Centre for Climate Change Economics and Policy

Grantham Research Institute on Climate Change and the Environment

RESPONSE TO THE EUROPEAN COMMISSION'S CONSULTATION ON CARBON CAPTURE AND STORAGE (CCS)

July 2013

Centre for Climate Change Economics and Policy

Grantham Research Institute on Climate Change and the Environment

In collaboration with The Grantham Institute for Climate Change and Imperial College London

Grantham Institute for Climate Change
An institute of Imperial College London

Imperial College London

The Grantham Foundation for the Protection of the Environment

Global Green Growth Institute

ESRC Economic & Social Research Council

University of Leeds

LSE The London School of Economics and Political Science

The Centre for Climate Change Economics and Policy (CCCEP) was established in 2008 to advance public and private action on climate change through rigorous, innovative research. The Centre is hosted jointly by the University of Leeds and the London School of Economics and Political Science. It is funded by the UK Economic and Social Research Council and Munich Re. More information about the Centre for Climate Change Economics and Policy can be found at: http://www.cccep.ac.uk

The Grantham Research Institute on Climate Change and the Environment was established in 2008 at the London School of Economics and Political Science. The Institute brings together international expertise on economics, as well as finance, geography, the environment, international development and political economy to establish a world-leading centre for policy-relevant research, teaching and training in climate change and the environment. It is funded by the Grantham Foundation for the Protection of the Environment, which also funds the Grantham Institute for Climate Change at Imperial College London. More information about the Grantham Research Institute can be found at: http://www.lse.ac.uk/grantham/

The Grantham Institute for Climate Change at Imperial College London is committed to driving research on climate change, and translating it into real world impact. Established in February 2007 with a £12.8 million donation over 10 years from the Grantham Foundation for the Protection of the Environment, the Institute's researchers are developing both the fundamental scientific understanding of climate change, and the mitigation and adaptation responses to it. The research, policy and outreach work that the Institute carries out is based on, and backed up by, the world leading research by academic staff at Imperial College. More information about the Grantham Institute can be found at: http://www.imperial.ac.uk/climatechange

Acknowledgements: Samuela Bassi, Alina Averchenkova and Samuel Fankhauser have taken primary responsibility for this submission, in collaboration with Niall Mac Dowell and Iain Macdonald of Imperial College London and Chris Duffy, Cameron Hepburn, Ioanna Sikiaridi, Bob Ward and Dimitri Zenghelis of the Grantham Research Institute on Climate Change and the Environment at the London School of Economics and Political Science. Financial support from the UK Economic and Social Research Council (ESRC), as well as the Grantham Foundation for the Protection of the Environment is gratefully acknowledged.

This policy paper is intended to inform decision-makers in the public, private and third sectors. It has been reviewed by at least two internal referees before publication. The views expressed in this paper represent those of the author(s) and do not necessarily represent those of the host institutions or funders.

Overview

We welcome this consultation on the Future of Carbon Capture and Storage (CCS) in Europe launched by the European Commission in March 2013 (COM(2013) 180 Final). With this response we hope to contribute information and analysis relevant to the following questions outlined in the consultation:

Q3: Should the Commission propose other means of support or consider other policy measures to pave the road towards early deployment?

Q4: Should energy utilities be required to install CCS-ready equipment for all new investments in order to facilitate the necessary CCS retrofit?

Q6: What are the main obstacles to ensuring sufficient demonstration of CCS in the European Union?

Question 6 is discussed in Section 2 of this document, while question 3 and 4 are dealt with in Section 3 and 4 respectively. A summary of our key recommendations is provided in Section 5.

Evidence was collated from the recent literature and from conversations with experts from Imperial College London and the London School of Economics and Political Science.

Overall, we conclude that there is a clear environmental and economic case for investing in CCS development today. The viability of deploying CCS at scale depends mostly on addressing a number of economic and institutional issues, related to costs, liabilities, as well as building confidence amongst investors and the general public. More coherent and ambitious policy measures are needed to ensure that the most cost-effective technologies are developed, both for power plants and for industrial applications, and throughout all the stages of the CCS chain, from capture to storage. Besides providing additional public and private funding, it will be essential to set clearer CCS policy objectives, including clarifying the liability regime and network infrastructure plans.

The Grantham Research Institute on Climate Change and the Environment at the London School of Economics and Political Science, in collaboration with the Grantham Institute for Climate Change at Imperial College, is undertaking a full analysis of the challenges the European Union faces to meet the need for significant CCS deployment by the 2030s, providing scientific insights and policy recommendations. The policy brief is expected to be published by the end of 2013.

1 Introduction

With carbon dioxide emissions concentrations now past 400 ppm, the time to keep temperature rise below 2°C is narrowing. Modelling scenarios for a future energy mix that is compatible with climate change objectives include a rate of CCS penetration that ranges from 7 to 50 per cent of total electricity generation by 2050 (see UKERC (2013) for the UK, European Commission (2011) for the European Union, and IEA (2012a) for worldwide estimates). Failure to develop CCS will increase the capital costs of reducing power sector emissions (to level consistent with a maximum 2°C rise in average global temperatures) by 40 per cent (IEA, 2012a).

The main elements of CCS technology – capture, transportation and storage – have already been developed and are being applied in several industrial sectors. Capture technologies are at an advanced stage of industrial development. Carbon dioxide is already being transported, via pipelines, ship and road tanker, primarily for use in the food industry or for oil and gas recovery. In some cases it is being transported in relatively large amounts. For example, while not strictly classified as CCS activities, enhanced oil recovery (EOR) projects in the Permian Basin in Texas yearly process, transport and re-inject around 23 million tonnes of recycled carbon dioxide[1]. As for storage, four large-scale CCS projects have carried out sufficient monitoring to provide confidence that injected carbon dioxide will be permanently retained. Collectively they have stored about 50 million tonnes of carbon dioxide to date (IEA, 2013)

Worldwide, more than 20 CCS demonstration projects are operating successfully, of which two are in Europe (Norway). Most have industrial applications, such as oil and gas processing or chemical production, which capture carbon dioxide for commercial reasons. Eight of these have the full CCS chain (from capture to storage), five of which are made economically feasible through EOR (GCCSI, 2012). A further nine projects are currently under construction and should be operational by 2016 (IEA, 2013).

However, while CCS technology is already reasonably well developed, applying it on a larger scale and integrating it into power plants and heavy emitting industries remains a substantial challenge. Furthermore the storage of huge quantities of carbon dioxide underground raises new issues of liability and risk.

It is therefore crucial to understand where the key obstacles to CCS development lie, and how policy can help to speed up the deployment of CCS at large scale. These issues are discussed in the sections 2 and 3 respectively.

2 What are the main obstacles to ensuring sufficient demonstration of carbon capture and storage in the European Union?

A number of obstacles currently hamper the scaling up of carbon capture and storage (CCS). These are mostly associated to economic costs of CCS and related research and development (R&D), liability issues associated with storage, policy uncertainty and public and political perception. These are described in more detail below.

Costs and R&D. A fundamental barrier to CCS deployment is cost. Carbon dioxide capture, in particular, is the most expensive phase. Capture costs include not only the

[1] http://www.netl.doe.gov/publications/proceedings/04/carbon-seq/017.pdf

capital costs of equipment, but also a range of running costs, in particular for the energy required by the separation process (leading to efficiency losses) and, to a lesser extent, for solvents and additional operations and maintenance costs. Costs vary across the different capture technologies, such as post-combustion, oxyfuel or integrated gasification combined cycle. However, regardless of the process, it is the capture facilities and the additional energy requirements that have the largest impact on cost (GCSSI, 2012).

The cost per tonne of carbon dioxide captured tends to be lower for coal-CSS than for gas-CCS. As noted in the European Commission's Consultative Communication, the IEA (2012b) estimated that the cost of carbon dioxide capture from power stations can be in the order of €40/tonne of carbon dioxide captured for coal plants and €80/tonne carbon dioxide for gas plants, since the carbon dioxide intensity of gas power plants (i.e. the amount of carbon dioxide emitted per kWh) is almost half that of coal plants. However, the cost per 'clean' kWh is likely to be less for gas-CCS, depending on fuel costs and the relative economics of coal and gas (see for example Popa et al., 2011).

As for carbon dioxide storage, research is ongoing to identify the most suitable locations, and significant opportunities appear to be available (for example, in the North Sea). For instance, in the UK, storage capacity in oil and gas fields is considered in the range of 7.4-9.9 Gigatonnes (Gt) of carbon dioxide, while storage in saline fields could be around 6.3-62.7 Gt (Senior CCS Consulting Ltd, 2010). Costs can vary significantly, likely from €1 to €20 per tonne of carbon dioxide (ZEP, 2011), but are significantly lower than for capture. Nevertheless, there is significant uncertainty attached to current storage capacity estimates, especially of saline aquifers formations. There is also uncertainty as to who will operate such storage sites and how they will be managed. The implications of transporting and storing carbon dioxide across countries are also not fully understood.

As for network and transportation, the technology required is not dissimilar to that used for natural gas supply, but large-scale planning and investment will be needed at the member state and European level. Typical transport costs for an onshore pipeline can range from around €1.5 to €5 per tonne of carbon dioxide, depending on volume transported and the distance. Offshore pipelines are more expensive, with costs ranging from €3.5 to €9.5 per tonne of carbon dioxide. For ships, cost can be between €11 and €16 per tonne of carbon dioxide (ZEP, 2011).

Overall, costs are generally high in the early stages of a new technology – CCS is no different. Further development and refinement of existing technologies and innovative breakthroughs will be vital to reduce the cost of CCS, but so far the European Union Emission Trading System's (EU ETS) carbon price has been too low to stimulate investment in both research and development (R&D) and deployment.

Policy uncertainty and investors' confidence. Currently there are no commercial scale projects from which financiers can gain confidence in the CCS business model (CCS Cost Reduction Taskforce, 2013). Furthermore, there is significant uncertainty about CCS policy objectives and potentially unintended consequences from the interaction of different policies (for example, policy that accelerates CCS deployment could lower the price of carbon allowances in the EU ETS). The level of financial and political support for

CCS in the medium to long term is also unclear. Lack of clarity regarding safety regulations and liability issues, as well as national and international storage and transportation, also adds uncertainty to future investment decisions.

Liability issues. The European Union CCS Directive (2009/31/EC) identifies a number of liabilities for CCS storage providers. These, together with the commercial liabilities associated with a CCS value chain, create risk for the storage providers, which has to be adequately managed. There is, however, large uncertainty with regard to the extent of liability of the CCS installations and carbon dioxide storage in case of accident and/or leakage. Some liabilities are essentially not insurable and would require some form of government guarantee.

Public and political perception. CCS is viewed, in some instances, as being incompatible with key elements of low-carbon economy, as it could lead to potential moral hazard, for example, if used as an excuse for continued investment in unabated fossil fuel infrastructure. It is also associated with centralised energy systems, perceived as inimical to investment in smart grids and interconnection. For instance, this has fed into public perception of CCS and widespread opposition to carbon dioxide transport and storage in Germany (Littlecott et al., 2013). Furthermore, until more is known about the operation of storage facilities, the risk of accidental leakage is likely to be perceived as high by industries and the general public.

3 What policies can help overcoming these obstacles?

Given the obstacles noted above, it will be essential to provide a package of finance and regulation to pull carbon capture and storage (CCS) from demonstration to deployment at scale. This includes a strong price signal to invest in CCS to be delivered through the European Union Emission Trading System (EU ETS), as well as other complimentary policies.

First, for policies to be effective it is crucial to understand where funding support is needed most, and therefore how to prioritise funding resources.

Arguably, funding should target the areas of research, development and deployment (RD&D) that can best deliver reduced costs. These should include next generation technologies that can help improve plant efficiency and reduce the cost of capture, such as post-combustion carbonate looping and chemical looping (Florin & Fennel, 2010).

A prudent approach could be to prioritise support for gas-CCS, as opposed to coal-CCS, because the cost per kWh of 'clean' electricity is likely to be cheaper (although this will also depend on the relative price of coal and gas) and as lifecycle emissions of gas power plants are significantly lower than for coal (CCC, 2013). However, the imperative for energy security means member states with large domestic coal resources, such as Poland, may to want to prioritise coal-CCS.

Biomass Energy with CCS (BECCS) will also be an important area of research as, in addition to generating 'clean' electricity, it is also one of the most mature 'negative emissions technologies' (see for example McGlashan et al., 2012). BECCS should be integrated within the general CCS strategy, and early demonstrations projects should be encouraged at the member state and European level. An important potential constraint is the sustainability of the biomass chain, which needs to be thoroughly investigated, including direct and indirect impacts on land use change.

CCS funding, which so far has mostly focused on power plants, should also address industrial applications more prominently. CCS is currently the only technology available to achieve large scale carbon dioxide emission reductions in the industrial sector. According to the International Energy Agency (IEA, 2013), almost half of the carbon dioxide that would need to be captured via CCS between 2015 and 2050 should be from industrial applications. There can be large emissions reduction gains from applying CCS to large carbon dioxide intensive sectors, like iron and steel, cement and refineries. Some sectors, like ammonia production and natural gas processing, already routinely apply carbon dioxide separation, and in these cases the cost of carbon capture could be half those of power plants (Brown et al., 2012). There is also scope for reducing operating costs in industries, like cement, where waste heat could be recuperated for carbon dioxide capture. For cement, for example, deployment should aim to begin as early as the 2020s and full commercialisation by the 2030s (Brown et al., 2012).

It would also be valuable to encourage the exploration of innovative applications, such as ship-based CCS. This will require installing CCS equipment on board of ships, as well as installing temporary storage and transport facilities in already congested port infrastructures. The technology can be theoretically viable, as proved by a recent project by DNV (Det Norske Veritas), and could help reducing ship carbon dioxide emissions by up to 65 per cent[2]. CCS applications on vessels would also fit well with the European Commission's and the International Maritime Organization's (IMO) efforts to curb greenhouse gas emissions from the shipping sector. The technology, however, is still costly, and large upfront investment will be required to develop a prototype, therefore both public and private support may be needed to fully investigate this option.

As for storage, it will be crucial to move faster to map, qualify and verify carbon dioxide storage opportunities and broaden data collection from sites, such as in the North Sea. It will be sensible to prioritise demonstration on options with the lowest risk, such as storage in depleted gas fields in the UK (Senior CCS Solutions Ltd, 2010). Saline aquifers, especially in the southern North Sea and offshore Scotland could offer large potential at the European level, but there is a long lead time and significant risk to validate them as a specific storage option. This should be investigated further.

Secondly, once the key areas of investment are appropriately identified, funding sources and regulatory mechanisms should be identified and designed.

Market-based measures should arguably be devised and managed at the member state level, as these will largely depend on national circumstances, like energy market structures, domestic energy resources and the interaction with other national policies. There may be scope, however, for European-wide guidance or targets. For instance, Littlecott et al. (2013) suggest the introduction of a European Union CCS milestone

[2] http://www.ship-technology.com/features/featureonboard-carbon-capture-dream-or-reality

target or, should this prove to be to contentious, to adjust the current European Union renewable energy target to allow it to be met through CCS.

There is also an argument for redeploying subsidies currently allocated to fossil fuels to support CCS. These can also make the removal of environmentally harmful subsidies less controversial, as funds will ultimately be re-allocated within the fossil fuel industry.

It would also be helpful to consider the potential to adjust state-aid rules affecting CCS deployment. Ensuring compliance with state-aid rules, for instance, repeatedly came up in discussion during the preparation for the CCS commercialisation competition in the UK, and can have significant impact on investment decisions.

The short term economics of demonstration projects can be improved by re-use of captured carbon dioxide, notably for Enhanced Oil recovery (EOR), which can give some economic pay-back. The prices paid in the United States for carbon dioxide captured (?) are in the range of $15-30 per tonne (Brown et al., 2012). Some research projects are already ongoing (e.g. the EOR Joint Industry project in the North Sea, funded by the Scottish government and some private companies[3]), and similar initiatives could be explored in other sites. The timing for implementing EOR will be important: there is only a certain window of opportunity in the lifetime of an oil field when EOR can be implemented efficiently. Missing the window could imply that certain CCS project could lose their profitability. There are also a number of emerging technologies which could utilise and permanently store carbon dioxide, such as for chemical uses, concrete and plastic production or algae fertilisation (IEA, 2013). Further research in these areas would be much needed to create a business case around new commercial applications of captured carbon dioxide.

Third, regulatory measures should be carefully designed to address the issue of liabilities. This, in turn, can help improve public perception and understanding of CCS risks and potential.

Storage management and property rights should be clarified, as well as the role of governments in storage exploration, appraisal and development. Monitoring should be appropriately regulated, as failure to do so could cause a decline in public trust for storage facilities and operators.

Some liability issues could be addressed with new forms of ‘innovative’ finance, for example where traditional insurance products are modified to transfer, under tightly defined criteria, a subset of the carbon dioxide leakage risk during the injection phase (for a full description see Climate Wise, 2012). Some risks, however, will remain uninsurable. Ultimately, neither insurers not storage operators will be able to bear unlimited liabilities. In these cases, risk sharing with governments will be required (Climate Wise, 2012). The experience developed in the context of nuclear waste can also help defining the responsibility of governments and private companies where liabilities are not limited in size.

In order to improve public perception, it will be also important to clarify and emphasise the role of CCS in balancing an electricity system with increasing intermittent

[3] http://www.sccs.org.uk/expertise/CO2-EORAllEnergy2013.pdf

renewables, in reducing emissions in carbon intensive industrial production, and in leading to 'negative emissions' when applied to biomass. On this latter point, there is evidence that the option of implementing BECCS leading to carbon negative energy has been shown to reduce 'NIMBY' (Not-In-My-Backyard) complaints (for example see Wallquist et al., 2012).

Finally, it should also be taken into account that, ultimately, the implementation of CCS will most likely lead to an increase in the price of electricity and industrial output. The distributional impacts of expected price increases should be carefully assessed and possible flanking measures, for example to offset high energy prices in poor households, should be investigated.

4 Should energy utilities be required to install carbon capture and storage-ready equipment?

Mandating energy utilities to install carbon capture and storage (CCS)-ready equipment would be, in principle, a sensible requirement. This can avoid potential technology lock-in and reduce the cost of future retrofitting. This is also fully acknowledged in the International Energy Agency in its 2013 Technology Roadmap which recommends, inter alia, to develop regulations and incentives that effectively require new-build base-load fossil fuel power plants to be CCS-ready (IEA, 2013).

CCS-ready plants are already a requirement in the UK for plants above 300 MW. The UK Department of Energy and Climate Change (DECC) requires that proposed power plants must demonstrate that there is sufficient space to accommodate capture facilities, that the retrofit is technically feasible, and that there is a feasible transport route to deliver carbon dioxide to an identifiable geological storage location offshore (Florin & Fennel, 2010).

We should be clear about what constitutes 'readiness' to install CCS technology. 'Readiness' typically implies ensuring that the design and location of a plant is able to accommodate the large area needed for CCS equipment. The electricity generation technology is typically unaffected, and so its impact on greenhouse gas emissions. The main changes are mostly around the location of power plant's equipment. The cost of such arrangements are largely site specific, as they will depend for instance on whether the new power plants are located in areas which will (or will not) allow for setting aside a large area for future CCS equipment. Changes in planning consent could be made so that plant location is made conditional on having sufficient space available for CCS.

As for carbon dioxide transport and storage, ensuring that storage capacity is available and that there is infrastructure in place to safely transport and inject carbon dioxide may be more difficult and costly to prove. In this regard, there is currently significant confusion as to what 'CCS-ready' implies in practice; this would need to be clarified in a consistent way across the member states.

5 Conclusions and recommendations

Based on the above considerations, a number of conclusions and recommendations can be drawn.

Given the importance of coal and gas in the current and future energy balance globally, according to most forecasts, carbon capture and storage (CCS) is a critical technology required to achieve greenhouse gas emission reductions at the required scale. A future without CCS may require even more expensive and radical changes to the energy system, including a higher reliance on renewable and nuclear energy.

The viability of deploying CCS at scale depends mostly on addressing a number of economic and institutional issues, related to costs, liabilities, as well as building confidence amongst investors and the general public. Technology itself is currently not the limiting factor. In this context, a range of large demonstration projects will be needed by 2020 in order to prove whether CCS at scale can be commercially viable and to generate required experience to minimise the risk of wrong or late investments.

Government intervention will be required in order to bring CCS deployment to scale. This could range from providing policy certainty in terms of carbon pricing, direct financial support to research and development, managing risk and liability, as well as through regulation (such as requirements for power plants)

Research and investment should be prioritised towards:

- more advanced and less costly second generation capture technologies;
- gas-CCS in member states which are not reliant on domestic coal, as this can be cheaper and lead to lower lifecycle greenhouse gas emissions;
- biomass energy with CCS, to investigate the full potential of negative emissions;
- industrial applications;
- new applications, such as to ship-based CCS.

New sources of finance and new or improved regulation should be explored, including:

- contributions from the fossil fuel sector, for example by re-allocating existing fossil fuel subsidies;
- Enhanced Oil Recovery (EOR) and other commercial uses of carbon dioxide;
- the potential to adjust state-aid rules affecting CCS deployment;
- the development of EU-wide CCS guidance or targets;
- clarification regarding storage liability and insurance options, including the role of government in risk sharing.

Making CCS-ready installations mandatory will be helpful, and potentially at limited costs, although this will likely not be a game changer in terms of CCS development. It will be important to develop a clear and consistent definition for ‘CCS-ready’ across all member states.

Overall, it will be crucial to provide clearer CCS policy objectives, including clarifying the liability regime and network infrastructure plans.

References

Brown, T., Gambhir, A., Florin, N., & Fennel, P., 2012. *Reducing CO2 emissions from heavy industry: a review of technologies and considerations for policy makers.* Grantham Institute for Climate Change Briefing Paper No.7. [pdf] London: Imperial College. Available at: https://workspace.imperial.ac.uk/climatechange/Public/pdfs/Briefing%20Papers/Reducing%20CO2%20emissions%20from%20heavy%20industry_Briefing%20Paper%207.pdf

CCS Cost Reduction Taskforce, 2013*. The potential for reducing the costs of CCS in the UK - Final Report.* [pdf] London: CCS Cost Reduction Taskforce. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/201021/CCS_Cost_Reduction_Taskforce_-_Final_Report_-_May_2013.pdf

Committee on Climate Change (CCC), 2010. *The Fourth Carbon Budget: Reducing emissions through the 1990s.* [pdf] London: CCC.. Available at: http://www.theccc.org.uk/reports/fourth-carbon-budget

Committee on Climate Change (CCC), 2013. *Reducing the UK's carbon footprint and managing competitiveness risks.* [pdf] London: CCC. Available at: http://www.theccc.org.uk/publication/carbon-footprint-and-competitiveness/

European Commission (EC), 2011. *Impact Assessment Accompanying the document Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions - Energy Roadmap 2050.* Commission Staff Working Paper. SEC(2011) 1565/2 Part 1/2. [pdf] Brussels: European Commission. Available at: http://ec.europa.eu/energy/energy2020/roadmap/doc/sec_2011_1565_part1.pdf

Finon, D., 2013. The transition of the electricity system towards decarbonisation: the need for change in the market regime. In *Climate Policy*, Vol.13, NO.S01, S130-S145.

Florin, N. & Fennel, P. 2010. *Carbon capture technology: future fossil fuel use and mitigating climate change.* Institute for Climate Change Briefing Paper No.3. [pdf] London: Imperial College. Available at: https://workspace.imperial.ac.uk/climatechange/Public/pdfs/Briefing%20Papers/Grantham%20Briefing%20paper_Carbon%20Capture%20Technology_November%202010.pdf

Global CCS institute (GCCSI), 2012. *The Global Status of CCS 2012*. [pdf] Canberra (AU): GCSSI. Available at: http://cdn.globalccsinstitute.com/sites/default/files/publications/47936/global-status-ccs-2012.pdf

Her Majesty's Government (HMG), 2011. *The Carbon Plan: Delivering Our Low Carbon Future.* [pdf] London:DECC. Available at: http://www.decc.gov.uk/assets/decc/11/tackling-climate-change/carbon-plan/3702-the-carbonplan-delivering-our-low-carbon-future.pdf

International Energy Agency (IEA), 2012a. *Energy Technology Perspectives (ETP) 2012 - Pathways to a Clean Energy System*. ISBN 978-92-64-17488-7. Paris: IEA.

International Energy Agency (IEA), 2012b. *Cost and Performance of Carbon Dioxide Capture from Power Generation.* Paris: IEA. [pdf] Available at: http://www.iea.org/publications/freepublications/publication/costperf_ccs_powergen.pdf

Littlecott, C., Pearson, I. & Svendsen Skriung, C., 2013. *Moving CCS forward in Europe*. [pdf] ENGO network on CCS. Available at: http://www.e3g.org/images/uploads/ENGO_Network_on_CCS_-_Moving_CCS_forward_in_Europe_final.pdf

McGlashan, N.R., Workman, M.H.W., Caldecott, B. & Shah, N., 2012. *Negative Emissions Technologies.* Grantham Institute for Climate Change Briefing Paper No.8. [pdf] London: Imperial College. Available at: https://workspace.imperial.ac.uk/climatechange/Public/pdfs/Briefing%20Papers/Briefing%20Paper%208.pdf

Popa, A., Edwards, R. & Aandi, I., 2011. Carbon capture considerations for combined cycle gas turbine. *Energy Procedia*, Volume 4, 2011, Pages 2315-2323.

Senior CCS Solutions Ltd, 2010. *CO_2 storage in the UK – Industry Potential*. [pdf] London: UK Department on Energy and Climate Change (DECC). Available at: http://www.ukccsrc.ac.uk/system/files/10D512.pdf

Skea, J., Ekins, P. & Winskel, M. (Eds.), 2011. *Energy 2050: the Transition to a Secure, Low-Carbon Energy System for the UK*. London: Earthscan.

UK Energy Research Centre (UKERC), 2013. *The UK energy system in 2050: Comparing Low-Carbon, Resilient Scenarios.* [pdf] London: UKERC. Available at: http://www.ukerc.ac.uk/support/tiki-download_file.php?fileId=2976

Wallquist, L., Seigo, S. L., Visschers, V. H. M., & Siegrist, M., Public acceptance of CCS system elements: A conjoint measurement. *Int. J. GHG. Con*., 2012, 6, 77-83

Zero Emission Platform (ZEP), 2011. *The Cost of CO_2 Capture, Transport and Storage. – Post demonstration CCS in the EU.* [pdf] Available at: http://www.zeroemissionsplatform.eu/library/publication/165-zep-cost-report-summary.html