An integrated assessment of Carbon dioxide capture and storage in the UK

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Abstract

Geological carbon dioxide storage (CCS) has the potential to make a significant contribution to the decarbonisation of the UK. Amid concerns over maintaining security, and hence diversity, of supply, CCS could allow the continued use of coal, oil and gas whilst avoiding the CO_2 emissions currently associated with fossil fuel use. This project has explored some of the geological, environmental, technical, economic and social implications of this technology. The UK is well placed to exploit CCS with a large offshore storage capacity, both in disused oil and gas fields and saline aquifers. This capacity should be sufficient to store CO_2 from the power sector (at current levels) for a least one century, using well understood and therefore likely to be lower-risk, depleted hydrocarbon fields and contained parts of aquifers. It is very difficult to produce reliable estimates of the (potentially much larger) storage capacity of the less well understood geological reservoirs such as non-confined parts of aquifers. With the majority of its large coal fired power stations due to be retired during the next 15 to 20 years, the UK is at a natural decision point with respect to the future of power generation from coal; the existence of both national reserves and the infrastructure for receiving imported coal makes clean coal technology a realistic option. The notion of CCS as a 'bridging' or 'stop-gap' technology (i.e. whilst we develop 'genuinely' sustainable renewable energy technologies) needs to be examined somewhat critically, especially given the scale of global coal reserves. If CCS plant is built, then it is likely that technological innovation will bring down the costs of CO_2 capture, such that it could become increasingly attractive. As with any capital-intensive option, there is a danger of becoming 'locked-in' to a CCS system. The costs of CCS in our model for UK power stations in the East Midlands and Yorkshire to reservoirs in the North Sea are between £25 and £60 per tonne of CO_2 captured, transported and stored. This is between about 2 and 4 times the current traded price of a tonne of CO_2 in the EU Emissions Trading Scheme. In addition to the technical and economic requirements of the CCS technology, it should also be socially and environmentally acceptable. Our research has shown that, given an acceptance of the severity and urgency of addressing climate change, CCS is viewed favourably by members of the public, provided it is adopted within a portfolio of other measures. The most commonly voiced concern from the public is that of leakage and this remains perhaps the greatest uncertainty with CCS. It is not possible to make general statements concerning storage security; assessments must be site specific. The impacts of any potential leakage are also somewhat uncertain but should be balanced against the deleterious effects of increased acidification in the oceans due to uptake of elevated atmospheric CO_2 that have already been observed. Provided adequate long term monitoring can be ensured, any leakage of CO_2 from a storage site is likely to have minimal localised impacts as long as leaks are rapidly repaired. A regulatory framework for CCS will need to include risk assessment of potential environmental and health and safety impacts, accounting and monitoring and liability for the long term. In summary, although there remain uncertainties to be resolved through research and demonstration projects, our assessment demonstrates that CCS holds great potential for significant cuts in CO_2 emissions as we develop long term alternatives to fossil fuel use. CCS can contribute to reducing emissions of CO_2 into the atmosphere in the near term (i.e. peak-shaving the future atmospheric concentration of CO_2), with the potential to continue to deliver significant CO_2 reductions over the long term.

Keywords: public perception, legal, storage capacity, techno-economics

Introduction

This paper aims to provide a brief overview of some of the key findings from a three year collaborative and integrated assessment of Carbon dioxide capture and storage (CCS) in the UK context, conducted for the Tyndall Centre. More detailed results can be found in the full technical report and a book from the study [1,2]. Detailed reviews of CCS technology in an international context can be found in [3, 4]. This paper presents a summary of the results for the following broad topics: geological storage, risks, legal aspects, technical and economic feasibility, and public acceptability.

Geological Storage of CO_2

The critical first question in assessing CCS is to ask whether there is a strong and solid geological case for the safe and secure long-term storage of CO_2 in depleted oil and gas reservoirs and in saline aquifers. Unless this question can be answered in the affirmative, the case for CCS is greatly weakened. There are sound underlying reasons why secure storage should, in principle, be possible. For example, many oil and gas reservoirs have stored natural gas (sometimes containing significant volumes of CO_2) for thousands to millions of years, whilst natural geological reservoirs of CO_2 are also known which have been there for similarly long periods of time. However, the suitability of each potential geological reservoir needs to be explored on a case-by-case basis because of the high degree of heterogeneity of reservoirs. There are no generic assumptions that can be made regarding the suitability for CO_2 storage at particular sites.

Given that CCS is ‘in principle’ a viable approach, the next question concerns the capacity for storage in geological reservoirs. Our research suggests that the CO_2 storage capacity of the UK’s oil and gas fields is approximately 6.2 Gt, sufficient to store about 35 years worth of CO_2 emissions from UK power stations (at current emission levels). The UK’s oil and gas fields are well understood geologically because of their extensive exploitation and the associated accumulation of scientific data, knowledge and tools (such as reservoir simulation models). Much greater uncertainty is associated with the storage capacity of aquifers, because these structures are much less well characterized scientifically. Previously, very high estimates of the potential capacity of these formations, for the UK as a whole, have been presented. For example, the DTI [5] presents an estimate of almost 250 Gt CO_2 based on earlier calculations by Holloway and Baily [6]. Recent research [7,8] has studied the Southern North Sea basin in detail, including consulting maps and extensive geological data; as a result a more cautious revised estimate of the CO_2 storage capacity of aquifers in the Southern North Sea Basin of approximately 14 Gt CO_2 is presented, this is sufficient to store about 89 years worth of CO_2 emissions from UK power stations (at current emission levels). The key difference between these two estimates lies in assumptions about the fraction of the total pore volume of all potential reservoir formations that would be available for CO_2 storage. This latest figure is still regarded as being only a very rough estimate [7] and does not include, for example, considerations of leakage. There is no widely accepted methodology for calculating the storage capacity of aquifers in the absence of detailed geological data and such detailed data is rarely already available for non-hydrocarbon aquifers, leaving us in a situation of high uncertainty. It is likely that we will only get a better understanding of actual capacity through learning-by-doing, i.e. by initiating CO_2 storage projects and devoting sufficient R&D activity to learning more about reservoir capacities and how reservoirs respond to storage of increasing volumes of CO_2.

Risks and Potential Impacts of Leakage

The key risk with respect to CO_2 storage is that of possible leakage (see [7] for further explanation of potential leakage routes). No generic assumptions about the risks of leakage are possible. Instead, it is necessary to evaluate the risks of leakage on a case-by-case basis. Leakage is important for two reasons. Firstly, it can reduce the effectiveness of meeting the objective of CCS, namely storing CO_2 to ensure that it does not enter the atmosphere thereby contributing to anthropogenic climate change. Secondly, leakage could pose potential health, safety and environmental risks to humans, other organisms and ecosystems.

Health, Safety and Local Environmental Impacts

The risks to human health and safety and to other organisms and ecosystems that might arise from the leakage of CO_2 from off-shore storage reservoirs are described in [7], the general conclusion being that such risks need to be assessed on a case-by-case basis but are by no means ‘show stoppers’. The risks arising from the physical infrastructure associated with the collection, compression and piping of CO_2 on land to the storage facility have been analysed by Det Norsk Veritas (DNV) for the UK Department of Trade and Industry [9] DNV utilised a conventional risk assessment methodology used in the chemical industry, known as HAZOP, to analyse and quantify the risks associated with the operation of a CCS plant and pipeline to transport CO_2 to storage reservoirs under the seabed. Where specific numbers were not available because of a lack of experience, an iterative Delphi process was employed with external experts providing estimates of the relevant numbers. DNV concluded that the risks of explosions and the associated risks to human operatives were equivalent to those arising from other large industrial plant handling compressed gases at low temperature. DNV also noted that the risks could be adequately managed by following best practice guidelines in industries dealing with power plants and high pressure gases.

The Impact of Leakage upon the Effectiveness of CCS

If too much CO_2 leaks out from reservoirs, and / or this leakage occurs too quickly, then CCS could become pointless as a mitigation option. A critical question is what is the appropriate time frame for assessing the permanence of CO_2 storage. The answer to this question depends in part upon how far into the future present day society feels that it should shoulder responsibility. A typical time period quoted is 1000 years, implying a leakage rate of 0.1%. This time period fits quite well into our understanding of the climate system, since we anticipate that global CO_2 emissions will peak well before the year 3000 under all scenarios, allowing the slow move towards equilibrium between the major carbon sinks. The significance of leakage from CO_2 storage has to be investigated on a global scale and acceptable leakage rates will depend upon the extent to which CCS is deployed globally. In its Special Report [4], the IPCC states that: “the political process will decide the value of temporary storage and the allocation of responsibility for stored CO_2”. We believe that this is appropriate, given the role of moral and political values in considering the acceptability of leakage.

Legal aspects of Geological CO_2 Storage

Nearly all of the UK’s identified CO_2 storage potential is offshore. Amendment of the London Convention and OSPAR treaties may be necessary before CO_2 storage in saline aquifers can take place offshore and this could take years, especially as little is known about the impact of leaks of CO_2 into the marine environment. Provisions of the OSPAR Convention may appear anomalous when interpreted for CCS; for example, if CO_2 is sourced from onshore facilities and injected beneath the sea bed from a ship, an offshore installation or other structure in the maritime area (excluding pipelines) for the purposes of mitigating climate change, it would breach the Convention. Yet, if the injection of CO_2 occurs from offshore installations produced on the same or other offshore installations (e.g. together with natural gas), it would not require modification of the

Convention, even though the purpose would once again be climate change mitigation [10]. Clearly, clarification and modification of the legal framework will be necessary before CCS can become an established carbon abatement technology and before companies are likely to initiate major investments in CCS technology.

Technical and Economic Feasibility

There are no technical barriers to CO_2 capture and storage. Each technological step throughout the entire CCS chain is proven and there are major drives to reduce the cost of CO_2 capture. Pilot power stations fitted for CO_2 capture are being constructed and CO_2 storage is already taking place at an industrial scale at the Sleipner CO_2 storage site in the North Sea. Moreover, steps have been taken to implement a full chain project in the UK, namely the Miller Field / Peterhead project led by BP. The commercial attractions of Enhanced Oil Recovery (EOR) at today's oil prices make wider scale deployment in the North Sea oilfields a distinct possibility in the short term. Nonetheless there are several economic impediments to the wide scale deployment of CCS in the UK. The costs of CCS in our techno-economic model for UK power stations in the East Midlands and Yorkshire to reservoirs in the Southern North Sea are between £25 and £60 per tonne of CO_2 captured from PF and IGCC coal power plant, transported and stored [11,12]. This is between 2 and 4.5 times the current traded price of a tonne of CO_2 in the EU Emissions Trading Scheme.

The wholesale electricity market in the UK is very competitive and no operator will be able to remain competitive when deploying CCS unless the correct fiscal incentives are in place. These incentives would have to include a price for the CO_2 saved through utilizing CCS, for example through extension of the current Renewables Obligation into a 'Zero Carbon Obligation' or 'Decarbonised Electricity Certificates' (including CCS, nuclear and renewable energy), or perhaps through a separate 'CO_2 Storage Obligation' put upon electricity suppliers. Some kind of guarantee of long term stability in such a support mechanism would be required that would allow investment in new power plant or retrofits to take place. Ultimately the market penetration of CCS will depend on the relative fuel prices for gas and coal and the way in which any fiscal incentives are distributed between nuclear, renewable and CCS power generation technologies.

Public Acceptability

Research suggests that CCS may be more acceptable to the public than some other low-carbon options, such as nuclear power and higher energy bills (assuming that far-reaching CO_2 reduction targets have to be met). On the other hand, CCS is considerably less attractive to the public than renewable energy and energy efficiency. Two independent surveys and work with Citizen Panels in the UK have confirmed these broad findings, though the surveys differ in the extent to which CCS was perceived positively. In the Tyndall survey [13,14], conducted within the present study in 2003, there was considerably more support for CCS than in a survey by Curry *et al.* [15]. The Tyndall survey also illustrated a stronger contrast between CCS (perceived positively) and nuclear (perceived negatively) than the survey by Curry *et al.* The most striking difference between our survey and that of Curry *et al.* is the high percentage of respondents in the latter who replied 'don't know' (at 50%) when asked about the desirability of using CCS compared to other low- or zero-carbon mitigation options compared to an equivalent question in the Tyndall survey, where only 10% responded that they did not know (and a further 13% were 'neutral', for which there was not an equivalent category in Curry et al. (2004)).

A likely explanation of this difference in the results from the two surveys is that the Tyndall survey provided more information about what CCS is and how it works than the Curry *et al*. survey. A limitation of this type of the survey is that it is not possible to present much technical information about the various carbon mitigation options, e.g. regarding their environmental and other impacts and costs. With such limited survey work it is not possible to make any strong conclusions, especially regarding the comparison of CCS with other CO_2 mitigation options. Public opinion in the UK regarding nuclear power is not static, but appears to be shifting over the past few years towards a more favourable perception. One survey of public perceptions of CCS in the USA found that the respondents actually preferred nuclear power to coal with CCS [16]. Other survey work has demonstrated that many respondents are unaware of the low-carbon status of nuclear power, or of the relatively higher costs of many renewables [15], and it is likely that this additional information would change the respondents' comparison of carbon mitigation options. The work in the Citizen Panels conducted for the present study suggests that, to win public support, CCS has to be presented in the context of global climate change and that there needs to be some recognition of the scale of the problem and the urgency of reducing CO_2 emissions.

Conclusions from the study

This paper has briefly summarized some of the key findings from a collaborative integrated assessment of CCS in the UK context with the following general conclusions.

The UK has sufficient storage capacity to store CO_2 from the power sector (at current levels) for a least half a century, using both well understood, and therefore likely to be lower-risk, depleted hydrocarbon fields and less well characterized and therefore some what higher risk aquifers. It is very difficult to produce reliable estimates of the storage capacity of aquifers and no generic methodologies exist. The greatest uncertainty with respect to CCS is whether the CO_2 will leak from the reservoirs and, if so, how quickly. Leakage does not negate the value of CCS as a carbon mitigation option provided that the leakage rate is very low. Establishing an 'acceptable' leakage rate is highly complicated and depends on a large number of scientific, economic, financial, social, political and even moral factors.

CCS is not yet a cost-effective way of reducing CO_2 emissions (compared to other options, some of which, e.g. renewables, are supported through government incentives). To become cost-effective, it will probably be necessary to provide some additional public subsidy or incentive, at least in the short to medium-term or until such as time as the market value of a tonne of CO_2 abated is considerably higher. The notion of CCS as a 'bridging' or 'stop-gap' technology (i.e. whilst we develop 'genuinely' sustainable renewable energy technologies) needs to be examined somewhat critically, especially given the scale of global coal reserves. If CCS plant is built, then it is likely that technological innovation will bring down the costs of CO_2 capture further, such that it could become increasingly attractive, though of course the costs of renewable energy are also likely to come down.

Also important are the perceived risks associated with different power generation technologies that can offer carbon reduction opportunities. The following risks have to be evaluated in comparing the options: technological, economic & financial, environmental, socio-political, fuel security, reliability, flexibility & reversibility (lock-in).

Some preliminary evidence suggests that CCS may be a more acceptable decarbonisation option to the public than new nuclear fission. Public and stakeholder support for CCS will depend, however, on evidence that Government and industry are also vigorously pursuing energy demand reduction, energy efficiency and renewables. It is the portfolio of options which is critical for public and stakeholder sanction, rather than any single option being privileged.

The legal framework requires clarification and appropriate modification. In particular, the OSPAR Convention needs to be modified if CO_2 storage for the purposes of climate change mitigation is to be clearly permitted under the terms of the Convention. It is unlikely that the private sector will undertake large scale investment in CCS until such time as a clear legal framework is in place.

The extent to which CCS is implemented in the UK is likely to depend on a number of factors, including the degree to which CO_2 emissions reduction is regarded as a priority by government, stakeholders and, possibly, the public – should they choose to engage in the debate. CCS is one of the few technologies which could deliver large CO_2 cuts in a short time-period (i.e. peak-shaving the future atmospheric concentration of CO_2) and this may be perceived as being a necessary response should large scale climate related disasters mobilise political concerns.

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Carbon capture and storage (CCS), or carbon capture and sequestration and carbon control and sequestration, is the process of capturing waste carbon dioxide (CO2), transporting it to a storage site, and depositing it where it will not enter the atmosphere. Usually the CO2 is captured from large point sources, such as a cement factory or biomass power plant, and normally it is stored in an underground geological formation. The aim is to prevent the release of large quantities of CO2 into the atmosphere Figure 18.3. A simplified block diagram for integrated gasification combined cycle with and without carbon dioxide capture and storage. There are different types of commercialized CO2 capture processes, and all of them are based on three major ideas of CO2 separation: precombustion, oxy-combustion, and postcombustion (Kanniche et al., 2010). In precombustion process, the first step is converting the hydrocarbon fuel to syngas stream.Â One of the major challenges of carbon dioxide capture by chemical absorption is that the large volume of gas must be handled. Due to mass transfer limitation, if traditional separation equipment such as packed column are used, the equipment will be exceptionally huge and expensive. CCS is an integrated process involving three stages: Capture of CO2 from power stations and other large industrial sources, Transporting CO2 (usually in pipelines) to a storage site, Permanent storage of CO2 in deep geological features.Â Sign-up below to receive emails with the latest news, information and updates for Carbon Capture and Storage (CCS). E-mail address: Link URLs in this page.Â Assessment of the major hazard potential of carbon dioxide (CO2) (PDF) https://www.hse.gov.uk/carboncapture/assets/docs/major-hazard-potential-carbon-dioxide.pdf. More resources https://www.hse.gov.uk/carboncapture/resources.htm. Modelling releases and dispersion https://www.hse.gov.uk/carboncapture/major-hazard.htm#Modelling. Carbon capture and storage is a suite of technological processes which involve capturing carbon dioxide (CO2) from the gases discarded by industry and transporting and injecting it into geological formations. The major application for carbon capture and storage (CCS) is in reducing CO2 emissions from power generation from fossil fuels, principally coal and gas. However, CCS can also be applied to CO2-intensive industries such as cement, iron and steel, petrochemicals, oil and gas processing and others.Â Storage in the water column is considered to present a high environmental risk and the directive on the geological storage of CO2 bans it within the Union. Mineral storage is currently the subject of research. Developments will be kept under review. Carbon capture and storage projects. Carbon capture and storage is the name given to a combination of technologies that captures and stores carbon dioxide deep underground, preventing its release into the atmosphere. We are helping to develop large-scale commercial projects and have research partnerships with industry and leading academic institutes.Â Quest is a fully integrated CCS facility, designed to capture, transport and store more than a million tonnes of CO2 annually deep underground. In less than five years since its start up, Quest has captured and safely stored five million tonnes of CO2 and at a lower cost than anticipated.