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Guidance on Carbon Capture Readiness and Applications under Section 36 of the Electricity Act 1989: consultation response

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Executive summary

We welcome the broad thrust of the DECC's draft guidance document on carbon capture readiness at new power stations, and of the Secretary of State's proposals for additional requirements for carbon capture and storage. We suggest several clarifications that could usefully be provided, either in the guidance document, or in subsidiary documents. Specifically, we suggest the establishment of a process of continual review of the realistic capacity of carbon dioxide storage reservoirs and the criteria for introducing new carbon storage reservoirs. We further suggest that to allow for the rapid rate of generation of new scientific information, the following are needed. First, an explicit, quantitative statement of the timescale that government considers sufficient for a reservoir to store carbon dioxide securely. Second, the inclusion in the guidance document of plans to accelerate the release into the public domain of seismic, borehole log, well injection test, and drilling record data generated by the private sector. Third, an explicit statement of government's view on the extent to which bio-fuel power stations should be covered by regulations requiring carbon capture readiness. Finally, the production of a companion document giving similar guidance for the retro-fitting of carbon capture and storage systems at existing power stations. We also suggest that the guidance document could benefit from being updated in a number of ways, in the light of the Secretary of State's additional proposals. Specifically, we suggest that, if different regulations are to apply to coal and natural gas, it would be useful for the guidance document to mention the two fuels separately. If some electricity generators are to be required to undertake carbon capture and storage from start-up of new facilities, the advice in the guidance document, that they do not need to commit themselves to using a particular storage reservoir at that stage, is no longer correct. The guidance document could usefully include measures to counter any disincentives to private-sector funding of carbon capture and storage research. We propose that the same review process that continually reassesses the realistic capacity of carbon dioxide storage reservoirs and the criteria for introducing new carbon storage reservoirs, may also need to keep under continual review the list of issues that applicants for power station construction permits can usefully address. Finally, we suggest that it would be helpful for applicants to provide details of their plans for monitoring of CO_2 during and after its injection into a reservoir.

1 About us

The Institute of Theoretical Geophysics is a research group within the Departments of Applied Mathematics and Theoretical Physics and Earth Sciences, in Cambridge University. The various members of the Institute of Theoretical Geophysics are involved in developing nonlinear mathematical models and comparing the results with specially designed laboratory experiments. They then aim to extrapolate these new concepts to describe quantitatively large-scale natural events, such as volcanic eruptions, melt migration in the crust of the Earth, sedimentary structures, hazardous rock falls, ice propagation and formation in polar seas, and natural hazard prediction and assessment. In recent years, one of our key theoretical and experimental research themes has been the fluid mechanical behaviour of captured carbon dioxide, subsequent to its injection into geological reservoirs.

The contents of this document have been agreed by those current members of the Institute of Theoretical Geophysics working in research related to carbon capture and storage, namely Prof. Herbert E. Huppert FRS, Madeleine J. Golding, Dr. Mark A. Hallworth, Dr. Daniel C. Hatton, Dr. Jerome A. Neufeld, and Dr. Dominic Vella.

2 Introduction

We welcome the draft guidance on carbon capture readiness [4], and the Secretary of State's statement of 23rd April 2009 on further requirements for carbon capture and storage [23]. These are important steps towards the deployment of a suite of technologies with the potential to make the largest single contribution, in the short and medium term, to decarbonizing Britain's, and the world's, energy generation [27]. We congratulate the Secretary of State, and everyone involved in the drafting of the guidance document, on their high-quality work.

3 Consultation question 1: clarity of the guidance document

The draft guidance document [4] is admirably clear in stating the general requirement, to be contained in the British transposition of the forthcoming EU directive on the geological storage of carbon dioxide [3], for new combustion power stations to be carbon capture ready. We are also pleased to see that the draft guidance document spells out the need to consider all of the capture, transport, and storage stages of the carbon capture and storage process, when demonstrating that a plant is carbon capture ready. In the subsections that follow, we detail some specific areas where we believe that either the guidance document, or a subsidiary document, could usefully provide further clarification. As befits the nature of our collective research experience, we will focus mainly (but not wholly) on the storage side of the issue, i.e. on paragraphs 29–38 of the draft guidance document. We will draw to a large extent on original research conducted by our own group, although we will also include work undertaken elsewhere as necessary.

3.1 Types of data taken into account in DTI study of reservoir suitability

Paragraphs 30–31 of the draft guidance document [4] suggest that the standard way an applicant might demonstrate that a proposed CO_2 storage reservoir is appropriate is to note that the reservoir was found to have a suitable "realistic storage capacity" in an earlier DTI study [17].

We are pleased to see that the DTI study includes, in its assessment of realistic storage capacity, consideration of permeability, porosity, and heterogeneity of the reservoir, as well as quality of the cap rock. In this section, we will argue that scientific knowledge in this area is evolving rapidly. We will therefore suggest that it would be useful for the guidance document to initiate a process of continual review of estimates of realistic capacity of reservoirs. We will also note some particular types of field data and modelling studies that may be useful in that review process.

This evolution of scientific understanding is a process of completing finer details, starting from the outline narrative of the motion of CO_2 subsequent to its injection into a reservoir discussed in section 5.2.1 of the DTI study. Briefly, this outline narrative is as follows: the CO_2, being lighter than the surrounding interstitial fluid, rises through the reservoir rock under gravity, gradually spreading horizontally as it rises. This continues until the CO_2 reaches the impermeable cap rock overlying the reservoir. If this material is an effective cap rock, the CO_2 cannot rise further (this is known as "stratigraphic trapping"), but continues to spread horizontally (cf. also [7], where these ideas are applied to the specific, real situation at Sleipner).

Subsequent to this, some of the the carbon dioxide undergoes dissolution trapping. Dissolution trapping is a process whereby carbon dioxide dissolves in formation water as carbonic acid, forming a heavy product which would sink to, and be stably stored at, the bottom of reservoirs (cf. also [30, 13]). In addition, some of the CO_2 that has not dissolved in the formation water can be held by surface tension, in bubbles within pores that also contain water, a process known as "residual trapping" (cf. also [21, 30, 11]). At a still later stage, the dissolved carbonic acid resulting from dissolution trapping can react with rock materials, to form either solid metal carbonates (a particularly secure form of storage) or dissolved metal hydrogen-carbonates, a process known as "mineral trapping" (cf. also [28, pp. 92–93,108]; [30, 13]).

Scientific understanding has evolved particularly rapidly in the understanding of reservoir heterogeneity, and in characterizing the quality of cap rocks for secure CO_2 storage. There have been several recent advances concerning the effects of reservoir heterogeneity. Specifically, our new research published in the open domain suggests that vertical heterogeneity in reservoir permeability can be a controlling influence on the motion of injected CO_2 prior to the CO_2 reaching the cap rock, enhancing horizontal spreading [24, 18, 35, 25]. Whether enhanced horizontal spreading increases or decreases the security with which CO_2 is stored will depend on the details of reservoir geometry and cap rock heterogeneities.

One of our research projects also raises the possibility of a method by which vertical heterogeneity in reservoir permeability can be used to enhance rapid dissolution trapping. The more rapidly injected CO_2 mixes and dissolves with the host brine, the less one is reliant on the long-term containment capability of the cap rock. The proposed method consists of injecting CO_2 rapidly, near the bottom of a low-permeability sub-layer, underlain by a higher-permeability sub-layer; this enhances spreading at each sub-layer, encouraging convective mixing and increasing the CO_2/water contact area at which dissolution trapping can take place [18].

New evidence is also emerging on what constitutes a cap rock of sufficient integrity for purposes of secure carbon dioxide storage. Specifically, recent research suggests that, where the cap-rock is dipping (there is a dipping cap rock, for example, at the Otway Project site, [6]), horizontal spreading of CO_2, during an initial period subsequent to the CO_2 reaching the cap rock, is reduced by the dip. In this initial period, the spreading takes a symmetric form, but afterwards, the CO_2 starts to spread preferentially up the slope of the dipping cap rock and the spreading rate in the preferred direction is enhanced by the dip [33]. The length of the "initial period" depends on the permeability of the reservoir, the slope of the cap rock, and the injection rate, and may range from 11 days to 14 years. This (in common with the existence of dissolution trapping) suggests that the "capacity" of a reservoir may not be a fixed number, but may depend on how fast the CO_2 is injected. Whether the initially restricted horizontal spreading increases or decreases the security with which CO_2 is stored will depend on the details of reservoir geometry and cap rock heterogeneities.

In addition, new experimental data and quantitative theoretical models confirm a hypothesis mentioned in sections 5.1.1 and 5.5.1 of the DTI study, that the presence of faults (i.e. two-dimensional, high-permeability features) and/or boreholes in the cap rock will lead to CO_2 leakage towards the surface, on a timescale determined by the ease of flow through these faults [26]. Importantly, our current work suggests that the presence of faults could lead, in the later years of deployment, to much of the injected CO_2 escaping through the faults [26]. This highlights the importance of geological studies assessing the integrity of geological storage sites both before injection, and during the injection process.

Recent research further suggests that the presence of channel-like features in the base of the cap rock can enhance the horizontal spreading of CO_2 subsequent to the CO_2 reaching the cap rock [14]. Therefore, models assuming a smooth basal topography for the cap rock (cf. [22]) provide a lower limit on the horizontal spreading distance. Whether this enhanced horizontal spreading increases or decreases the security with which CO_2 is stored will depend on the details of reservoir geometry and cap rock heterogeneities.

Given the rapid rate of generation of new scientific information outlined above, we suggest that the estimates of realistic capacity from the DTI study are likely to need a process of continual review over the next several years, and that the guidance document should explicitly set up such a review process. This uncertainty is reflected in the substantial number of reservoirs where the DTI study notes that there is theoretical capacity, but not yet realistic capacity, and we envisage the results of the review process being, for the most part, a gradual conversion of some theoretical storage capacity into the realistic storage capacity category, as discussed in chapter 6 of the DTI study.

The review process will need access to field data (seismic studies, borehole logs, and results of well injection tests) showing the vertical heterogeneities in the permeability of reservoirs, the presence of any compartmentalizing faults in the reservoirs (the importance of this is noted in section 5.2.2 of the DTI study), and the locations of faults and other high-permeability routes to the surface in the cap rocks, including records of where boreholes have been drilled through the cap rocks. Given the existence of a leakage timescale in cases where the cap rock has fault-like features, it may also be sensible, in the guidance document, to quantify the timescale that government considers sufficient, for a particular reservoir and cap rock system to secure injected CO_2. A minimum figure, for a useful contribution to mitigating climate change, of a few hundred years has been mentioned [31], although the thousand-year timescale for unassisted dissolution trapping may also be relevant [13].

Seismic data have insufficient resolution to determine whether the basal topography of the cap rock contains channel-like features smaller than around 8 m [7], so it will be necessary either to rely on the lower limit to horizontal spreading provided by modelling for a smooth cap rock base, or to use ensemble modelling for various basal topographies.

On a minor point, we note that there is potential for confusion as a result of the words "valid" and "viable" being used apparently interchangeably, in both the DTI study and the draft guidance document, to describe the capacity of a reservoir once technical, economic, and regulatory limitations have all been taken into account.

3.2 Paragraph 38(ii) concerning introduction of new reservoirs

Either the guidance document [4], or (perhaps better) a subsidiary document, needs to specify what evidence of suitability of a reservoir will be required of applicants who invoke paragraph 38(ii) of the guidance document to introduce new storage reservoirs. As paragraph 30 of the draft guidance document states, the standard of reservoir suitability should be broadly similar to that used for estimating realistic capacity in the DTI study [17]. However, the criteria for introducing new reservoirs are likely to need to be at least as dynamic, in response to new scientific information, as the reservoir properties and standard of cap rock quality used to estimate realistic capacity for the reservoirs included in the DTI study (section 3.1 above), and to require the same kinds of field data. Hence, we suggest that the criteria for new reservoirs should be subject to the same continual review process as the estimates of realistic capacity for the reservoirs covered by the DTI study. Also, like the DTI study categories, these criteria could be firmed up by government stating quantitatively how long a period it considers sufficient for a particular reservoir and cap rock system to secure injected CO_2. Once again, the guidance document seems an opportune place both to initiate the review process and to state the timescale.

3.3 Securing the release of data obtained during oil and gas exploration

It is clear from the above (sections 3.1, 3.2) that detailed field data, from seismic studies, borehole logs, well injection tests, and records of drilling, will be an essential component of the review process, both for continual re-assessment of reservoirs covered in the DTI study [17] and for assessment of new reservoirs. Because undertaking new field campaigns has the potential to introduce considerable additional financial costs, it is important to take advantage of data already gathered in the course of oil and gas exploration. We understand that government and the oil and gas industry have already been working on moving data into the public domain, with exploration and development licences being conditional on data release after a multi-year confidentiality period [1]. However, there may be a need to speed up the process: sections 4.1.1.2 and 5.4.2.5 of the DTI study mention that some data potentially relevant to carbon capture and storage have not yet been released. Perhaps it would be useful for the guidance document [4], or the British transposition of the forthcoming EU directive [3], to state how government and the oil and gas industry will work together in future to make these and other relevant data available to carbon capture and storage planners.

3.4 Position of bio-fuels

The draft guidance document [4] states its domain of applicability as combustion plants with a capacity of 300 MW e or more. We assume that "combustion plant" is defined in the same way as in EU Directive 2001/80/EC [2], in which case the guidance as it stands is applicable to bio-fuel-based power stations. One could argue that a wholly bio-fuel-based power station has, through the growth of its fuel, already to some extent captured its CO_2 emissions before it produces them, which might lead to the suggestion that bio-fuel stations should be subject to lesser carbon capture obligations than fossil fuel stations

On the other hand, the "some extent", to which CO_2 is captured before it is produced, varies greatly between different bio-fuels, and in some cases may even be less than zero [12, 32]. The existence of co-firing plants that burn both fossil fuels and bio-fuels complicates the situation further. Also, the possibility that bio-fuels have already achieved some carbon capture before arriving at the power station does not diminish the potential for carbon capture and storage at bio-fuel-based plants to achieve further decarbonization of electricity supply. Further, we note that the forthcoming EU directive [3] specifically mentions the need to build experience of carbon capture and storage at bio-fuel plants.

Given the existence of these competing arguments, we suggest that, alongside the final guidance document, government might like to make an explicit statement on the extent to which it believes bio-fuels should be subject to the same carbon capture regulations as fossil fuels.

3.5 Retro-fit to existing power stations

The draft guidance document [4] is designed to build a framework for assessing carbon capture proposals for new power stations. However, one of the most exciting carbon capture proposals in the UK today, for the sheer scale of its ambition, is the Yorkshire and Humber Carbon Capture and Storage Partnership (cf. [29]), which is based on retro-fitting carbon capture and storage technology to existing plants. Therefore, we suggest it might be useful to produce a companion document alongside the present guidance document, to build a framework for assessing carbon capture proposals for existing power stations. This companion document will be useful whether or not government, at some later date, decides to introduce legislation requiring retro-fitting of carbon capture and storage technology to existing power stations.

3.6 Relationship to the Secretary of State's statement of 23rd April 2009

On 23rd April 2009, the Secretary of State for Energy and Climate change made a statement in the House of Commons [23], proposing two additional requirements for new coal-fired power stations. New coal-fired power stations permitted from 2009 onwards will be required to operate carbon capture and storage firstly on some fixed amount of their flue gas from the time they come into operation, and secondly on all of their flue gas by 2025, subject to the technology being technically and economically proven by 2020.

We welcome the Secretary of State's additional proposals: as far as mitigating climate change is concerned, we have reached a stage where readiness is no longer sufficient, and the time has come for action [15, 20, 8, 16]. Indeed, when the separate consultation on these proposals opens, we are likely to suggest that the eventual legislation implementing them leaves open the possibility of commencement of the 100 % capture obligation prior to 2025, if the technology is proven prior to 2020. We are also likely to suggest that government provides a much more detailed definition of "proven".

As we understand it, the Secretary of State's additional proposals were made subsequent to the drafting of the guidance document [4]. In the following sub-sections, we outline a few respects in which we believe the guidance document needs to be updated to take account of the Secretary of State's additional proposals.

3.6.1 Distinction between coal and natural gas

The draft guidance document [4] treats all combustion fuels alike. The Secretary of State's additional proposals [23], however, apply only to coal, not to natural gas or bio-fuels. For consistency with the additional proposals, the guidance document should perhaps, at least in those respects directly related to the additional proposals (see sections 3.6.2 and 3.6.3 below), mention different fuels separately.

Some may perceive it as inequitable that coal power station operators are required to capture 100 % of their carbon emissions by 2025, while no obligation to capture CO_2 is placed on natural gas power station operators, who will therefore be able to continue to produce approximately 50 % of the carbon emissions associated with unabated coal [19]. If the Secretary of State's proposals are to go ahead unaltered, there is a need to make an explicit case, perhaps alongside the final guidance document, to counter any such claims of inequity. Failing this, a way may need to be found to re-balance the obligations between coal and natural gas operators, without diminishing the overall reduction in carbon emissions achieved. One possibility might be to apply the requirement for 100 % capture by 2025 to natural gas as well.

3.6.2 Redundancy of paragraph 35 concerning post-start-up changes of proposed storage site

Paragraph 35 of the draft guidance document [4] says that applicants need not, by the beginning of power generation, commit themselves to using a particular storage reservoir. This will need editing in the light of the Secretary of State's first additional proposal [23], which will mean that, in practice, applicants have to commit themselves at the start of power generation by beginning to inject CO_2 into a particular reservoir.

3.6.3 Implications for research funding

Before commenting on this issue, we should declare that, as geophysics researchers, we have a particular interest in funding research on the geophysical aspects of carbon dioxide storage, a subject with which we have already gained significant experience.

The proposed obligation to apply carbon capture to 100 % of flue gas by 2025 is dependent on the technology being technically and economically proven by 2020 [23]. We assume that applying carbon capture will cost money (cf. [31, 13, 10]). This might mean that power station operators stand to gain financially from the technology *not* being proven. We are concerned that this will act as a disincentive to the electricity industry funding research relevant to the technical and economic feasibility of carbon capture and storage. A simple, but somewhat extreme, solution would be to impose the obligation irrespective of whether the technology is proven. In effect, this would mean forcing plants to shut down if the technology is not proven; this, of course, would have potential damaging implications for security of supply. A less draconian approach would be to use the publication of the guidance document [4] as an opportunity to introduce a structure of incentives for the private sector to fund CCS research, in addition to the direct public funding outlined in the 2009 budget [9].

4 Consultation question 2: additional issues that applicants might usefully seek to address

4.1 Issues arising directly from section 3 above

Our response to consultation question 1, above (section 3), gives a number of clues to additional issues that applicants, especially those seeking to introduce new storage reservoirs under paragraph 38(ii) of the draft guidance document[4], might usefully seek to address. Specifically, our comments in sections 3.1 and 3.2 suggest that providing the following kinds of data and model results is likely to be important.

- Seismic studies, borehole logs, and well injection tests to assess reservoir heterogeneity and compartmentalization
- Seismic studies, borehole logs, and records of drilling operations to assess the presence of high-permeability channels through cap rocks
- Either lower limits to horizontal spreading based on modelling with a smooth basal topography of the cap rock, or ensemble models with various different basal topographies

We also suggested that, given the expense of gathering new field data of these types, it is vital to maximize the extent to which data that have already been gathered are placed in the public domain. In the context of a new reservoir, one of the main ways in which applicant would need to use these data is in quantitative predictive modelling of the leakage timescale and horizontal spread of the injected carbon dioxide.

Equally important is that scientific understanding of what constitutes a suitable reservoir and a high quality cap rock for secure CO_2 sequestration is in flux (section 3.1 above). Hence, the list of issues that applicants might usefully seek to address can be expected to change over time, and needs to be kept under continual review.

4.2 Monitoring during and after injection

In addition to their plans for the capture and injection process itself, it is important that applicants outline how they will monitor the carbon dioxide during and after its injection into a reservoir, to make sure that the CO_2 stays buried, both in the immediate aftermath of its injection and throughout the period that government considers sufficient for CO_2 to remain securely stored (cf. [13]). Time-lapse seismics have proved successful, at Sleipner, in confirming that CO_2 is present in the reservoir, and where in the reservoir it resides over time [7]. Hence, applicants will need to commit to a programme of time-lapse seismic studies over a long period.

However, seismics will not tell the whole story: their resolution is insufficient to quantify with reasonable precision the volume of CO_2 that remains in the reservoir at any given time [7]. Therefore, applicants will need to consider additional monitoring techniques to complement their seismic studies. One possibility is drilling test wells to sample interstitial fluid in the reservoir, subject to the availability of a suitably acid-resistant cement to prevent the test wells themselves from becoming leakage pathways (cf. [5, 13]). Gravity surveys can also help to locate stored CO_2 [13]. In addition, for the detection of some types of leakage, one can monitor CO_2 concentrations in the sea or atmosphere at the surface [13]. It may also be important to keep logs of pressure and flow rate at the injection well(s), allowing continuous re-assessment of reservoir permeability, and its heterogeneity and anisotropy (cf. [34]).

5 Concluding remarks

The DECC's draft guidance document on carbon capture readiness at new power stations, and of the Secretary of State's proposals for additional requirements for carbon capture and storage, are important steps forward in the drive toward deploying this suite of technologies.

There are several ways in which the guidance document could be clarified, either within its own text, or in subsidiary documents. Specifically, the guidance document could establish a process of continual review of the realistic capacity of carbon dioxide storage reservoirs and the criteria for introducing new carbon storage reservoirs. To allow for the rapid evolution of scientific understanding, this review process would benefit from the following.

- An explicit, quantitative statement of the timescale that government considers sufficient for a reservoir to store carbon dioxide securely
- A plan, perhaps included in the guidance document, for faster publication of seismic, borehole log, well injection test, and drilling record data generated by the private sector
- An explicit statement by government, on the extent to which bio-fuel power stations should be covered by regulations requiring carbon capture readiness
- The production of a companion document providing equivalent guidance for the retro-fitting of carbon capture and storage systems at existing power stations.

In addition to these clarifications, the guidance document could benefit from being updated in a number of ways, in the light of the Secretary of State's additional proposals. Specifically

- If different regulations are to apply to coal and natural gas, it would be useful for the guidance document to mention the two fuels separately
- If some electricity generators are to be required to undertake carbon capture and storage from start-up of new facilities, the advice in the guidance document, that they do not need to commit themselves to using a particular storage reservoir at that stage, is no longer correct
- The guidance document could usefully include measures to counter any disincentives to private-sector funding of carbon capture and storage research

The same review process that continually reassesses the realistic capacity of carbon dioxide storage reservoirs and the criteria for introducing new carbon storage reservoirs, may also need to keep under continual review the list of issues that applicants for power station construction permits can usefully address.

Finally, we suggest that it would be helpful for applicants to provide details of their plans for monitoring of CO_2 during and after its injection into a reservoir.

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