consultation document, a number of first-of-kind CCS projects are at various stages of development but there is currently a lack of experience in projects which integrate capture of carbon dioxide (CO_2) at power stations with appropriate storage schemes. Widespread deployment of CCS requires that projects which provide this experience go ahead at an early stage, so that the lessons learned can be used to reduce technical risk to an acceptable level for subsequent commercial projects to be developed.

The current uncertainties in regulatory and policy frameworks are not ideal for the development of first-of-kind CCS projects, so could present a barrier to project development if it is not possible to provide sufficient clarity and certainty to ensure investor confidence. Given the need for development work before widespread deployment, it seems appropriate for the Government to consider specific measures to complement existing frameworks, in particular the EU Emissions Trading Scheme (ETS), in the short term. In the longer term, consistent frameworks will be important to facilitate widespread deployment of CCS. Since elements of these seem likely to require international co-operation and agreement, it is important that they are developed alongside the implementation of first-of-kind projects if the Government wishes to ensure that they do not become a barrier to widespread commercial deployment. The Government's current work in this area is noted and encouraged.

Potential carbon reductions

The CO_2 saving claimed for a CCS project depends on the baseline the project is compared to. For example, it could be argued that policy and other measures will not be enough to avoid the use of fossil fuel reserves for power generation and other applications. In this case, the use of carbon capture at power stations or other point sources would allow at least 85-90% of the CO_2 generated to be captured and removed for safe storage away from the atmosphere. However, it should be noted that the CO_2 saved (or abated) compared to the process without capture will be slightly lower than this since the efficiency penalty associated with the capture process requires that more fuel is burnt to generate the same power (or heat) output. Also, a full lifecycle analysis of the CCS project and its CO_2 savings should include any CO_2 produced in generating the energy required for transport and storage processes and not captured. It is also interesting to note that carbon capture plants based on pre-combustion capture generate hydrogen which is then used to generate electricity. In the longer term, this hydrogen could be used as part of a hydrogen economy. Alongside the use of hybrids powered by decarbonised electricity, this suggests that CCS could allow significant CO_2 reductions in the transport sector as well as in power generation and energy-intensive industry. Decarbonised electricity and hydrogen could also be used to reduce emissions in the building sector.

Since coal-fired power plants generally produce approximately twice as much CO_2 per unit of energy generated than gas-fired plants, the potential for absolute reductions in CO_2 released to the atmosphere is higher for coal than gas. Also, the absolute cost of CO_2 separation (per unit of CO_2 captured) is lower at coal-fired plant than gas-fired plant due to the higher concentration of CO_2 in the waste gas. In general, the variability in potential CO_2 emissions reductions between different technologies seems likely to be insignificant. For example, recent studies by the IEA Greenhouse Gas R&D Programme[1,2,3] have shown similar levels of capture for different technologies and it seems likely that in commercial projects the capture level will be determined by economic factors (i.e. the balance between the incremental cost of capturing more CO_2 compared with the cost associated with releasing that CO_2 to the atmosphere) rather than by technical constraints.

An obvious possible exception to this on a whole lifecycle basis is the use of Enhanced Oil Recovery (EOR) schemes for storage due to the resultant emissions from the use of additional oil recovered. However, it is not obvious how this variability should be assessed since the ratio of additional oil produced to CO_2 stored depends on a number of factors including the particular geology of the field in question and the injection scheme chosen[4]. CO_2 EOR is not the only method available for improving oil recovery so it could be argued that additional oil recovered could have been produced using some other method that would not have involved CO_2 storage of any kind. Also, additional oil is available internationally from many sources including unconventional reserves[5]. Thus, it seems reasonable to suggest that, at least in the short to medium term, the implementation of CO_2 EOR will not significantly increase the volume of oil available for use, but could allow CO_2 storage that would not otherwise have occurred. Finally, it should also be noted that oil consumed in countries with a CO_2 cap (e.g. Annex 1 countries that have ratified the Kyoto Treaty) should not contribute additional emissions to atmosphere if it assumed that the maximum volume of CO_2 emissions permitted by the cap occurs. Thus, in the longer term it seems reasonable to assume that successful climate change mitigation will only be achieved if CO_2 emissions limits are applied globally.

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[1] IEA Greenhouse Gas R&D Programme (2004) *Improvement in Power Generation with Post Combustion Capture of CO_2* Report PH4/33, Nov 2004. www.ieagreen.org.uk

[2] IEA Greenhouse Gas R&D Programme (2003) *Potential for Improvement in Gasification Combined Cycle Power Generation with CO_2 Capture* Report PH4/19, May 2003. www.ieagreen.org.uk

[3] IEA Greenhouse Gas R&D Programme (2005) *Oxy Combustion Processes for CO_2 Capture from Power Plant* Report 2005/9, Jul 2005. www.ieagreen.org.uk

[4] For example, a range of 0.18 to 0.43 tonnes of oil per tonne CO_2 (possibly higher for favourable fields) is used by Marsh, G. (2003) *Carbon Dioxide Capture and Storage – A Win-Win Option?* Future Energy Solutions Report to DTI, Report No. ED01806012, pp 5 of 45

[5] An estimate of carbon in various fossil fuel sources including unconventional reserves of oils and gas was included in the IPCC Third Assessment Report. See Figure 7-5 in IPCC (2001) *Climate Change 2001: Synthesis Report* http://www.ipcc.ch/pub/un/syreng/q1to9.pdf

It seems likely that establishing lifecycle CO_2 estimates to allow accurate comparison between various different CCS technologies will be challenging given the need to consider carefully how CCS schemes could be operated and project-specific variations which could be observed despite the expected lack of variation when technology potential is considered in isolation. In addition to potential variations associated with storage schemes such as those outlined above, various other aspects of CCS schemes require more careful consideration than is initially obvious. For example, although capture technologies seem likely to offer similar maximum CO_2 reductions in terms of considering a single plant in isolation, it is also important to note that power stations operate within a network (often called the grid) which balances supply and demand. Controllable, flexible plants, such as fossil-fired stations, play an important role within the grid providing back-up capacity for intermittent generation and allowing quick response if demand changes unexpectedly. The use of plant fitted with carbon capture, and associated potential variations in operating patterns, could provide CO_2 savings to the network as a whole which would not be identified by considering only a single plant in isolation[6].

This particular example also highlights the difficulty in developing lifecycle CO_2 assessments for other technologies since it clearly implies that the CO_2 saving associated with intermittent sources such as wind should consider the potential requirement for additional back-up capacity and its associated CO_2 emissions and if/how these should be included within a lifecycle CO_2 assessment. Issues such as this are beyond the scope of this consultation. However, it is clear that lifecycle analysis of CO_2 for various technologies should be treated with care and it is vital that studies explain their assumptions and methodologies fully if reasonable comparisons are to be made. It seems likely that the potential CO_2 savings cannot be precisely quantified in comparison to other technologies without a hypothetical baseline energy system scenario to guide the required analysis so that the impact of significant second order effects such as those identified here can be analysed appropriately.

Technology

A wide range of technologies are available or under development for CO_2 capture and a useful review can be found in the Intergovernmental Panel on Climate Change Special Report on CCS[7]. This also includes some indication of predicted costs for various technologies. However, as discussed in the later section addressing costs, it is important to realise that the true costs of CCS projects cannot be estimated accurately without appropriate experience on real projects and that costs will be subject to changes due to learning, particularly in the early stages of deployment, as discussed in the later section on costs. Thus, although capital cost estimates from engineering desk studies, such as those reported by the IEA Greenhouse Gas R&D Programme[8], are useful to give an indicative estimate they should not be seen as more accurate than the claimed +/-30% for IEA studies. Costs also change significantly with fuel prices, due to the additional fuel required in capture plants, and with general changes in engineering, procurement and constructions costs (which have increased significantly recently due to increased global demand).

The technologies closest to commercial deployment are amine scrubbing for post-combustion capture, steam methane reforming for pre-combustion capture using natural gas (as proposed by BP and partners for use at Peterhead power station[9]) and integrated gasification combined cycle (IGCC) for pre-combustion capture using coal. Vendors are already offering these technologies with appropriate commercial guarantees. Although, there is a need to scale-up some elements of plant required for these schemes and gain experience in integrating these technologies within whole schemes there is no need to prove novel technology. Amongst the less proven technologies, oxyfuel firing for pulverised coal is often considered to be more promising than many of the other remaining options being considered.

Post combustion capture with amine scrubbing is probably the most versatile capture technology. It is suitable for use at coal and gas-fired power stations for new-build and retrofit applications and

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[6] Chalmers, H. et. al. (2006) *Initial Evaluation of Carbon Capture Plant Flexibility* Accepted for oral presentation at the 8th International Conference on Greenhouse Gas Control Technologies, www.ghgt8.no

[7] IPCC (2005) *Special Report on Carbon dioxide Capture and Storage* www.ipcc.ch

[8] See references 1-3 above

[9] BP (2005) *BP and Partners Plan Clean Energy Plant in Scotland, Increasing Oil Recovery and Reducing Emissions* http://www.bp.com/genericarticle.do?categoryId=2012968&contentId=7006999

could also be applied to other point sources provided that the other gases in the waste gas stream, particularly some nitrogen oxides and sulphur compounds, can be removed to ensure that the amine system will work effectively. Different pre-combustion technologies are required depending on the fuel used, although the basic premise of plant operation (generating hydrogen to use for power generation and capturing the CO_2 as part of this process) is the same for all plants. Pre-combustion capture may be difficult to retrofit to IGCC plant because various elements of the plant, including the gasifier and gas turbine, require careful matching and integration. Thus, such plants are not well-suited to significant operational changes such as adding CO_2 capture. However, retrofitting capture to existing gas turbine plant, provided the combustion of hydrogen-rich gas instead of natural gas can be accommodated, may be the most convenient retrofit method (although not necessarily intrinsically the most cost effective) and the BP/SSE Peterhead scheme is an example of pre-combustion capture using natural gas. Unlike post combustion plant where additional equipment for the capture process must be fitted on site, for pre-combustion capture the hydrogen-rich gas could be generated at some distance from the plant if required and may also be supplied to a number of small gas turbine or other prime mover units. Another important point when considering the appropriateness of technologies for retrofit is whether the particular plants under consideration provide the necessary conditions to allow technologies to be successfully implemented. This leads to the concept of making new plant 'capture-ready' as discussed in the later costs section.

The literature generally agrees that CO_2 transport options are limited to pipeline or ship transport due to the volumes of CO_2 involved and the IPCC report also discusses development status and costs for these technologies. In general, it seems that CO_2 transport costs will vary between projects depending on many factors, not least the volume of CO_2 to be transported and the distance between the capture plant and the storage site. It is also important to consider whether schemes should establish point-to-point transport from source to sink in isolation or be encouraged to develop towards a coherent general infrastructure which could be used by many projects in the hope of reducing overall costs in the long term. Although CO_2 pipelines are not common in the UK, their use onshore is not new and has been standard practice for decades, for example in the Permian Basin in the USA. The use of offshore pipelines for CO_2 transport is less well developed but is not seen as a technological challenge. An engineering analysis of ship transport of CO_2 from capture schemes has been completed by the IEA Greenhouse Gas R&D Programme[10] and CO_2 ships have been used in a few other applications. However, the technology is still at an early stage of development.

Recent work by the IEA Greenhouse Gas R&D Programme has established cost curves for storage in the European[11] and US context[12] and shows the variability of costs depending on the storage scheme selected and the market conditions applied. The main CO_2 storage technologies applicable to the UK situation are:

- CO_2 EOR combined with CO_2 storage;
- Storage in depleted/disused oil and gas fields;
- Aquifer storage in closed or open structures; and
- Unmineable coal seams (potentially as part of an enhanced coal bed methane project).

Initial estimates from an IEA Greenhouse Gas R&D Programme report are repeated in the recently published Carbon Abatement Technology Strategy[13] and suggest that the use of depleted gas fields and deep saline aquifers could play more significant roles than other storage options, in terms of storage capacity in the longer term.

It is expected that costs could vary significantly between projects, particularly where EOR is involved since project economics will also be sensitive to oil price in these schemes. Onshore EOR with CO_2, usually using CO_2 from natural sources, is a well understood, commercially proven operation. The Weyburn EOR project in Canada is now in its second phase and is also providing

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[10] IEA Greenhouse Gas R&D Programme (2004) *Ship Transport of CO_2* Report PH4/30, Jul 2004. www.ieagreen.org.uk

[11] IEA Greenhouse Gas R&D Programme (2005) *Building the Cost Curves for CO_2 Storage: European Sector* Report PH2005/2, Feb 2005. www.ieagreen.org.uk

[12] IEA Greenhouse Gas R&D Programme (2005) *Building the Cost Curves for CO_2 Storage: North America* Report PH2005/3, Feb 2005. www.ieagreen.org.uk

[13] pp 24 of DTI (2005) *A Strategy for Developing Carbon Abatement Technologies for Fossil Fuel Use* http://www.dti.gov.uk/energy/sources/sustainable/carbon-abatement-tech/techstrategy/page19434.html

useful experience to apply to other CCS projects[14]. There has been significantly less experience with offshore storage projects of all kinds, but the ongoing Sleipner aquifer storage scheme indicates that these are certainly technically possible[15]. A DTI study considering potential demonstration of CO_2 EOR for the UK[16] suggests that the technology for offshore CO_2 EOR is also readily available, although there may be other barriers to commercial deployment.

It seems likely that the different technologies available for capture, transport and storage could be 'mixed and matched' with very few limitations. Particular aspects which require careful consideration are the quality of CO_2 produced by the capture plant and the matching of timescales for capture, transport and storage of CO_2. Initial indications are that the expected impurities in CO_2 produced by capture plants will not cause significant technical difficulties for transport or storage operations or have adverse environmental impacts. However, this is an area where further work is required based on first-of-kind schemes integrating all stages of CCS in single projects. The matching of CO_2 production from capture plants (which may vary considerably depending on the operating pattern of the CO_2 source, for example as a fossil-fired power plant varies its output to match electricity demand) to transport and storage scheme requirements could be challenging and may require the use of interim storage facilities to allow some mismatch to be accommodated. In particular, CO_2 EOR schemes are likely to have particular demand schedules for CO_2 use that must be considered and transport systems may require minimum volumes of CO_2 to be available to maintain stable operation.

Engineering and manufacturing capability

It is important to note that the main, if not only, motivation for developing CCS projects is as a CO_2 mitigation strategy in response to concerns over dangerous climate change that could be caused by greenhouse gas emissions. Thus, in common with other measures designed to mitigate the risk of dangerous climate change, traditional economic analytical techniques such as cost/benefit analysis cannot be meaningfully applied due to the large uncertainties and long timescales involved[17]. However a qualitative discussion of the pros and cons of early adoption of CCS technology in the UK is useful in determining whether Government should provide incentives for commercial deployment and, if so, what their main aim should be.

The UK currently occupies an almost unique position within the international community since it has a window of opportunity to develop first-of-kind CCS schemes that seem likely to meet various other political and economic goals. In particular, it is widely accepted that much of the UK electricity generation capacity needs to be replaced by 2020 so there is an obvious opportunity to implement new technology within this replacement programme. Although there are risks and uncertainties associated with developing first-of-kind projects, if such schemes are supported now plants could be commissioned around 2010. Later investment decisions concerning the rest of the fleet should then be made on a significantly more reliable evidence base since they can take account of lessons learned in these early projects.

Also, the working patterns of the North Sea are currently undergoing significant change as decommissioning of early fields is expected to become a significant activity. This suggests that a number of fields should be at an appropriate stage in their life to make good use of secondary and tertiary recovery methods including CO_2 EOR which may improve the economic case for CCS projects. Equally importantly, it also implies that the UK is home to a skilled community who are suitably qualified and experienced to design and develop CO_2 storage projects successfully and who are likely to welcome the opportunity to extend the working life of the North Sea by supporting these developments. If the North Sea fields are decommissioned before CO_2 storage is implemented in the UK Continental Shelf then it is likely that these skills will be lost since these workers will move to other areas.

It is also important to consider the international aspects associated with early adoption of CCS in the UK. Firstly, the consultation notes that 'As an international leader on climate change, the UK

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[14] See www.ptrc.ca for details of Phase I and Phase II results and activities
[15] See http://www.iku.sintef.no/projects/IK23430000/
[16] DTI (2004) *Implementing a Demonstration of Enhanced Oil Recovery Using Carbon Dioxide* http://www.dti.gov.uk/files/file19119.pdf
[17] Stern Review (2006) *Discussion Paper: What is the Economics of Climate Change?* http://www.treasury.gov.uk/media/213/42/What_is_the_Economics_of_Climate_Change.pdf

Government is determined to remain at the forefront of developments'[18]. Early implementation of CCS within the UK is one option for Government to demonstrate this commitment. If appropriate first-of-kind projects can be developed to evaluate both technical and commercial viability of CCS schemes this should allow international negotiations to use the evidence gathered to consider appropriate use of the technology within the relevant policy and regulatory frameworks. Also, the need to reduce CO_2 emissions in response to concerns about the potential for dangerous climate change is clearly a global issue. Thus, technologies developed to tackle CO_2 emissions have potentially huge overseas markets[19] that could provide significant revenues in exported technologies and intellectual property rights.

The UK has seen a decline in engineering training across disciplines in recent years. Thus, it seems likely that there could be skills gaps that should be addressed as a priority to ensure that these do not become a barrier to the development of CCS in the UK. As well as the need to retain appropriate expertise for storage schemes discussed above, there is a need to support training of engineers who can develop other aspects of CCS projects and work effectively within projects which will require the integration of skills from a broad range of engineering and scientific disciplines. A better evidence base for assessing skills gaps should be developed as a matter of urgency and it seems likely that appropriate training schemes will be required, in industry and universities, and so should be developed and supported as soon as possible. The EI is well placed to undertake this work with appropriate Government support given the skills/training work already completed and the strong industry and educational networks it has. The sharing of best practice at a national and international level is also crucial and the EI welcomes the announcement of agreements between the UK Government and other countries to facilitate this.

Regulation, liability and public acceptance

Although there is some scope to develop CCS schemes within the current regulatory frameworks there are obvious limitations. It is widely recognised that the legality of most offshore storage options is not clear under international treaties to protect the marine environment. This could limit the use of CCS within the UK, particularly for projects which do not have easy access to fields suitable for EOR (including those better placed for transport to the Southern North Sea rather than the Northern North Sea).

The development of appropriate regulatory frameworks to reduce risk and uncertainty for onshore aspects of CCS projects should also be carefully considered. For example, careful consideration may be required in determining if and how a CO_2 transport infrastructure should be developed. Although this should not be a 'show-stopper' and lessons can be learned from international experience such issues should not be ignored. Environmental legislation affecting power stations also has a significant impact on the potential implementation of CCS in the UK. The EU ETS will be discussed in the later section on economic incentives and policy framework. However, it is also interesting to note that one outcome of the Large Combustion Plant Directive, which is expected to lead to the closure of around 50% of UK coal-fired plant, is that these plants may then be better candidates for retrofitting CO_2 capture. One significant barrier in the economic case for retrofitting CO_2 capture is the lost revenue associated with the extended outage required to fit the capture technology. Where plant have 'opted out', and so are now scheduled to close by 2016 with reduced operating hours from 2008, this barrier will be removed.

Since it is generally assumed that CCS in the UK requires the use of subsea storage schemes in the UK Continental Shelf, the main focus on establishing appropriate regulatory frameworks to protect the environment has been careful consideration of the OSPAR and London Conventions which are designed to protect the marine environment. In considering the potential impacts of CCS on the environment, it is also important to realise that it is likely that the business-as-usual scenario will also have some negative impacts on the environment, such as ocean acidification[20], as a result of continued CO_2 emissions at levels significantly above pre-industrial. Thus, the key issue for regulators is how the predicted impact of CCS schemes, with their associated risks and

[18] Para 1.25 of the consultation document

[19] Scottish Enterprise (2005) *Carbon Capture and Storage Market Opportunities 2005*
http://www.scottish-enterprise.com/publications/carbon-capture-and-storage-market-opportunities-2005.pdf

[20] Turley, C. et. al. *Reviewing the Impact of Increased Atmospheric CO_2 on Oceanic pH and the Marine Ecosystem* Ch. 8 in "Avoiding Dangerous Climate Change", Ed. Schellnhuber, H.J., Cambridge University Press, 20.
http://www.defra.gov.uk/environment/climatechange/internat/dangerous-cc.htm

uncertainties, compare with the other options. As well as ensuring due consideration is given to the marine environment, appropriate frameworks are required for the onshore aspects of CCS schemes, including the need to establish appropriate legislation to ensure the safety of workers and the general public from the potential dangers of a CO_2 release in enclosed areas where asphyxiation could be possible. Current HSE regulations for CO_2 used in other UK industries such as brewing should be sufficient to address these hazards. Any additional regulation considered for CCS schemes should be based on international experience of CO_2 EOR and storage to ensure that appropriate measures are identified and implemented.

The long term liability issues associated with CCS schemes are related to the integrity of storage sites and potential for CO_2 leakage long after CO_2 has been injected. These are often seen as some of the most significant barriers to developing successful CCS schemes. A recent DTI technology status report[21] on monitoring techniques for geological storage of CO_2 suggests that properly designed storage schemes should not require monitoring after the site has been abandoned in accordance with appropriate procedures to ensure that the scheme should not cause environmental damage. Given the length of long term liability associated with CO_2 storage it seems likely that it will be most appropriate for Government or an appropriate regulatory body to manage long term liability of CO_2 storage sites rather than the project operators. For example, it has been suggested that a Carbon Capture and Storage Authority could be established to oversee the industry and take on this role[22]. Short term liability issues are generally considered to be less serious and it seems likely that the costs associated with these should be identified and, where appropriate, mitigated as part of normal project risk management procedures.

A detailed understanding of likely public reaction to CCS is yet to be fully developed. However, early work carried out by the Tyndall Centre for Climate Change Research[23] suggests that the general public are likely to find CCS acceptable as part of a portfolio of technologies to reduce CO_2 emissions. Particular concerns raised are the potential impact of leaks from the storage site and the suggestion that using CCS is not solving the 'real problem' since the technology does not avoid the use of fossil fuels. It seems likely that these concerns can be best addressed by providing accurate, understandable information explaining the expected environmental impacts of CCS schemes and their potential role within a wider energy policy which encourages the development of other energy technologies while acknowledging the value of fossil fuels as part of the mix in the short to medium term. The EI would be happy to assist in developing such material.

Cost

The costs associated with CCS schemes can be categorised following a similar methodology to other large engineering projects and include capital expenditure, fixed and variable operating costs. Absolute costs and the relative importance of different cost categories within any given scheme will vary depending on the technology used. A useful review of the literature, as well as the limitations of current knowledge is given in the IPCC Special Report on CCS published in 2005. It notes that:

'The literature reports a fairly wide range of costs for employing CCS systems with fossil-fired power production and various industrial processes. The range spanned by these cost estimates is driven primarily by site-specific considerations such as the technology characteristics of the power plant or industrial facility, the specific characteristics of the storage site, and the required transportation distance of carbon dioxide (CO_2). In addition, estimates of the future performance of components of the capture, transport, storage, measurement and monitoring systems are uncertain. The literature reflects a widely held belief that the cost of building and operating CO_2 capture systems will fall over time as a result of technological advances.'[24]

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[21] Pearce, J. et. al. (2005) *Technology Status Review – Monitoring Technologies for the Geological Storage of CO_2* DTI Cleaner Fossil Fuels Programme, Report No. COAL R285 DTI/Pub URN 05/1033 http://www.dti.gov.uk/energy/coal/cfft/cct/pub/r285.shtml

[22] For further discussion of this concept see Vol. 1, pp48/9 of the House of Commons Science and Technology Committee 2006 report *Meeting UK Energy and Climate Change Needs: The Role of Carbon Capture and Storage* http://www.publications.parliament.uk/pa/cm200506/cmselect/cmsctech/578/578i.pdf

[23] Shackley, S. et. al. (2005) The public perception of carbon dioxide capture and storage in the UK: results from focus groups and a survey. *Climate Policy 4: 377-398*

[24] pp8-3 of ref 6 (2005 IPCC Special Report on CCS)

The general expectation that costs for CCS projects will fall is based on a range of assumptions including comparison with the introduction of other new technologies and the expectation that competitive markets will drive technological progress as well as reducing costs as vendors compete for work. The difficulty of modelling technological progress within economic models is well known and it is not yet clear if and how expected cost reductions in CCS technologies can be accurately predicted. Some initial work has now been undertaken[25] but it is seems likely that practical experience with integrated CCS projects will be required before CCS costs can be discussed with more certainty.

Clearly, the relative price of coal and gas, as well as the cost of emitting CO_2 will affect the costs of CCS schemes and will thus affect their profitability. A useful illustration of the preferred technology for various gas and carbon prices was given in the 2005 BCURA Coal Science lecture[26]. In general, high gas prices improve the profitability of coal-fired plant and high carbon prices make the use of carbon capture a more attractive option. One key challenge for investors is developing robust portfolios of plant that minimise the risk associated with investing in particular technologies when profitability depends significantly on unknowns such as fuel and carbon price. Since this is a complex problem involving many variables which are difficult to predict, it is important that appropriate sensitivity analysis is carried out in considering the economics of CCS schemes and that the impacts of different assumptions are understood in interpreting results reported by studies, particularly when results from different studies are compared.

CO_2 EOR as part of a CCS scheme is one of many options available to improve oil recovery in the UK Continental Shelf and elsewhere. Since CO_2 EOR increases the complexity of storage schemes compared to other options, it is likely that it could increase the initial capital cost of a CCS project. However, revenue associated with additional oil recovered would be expected to more than counteract this effect for a commercial scheme. In general, CO_2 is a suitable gas for EOR and could be used within the UK Continental Shelf. However, the most suitable schemes for improved oil recovery (IOR) at any given field will be determined by a number of factors, including many that are specific to that field including particular geological aspects, previous operations and the availability of other gases or water for IOR schemes. Thus, although it can be generally assumed that CO_2 EOR would normally be part of a secondary or tertiary IOR scheme, it is difficult to provide more specific analysis of the likely applicability of CO_2 EOR without appropriate detailed work to assess the suitability of the technique for various candidate fields. It also seems likely that the forecast (and actual) cost of oil will have a significant role to play in determining which IOR projects, if any, are viable since any projects requiring major investments will not be undertaken unless operators are reasonably certain that the additional oil recovered should provide an appropriate profit to justify that investment and its associated risk.

The concept of capture-ready plant is also inherently linked to the risk associated with investment decisions for projects requiring significant capital investment. As discussed above, various changes in market conditions including fuel and carbon price can alter which power plants are most economically attractive. In particular, it is currently unclear what the future cost of emitting CO_2 might be under future phases of EU ETS. Also, there is still significant work to be done in developing first-of-kind CCS projects and integrating all the major components of capture, storage and transport so that technical lessons can be learned and overall costs reduced. Although a few projects are required to do this, it is possible that significant volumes of new build plant will be designed and built before capture technology has become fully commercial in terms of technical risk and economic viability. However, power plants have typical lifetimes of at least 30 years and it seems likely that CCS schemes could become the norm well before current new build reaches the end of its operating life. Thus, ensuring that fossil-fired power plants that are designed and built while first-of-kind projects are implemented are suitable for retrofit of carbon capture is likely to be crucial in ensuring that 'carbon lock-in' due to CO_2 emissions from these plants is avoided, particularly in countries where significant capacity of fossil-fired, and especially coal-fired, generation is expected to remain in the energy mix for the foreseeable future. For UK utilities, a key aim of capture ready plant design would be to ensure that the risk associated with the current uncertainties surrounding CCS development and the framework it will operate are mitigated since

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[25] Riahi, K. et. al. (2004) Technological learning for carbon capture and sequestration technologies *Energy Economics 26: 539-564*

[26] See slide 64 of the 54 the BCURA Robens Coal Science Lecture, 10 October 2005 at The Royal Institution, given by Dr A. Jones http://www.bcura.org/csl05.pdf

plant operators will have the option of adding capture if and when the market conditions indicate that this would be favourable.

Capture-ready power plants should be designed so that the whole lifecycle costs of the power plant are minimised. During the early stages of plant design potential capture schemes should be explored so that relatively minor changes in plant design can be identified that would significantly reduce costs of adding capture later – and certainly ensure that it would not be impossible for an appropriate retrofit to be carried out a later date. For example, capture-ready plant should ensure that enough space is left to add capture equipment and the site location is suitable for CO_2 transport to safe geological storage. It is likely that the additional cost associated with changes such as these will be minimal but such considerations are important in allowing retrofit of capture equipment to be feasible. Other more significant changes might also be made. In all cases the decision to change plant design in the light of the potential later addition of capture should be justified by appropriate analysis considering the whole lifecycle costs of the scheme under various scenarios for adding capture. Thorough analysis of the costs associated with capture-ready plants is not yet readily available, but an IEA study in response to the 2005 G8 Gleneagles Communiqué[27] should help to fill this gap.

The profitability of CCS for businesses in the electricity sector and elsewhere is currently unclear. Investors need to consider a number of factors including the cost of emitting CO_2 over the whole plant lifetime, likely developments in CCS technology as lessons are learned from first-of-kind schemes and expected cost reductions resulting from market competition and other actions. It is also important to remember that CCS projects will require a viable business case for all project participants. Given the uncertainty over CCS costs and the need to consider the details of particular aspects of CCS schemes as well as overall project viability it is difficult to quantify the current shortfall in considering the profitability of CCS. The evidence gathered by the House of Commons Science and Technology Committee[28] is a useful resource in identifying the position of many of the major players in the UK. Overall, it seems likely that the most important action required for CCS to become a profitable option for businesses is for uncertainties to be reduced as much as possible. In particular, the development of first-of-kind schemes as soon as possible so that technical risks can be better understood is crucial. Also, careful consideration of an appropriate policy framework to provide appropriate value for CO_2 savings associated with CCS schemes is needed so that investors can be given appropriate assurances and projects are not required to carry unacceptable political risk.

Economic incentives and policy framework

The current policy framework, including the recently introduced EU ETS, has stimulated interest in technology for reducing CO_2 emissions, including first-of-kind schemes to demonstrate fully integrated CCS[29]. However, there is a general need to develop the current policy and regulatory environment so that it is more stable and predictable. Investments in UK power generating capacity will be required within the next decade and this will require commercial decisions to be taken which consider a range of risky and capital intensive projects, including some options which include CCS. In particular, the current design of EU ETS does not provide CO_2 price signals over the tens of years required to inform investment decisions so it is crucial that Government explores appropriate methods to provide price stability and certainty.

A number of issues could be considered with regard to CCS when policy mechanisms to reduce CO_2 emissions are discussed. According to the consultation document, UK environmental policy making should take account of a number of principles including the use of an appropriate evidence base and the consideration of a long term strategy[30]. A key requirement in establishing the evidence base required for long term decisions on CCS implementation is that first-of-kind projects are able to proceed to commissioning by around 2010. Although there are obvious risks

[27] (2005) *The Gleneagles Communiqué* and *Gleneagles Plan of Action* http://www.fco.gov.uk/Files/kfile/PostG8_Gleneagles_Communique,0.pdf

[28] House of Commons Science and Technology Committee (2006) *Meeting UK Energy and Climate Change Needs: The Role of Carbon Capture and Storage* Vol. 2: Oral and Written Evidence. http://www.publications.parliament.uk/pa/cm200506/cmselect/cmsctech/578/578ii.pdf

[29] For example, ref 8 and also RWE (2006) *RWE npower announces feasibility study for 1000MW 'Clean Coal' power station at Tilbury in Essex* http://www.rwe.com/generator.aspx/templateId=renderPage/id=76864?pmid=4001088

[30] Box on pp 12 of consultation document

associated with supporting these early projects, the lessons learned by this initial deployment should significantly reduce uncertainties, providing the evidence base required to make an accurate judgement of the potential for widespread commercial deployment of CCS in the next decade and beyond.

Environmental policy making should also ensure that intervention occurs at the 'appropriate level' and that 'Action to protect the environment [takes] account of wider economic and social objectives'[31]. Although, the consultation asks respondents to consider 'policy mechanisms to reduce CO_2 emissions in the UK economy', the development and implementation of CCS is clearly an international issue. Thus, UK action on CCS could have an important role to play in developing international understanding of the technology and hence potential widespread deployment worldwide. Implementing CCS in the UK could also have significant benefits for UK plc and, in particular, communities who currently rely on the UK offshore industry. Although the potential effects of CCS implementation in these areas are difficult to quantify, they are important and are linked with the retention of appropriate skills within the UK to allow successful deployment of CCS.

Finally, it is important to remember the need to choose the 'right instrument….to meet each particular objective'[32]. For CCS schemes, this will require a detailed understanding of the different technologies involved at each stage of the scheme as well as appropriate analysis to determine how technology choice might affect the particular objectives of CCS projects for various stakeholders including investors, project operators and Government. The particular objectives identified as priorities by Government will determine which instruments are most appropriate and hence if and how particular mechanisms are designed to support particular technologies or elements of CCS schemes. Although it is not clear exactly which mechanisms should be best to support CCS development and deployment in the UK, it seems likely that measures based on abated CO_2 (with a carefully chosen baseline) may be most appropriate since it is generally assumed that first-of-kind projects should demonstrate technology that works. One appropriate method for providing this support could be Government underwriting of carbon price, complimenting the EU ETS rather than competing against it. Also, CCS schemes require significant capital investment due to the capacities involved so they are an obvious candidate for capital allowances. More generally, it is clear that the deployment of CCS in the UK (and elsewhere) requires appropriate regulatory and policy frameworks to reduce risks to acceptable levels for investor confidence. Thus, Government should consider mechanisms that provide appropriate long term signals whilst maintaining the flexibility required to ensure that these frameworks can develop as understanding of the technology and commercial viability of CCS improves. In addition, rapid development of first-of-kind projects could be critical to facilitate widespread commercial deployment of CCS so Government should consider whether specific measures to support these schemes may be appropriate while more permanent frameworks are developed.

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[31] Box on pp 12 of consultation document
[32] ibid