

# Call for Evidence form

Department for Energy Security & Net Zero, Open call for evidence  
CCUS: non-pipeline transport and cross-border CO<sub>2</sub> networks - call for evidence  
Published 7 May 2024

## General Information

Table 1: On behalf of organisation / company

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|-------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Full name and title (optional)                                                            | Dr Corinna Abesser                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| E-mail address                                                                            | BGSPolicy@bgs.ac.uk                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Organisation / Company                                                                    | British Geological Survey                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Position within Organisation / Company                                                    | Policy Director                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Who are you responding on behalf of, and what is your interest in this call for evidence? | <p>The British Geological Survey is a world-leading geological survey and global geoscience organisation, focused on public-good science for government and research to understand earth and environmental processes.</p> <p>We are the UK's premier provider of objective and authoritative geoscientific data, information and knowledge to help society to use its natural resources responsibly, manage environmental change and be resilient to environmental hazards.</p> <p>Our research includes the study of carbon dioxide (CO<sub>2</sub>) storage and we are recognised as a European centre of excellence in this field. We have a dedicated carbon capture and storage (CCS) team that is active in several related research areas including:</p> <ul style="list-style-type: none"><li>- characterisation and capacity estimation of potential underground storage reservoirs</li><li>- potential chemical interactions of injected CO<sub>2</sub> with the surrounding rocks</li><li>- storage site monitoring technologies and integrated monitoring strategies</li><li>- assessment of long-term site performance, including evaluating consequences of potential leakage</li></ul> <p><a href="https://www.bgs.ac.uk/geology-projects/carbon-capture-and-storage/">https://www.bgs.ac.uk/geology-projects/carbon-capture-and-storage/</a></p> |

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| If you consent to members of the team reaching out for clarifications on responses provided, please provide contact details.   | Please direct all enquiries to <a href="mailto:BGSPolicy@bgs.ac.uk">BGSPolicy@bgs.ac.uk</a> . We will put you in contact with our experts. |
| Do you give permission for your anonymised evidence to be shared with external advisors for the purpose of technical analysis? | Yes.                                                                                                                                       |

## Call for Evidence questions

*You should read the full call for evidence and review the guidance for respondents (above in this document) before completing your response.*

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| <b>1. Please provide views on the potential long-term vision for the NPT sector.</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| <p>Research and analysis undertaken by the British Geological Survey of UK licenced appraised CO<sub>2</sub> storage capacity and UK capture rates indicates approximately 14 Mt CO<sub>2</sub> per year could be imported for UK storage in the late 2020s to 2050<sup>1</sup>. Non-pipeline transport of CO<sub>2</sub> (NPT) would enable and promote such an import market with the associated export income and reduction in cost per tonne of CO<sub>2</sub> stored for the UK. Import of non-UK CO<sub>2</sub> for storage could support the UK Government's vision for the UK to transition to a merchant-based market for CCS, from 2030 by providing additional income streams and developing a diversified market of emitters wishing to store CO<sub>2</sub> in UK stores.</p> <p>Successful implementation of NPT for non-UK CO<sub>2</sub> for storage could drive increased appraisal of UK capacity. A 20% increase in UK appraised capacity relative to current planned and licenced capacity could enable the UK to store up to 38 Mt CO<sub>2</sub> per year captured in Europe; this assumes all currently licensed stores are awarded storage permits and become operational. A 20% increase would require new storage capacity to become operational, in addition to that currently in development, and will therefore likely require additional CO<sub>2</sub> storage licensing rounds. It is worth reiterating that this additional capacity assumes that all stores currently being evaluated and appraised do become fully operational in the late 2020s and early 2030s. It is prudent to assume that not all these stores will achieve permit award, as a result of either technical or commercial reasons. To mitigate this risk, further appraisal is required, and the British Geological Survey has initiated appraisal in the Central North Sea to support future commercial appraisal by storage developers as part of future licensing rounds. The British Geological Survey has not estimated the maximum import potential that the UK could develop within commercial business models.</p> <p><sup>1</sup>Abel et al, 2024, Quantification of the UK CO<sub>2</sub> storage export potential for a carbon capture and storage service, BGS Open Report OR/24/004</p> |
| <b>2. Which regions and sectors of the economy will benefit most from NPT solutions unlocking CCUS? Which regions and sectors of the economy will continue to struggle to deploy CCUS? Should the government look to prioritise any particular regions or sectors of the economy for NPT?</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| <p>The majority of the UK's very significant potential CO<sub>2</sub> storage capacity is remote from the planned CO<sub>2</sub> storage pipeline infrastructure, for example, approximately one half of Scotland's storage capacity is more than 15 kilometres of oil and gas pipelines suitable for re-use for CO<sub>2</sub> transport<sup>2</sup>. NPT would enable access to the considerable storage capacity remote from a CO<sub>2</sub> transport pipeline networks planned for the Track-1 and Track-2- industry cluster CO<sub>2</sub> sources and promote re-use of suitable depleting hydrocarbon fields for CO<sub>2</sub> storage, including already licenced areas. Importantly, NPT could enable</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |

commercial resilience for operating UK CO<sub>2</sub> storage projects by diversifying and increasing CO<sub>2</sub> supply should UK capture and transport rates not achieve planned targets.

<sup>2</sup>Kirk et al, 2023, Scotland's offshore geological CO<sub>2</sub> storage capacity: an updated assessment for Crown Estate Scotland. BGS Open Report OR/23/052.

**3. Please provide details of your potential NPT or cross-border solution. Please provide any information on the timing of the project through the initial phase and into the future, and the minimum viable project.**

No response

**4. Please provide the technical and operational considerations for the major pieces of infrastructure, equipment, and transportation. Considerations may include information on the sizes and numbers of the above, CO<sub>2</sub> temperature and pressure conditions, loading/un-loading times and NPT journey lengths and duration. Please also provide the rationale for the technical and operational decisions.**

No response

**5. For the above NPT chain, please provide information on the expected ownership/operatorship (e.g. leasing, owned, shared ownership, etc) and expected commercial/contractual arrangements. Please include when equipment is to be shared between multiple entities or for sole use.**

. No response

**6. Please provide information on the elements in the NPT chain with the longest lead times which could be rate determining in the deployment of the NPT chain. Please provide any information that you have on timelines for delivery of your NPT chain (e.g. project delivery Gantt charts).**

No response

**7. What are the expected transport emissions and fugitive emissions expected within the NPT value chain? Please provide any information on how these emissions can be minimised.**

No response

**8. Could the costs associated with the full NPT value chain prevent investment and deployment of NPT solutions? If so, why?**

No response

**9. If available, please provide any assessments that have been carried out to show an NPT solution is more economically viable than a piped solution for your NPT value chain, or that a piped solution is not technically viable.**

No response

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| <b>10. Please provide evidence on the costs associated with NPT. Where possible disaggregated to the nodes delivered by NPT service providers (e.g. after capture plant and before delivery to the T&amp;S network). Where possible, please provide information in relation to the devex, capex and opex of the operation. Please include the stage and Association for the Advancement of Cost Engineering (AACE) Cost Class at which this cost data has been generated, and please share the methodologies and assumptions that have been utilised to generate this data.</b> |
| No response                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <b>11. What are the main financing risks with a disaggregated chain, and how do these differ to the full chain piped approach?</b>                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| No response                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <b>12. What are the main financing risks associated with operational flexibility, and how do these differ to the full chain piped approach?</b>                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| No response                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <b>13. Which archetype do you think would be most attractive to investors? Why?</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| No response                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <b>14. What types of financing are best placed to deliver NPT value chains?</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| No response                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <b>15. Do you agree the rationale for economically licensing NPT service providers does not exist? Or do you believe that some elements in the NPT value chain may still require some kind of economic licencing?</b>                                                                                                                                                                                                                                                                                                                                                           |
| No response                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <b>16. Considering the expected deployment timelines for potential NPT projects within the CCUS programme, can the risks associated with the deployment of an NPT value chain be effectively managed commercially between the different actors within the NPT value chain? If not, please provide evidence and rationale why these risks cannot be managed commercially.</b>                                                                                                                                                                                                    |
| No response                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <b>17. Please provide details on how you believe that the CCS Network Code24 would need to be updated to facilitate NPT.</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| No response                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <b>18. What changes to the Track-1 capture BMs do you envisage being required to make the capture BMs work for NPT solutions? What considerations would be required for power-BECCS and GGR BMs when developing for NPT? Please flag in your response which of the capture BMs you are answering in reference to.</b>                                                                                                                                                                                                                                                           |
| No response                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |

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| <b>19. How important should consistency in approach between capture BMs be? How important is consistency between NPT users and piped users within a specific BM (e.g. ICC via pipeline and ICC via NPT)?</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| No response                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| <b>20. If NPT solutions are assessed against pipeline solutions, would this raise any concerns?</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| No response                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| <b>21. If government is to allow all archetypes of NPT, how should an assessment of an NPT value chain be considered to allow comparisons?</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| No response                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| <b>22. Please provide views on the potential vision for cross-border CO2 T&amp;S networks in the UK.</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| No response                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| <b>23. With regard to Questions 18 and 19 and in the context of establishing crossborder CO2 T&amp;S networks, do you have a view on:</b><br><br><b>i) whether an economic licensing framework for CO2 T&amp;S might need to evolve to accommodate cross-border T&amp;S networks?</b><br><br><b>ii) how cross-border CO2 volumes should be viewed within a commercial landscape currently designed for domestically captured CO2 volumes?</b><br><br><b>iii) how service providers could manage the risks on a commercial basis that would allow for a merchant delivery model?</b><br><br><b>iv) whether there are any specific changes needed to the current suite of capture business models if CO2 cross-border T&amp;S networks are established?</b><br><br><b>For each answer please provide further explanation.</b> |
| No response                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| <b>24. With regard to Question 20 do you think any changes will be required to the CCS Network Code to ensure cross-border CO2 T&amp;S networks can be established?</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| No response                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| <b>25. To what extent would enabling NPT users and cross-border users incentivise storage exploration and appraisal activity? If not, why doesn't it?</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Approximately 14 Mt CO <sub>2</sub> per year, according to the findings of British Geological Survey research, could be imported for UK storage in the late 2020s to 2050 <sup>1</sup> . This is equivalent to more than 5% of the European storage target projected for 2050. Cross-border CO <sub>2</sub> Transport & Storage networks are essential for the UK to access CO <sub>2</sub> captured in Europe.                                                                                                                                                                                                                                                                                                                                                                                                             |

A 20% increase in BGS modelled storage would enable the UK to store up to 38 Mt CO<sub>2</sub> per year captured in Europe although would require new storage, not currently in development, to become operational. The earliest that this could become available, estimated here, is between 2032 and 2036 assuming a new storage licensing round was initiated as early as possible in 2024.

Increasing the UK's storage capacity by 50%, would enable Europe to store up to 74 Mt CO<sub>2</sub> per year with availability sometime in the mid-2030s. An increased available capacity for import would be equivalent to approximately one third of Europe's highest target storage rate for 2040.

Further analysis is needed to estimate the maximum amount of CO<sub>2</sub> that could be stored within UK national waters via NPT and assuming import from Europe. The British Geological Survey has initiated some preliminary appraisal to contribute to this analysis, but further integrated studies of storage appraisal and potential import via shipping must be undertaken.

<sup>1</sup>Abel et al, 2024, Quantification of the UK CO<sub>2</sub> storage export potential for a carbon capture and storage service, BGS Open Report OR/24/004

**26. Could a store which is solely reliant on NPT users be viable? What are the technical challenges to operating a store solely reliant on NPT users? How would this operating model impact the risk profile of the project?**

No response

**27. Please provide evidence for the potential viability of shipping CO<sub>2</sub> straight to the wellhead for CO<sub>2</sub> injection. Please expand on the risks/barriers and benefits of straight to wellhead shipping.**

No response

**28. What regulations need to be considered or amended for NPT value chains to deploy (excluding those regulations which are covered in the CCUS policy landscape section)?**

Enabling NPT could significantly incentivise further storage appraisal, by providing the financial incentives to develop further stores. Indeed, our analysis, as described above, indicates additional stores will be needed to maximise cross-border import of CO<sub>2</sub> from Europe.

A potential limitation to NPT, not described in the Government's vision, is the potential need for temporary onshore storage, as seen at the Norwegian CO<sub>2</sub> storage Northern Lights Project. Potential space for on-shore tanker storage may not be a limitation in coastal brownfield industrial sites but will require planning permissions requiring appropriate scheduling.

A further technical limitation, requiring further assessment is the potential to provide flow assurance through the well, which may be more limited in intermittent operational modes required by NPT compared to continuous injection systems more typical of pipeline transport. The potential impacts on flow assurance through intermittent injection, within the well and geological storage reservoir, arising from ship off-loading, need further evaluation and mitigation.

**29. Do the current processes to comply with existing health and safety or**

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| <b>environmental regulations or controls create barriers to NPT deployment when transporting CO2 via road, rail, barge, ship, or processing CO2 at intermodal facilities? If so, what are those barriers, and what would you suggest as an alternative?</b>                                                                                                        |
| No response                                                                                                                                                                                                                                                                                                                                                        |
| <b>30. Are there any specific changes to UK legislation, existing regulations or permitting processes which are necessary to support the development of crossborder CO2 T&amp;S networks?</b>                                                                                                                                                                      |
| No response                                                                                                                                                                                                                                                                                                                                                        |
| <b>31. What do you see as the biggest regulatory barriers to the growth of cross-border CO2 T&amp;S networks?</b>                                                                                                                                                                                                                                                  |
| No response                                                                                                                                                                                                                                                                                                                                                        |
| <b>32. What are your views on the best approach to creating interoperable CCUS networks?</b>                                                                                                                                                                                                                                                                       |
| No response                                                                                                                                                                                                                                                                                                                                                        |
| <b>33. How should the UK design the standards and specifications for CO2 T&amp;S which offers network users sufficient flexibility in store choice but also provide sufficient protection to core T&amp;S infrastructure? How can the UK ensure that its T&amp;S network design does not impede access to an interconnected and interoperable European system?</b> |
| No response                                                                                                                                                                                                                                                                                                                                                        |
| <b>34. Are there any technical or operational limitations that may exist that could be a barrier to domestic NPT or cross-border T&amp;S network deployment? Please explain.</b>                                                                                                                                                                                   |
| No response                                                                                                                                                                                                                                                                                                                                                        |
| <b>35. Is there any specific foundational infrastructure that must be operational in the UK before UK stores can offer storage to domestic NPT or international customers? If so, what should the UK prioritise?</b>                                                                                                                                               |
| No response                                                                                                                                                                                                                                                                                                                                                        |
| <b>36. Do you foresee any infrastructure innovations which could speed up the deployment of NPT and cross-border T&amp;S networks and/or reduce associated costs? Please provide any supporting evidence.</b>                                                                                                                                                      |

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| No response                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| <b>37. What are your views on other flexible users of CCUS networks, e.g. flexible use of technologies such as DACCS? Do you foresee that NPT and buffer storage could be complimentary to operate alongside a flexible piped user (e.g. projects that could ramp up or ramp down CO2 output, potentially including technologies such as DACCS).</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| No response                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| <b>38. Does the UK have the relevant skills and capability to deliver NPT? Does the UK have a competitive advantage to deliver certain elements of the NPT value chain?</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| No response                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| <b>39. What other areas should government be considering for successful deployment of NPT?</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| No response                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| <b>40. Please respond with any other comments that are not contained in the above questions.</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| <p><b>42. What other areas should government be considering for successful deployment of NPT?</b></p> <p>Successful deployment of NPT requires, as a prerequisite, sufficient storage capacity to be available to provide NPT operators with confidence that storage capacity will be available at the time needed, when they are developing their projects (see responses to questions 4 and 25). This therefore requires NSTA to provide sufficient signals that future licensing rounds will be undertaken. BGS reviews of current publicly available information on current licence holders plans suggests that it can take between 6 and 8 years for a storage site to be awarded a permit, once a licence has been awarded. The first licensing round took approximately 24 months to complete, from round opening to award of licences. Our experience suggests that it may take a potential applicant up to 18 months to undertake pre-licence appraisal to submit a successful licence application, prior to round opening. Therefore, in summary, it may take up to 10 years for some storage sites to become operational. As Europe has now signalled an intention to increase its capture rates, we see an opportunity to support development of our domestic storage industry. Appraisal of new UK sites should start now to be ready for increased capture in north-west Europe in the mid to late 2030s. One important way of speeding up storage appraisal is to undertake 'pre-competitive' assessments in support of future licensing rounds, in a similar way to past hydrocarbon licensing rounds. The BGS is initiating some of this assessment and would strongly encourage the Government to develop an integrated programme of appraisal in the next 5 years to ensure we can take advantage of non-pipeline transport of CO<sub>2</sub> captured both domestically and from Europe.</p> <p><b>43. Please respond with any other comments that are not contained in the above questions.</b></p> <p>A consultation BGS held with storage developers and researchers identified several research questions which stakeholders considered must be addressed to support the scale-up of CO<sub>2</sub> storage. These can be summarised as:</p> <ol style="list-style-type: none"> <li>1. Predicting pressure responses and understanding pressure budgets in connected aquifers</li> </ol> |

2. Investigating the impacts of variable injection rates and Joule-Thompson cooling on well infrastructure and injectivity
3. Understanding risks to containment in the deep overburden
4. Ensuring sufficient storage capacity
5. Optimised monitoring for scale-up
6. Improving understanding of fluid behaviour in the wellbore, the injection infrastructure and the subsurface storage complex to assess consequences for flow assurance and storage efficiency

Of these high-level questions, the following are directly relevant to and may constrain the potential for NPT:

1. *Predicting pressure responses and understanding pressure budgets in connected aquifers.* As CO<sub>2</sub> is injected into aquifers, such as the Bunter Sandstone Formation in the Southern North Sea, the saline water already contained within the pore space is displaced. This will cause a pressure increase. There are several storage licences now expected to be proposing injection into connected aquifer zones and their simultaneous injection could lead to a cumulative and widespread pressure increase. The potential impacts of this pressure increase include:
  - a. Reduced overall storage capacity, as each storage site's maximum allowable injection pressure could be reached sooner than predicted.
  - b. Reduced back-up storage capacity for sites with primary injection into deeper reservoirs.
  - c. Reduced injection rates if pressure thresholds are reached in individual wells
  - d. Potential impacts on the geomechanical response of the storage complex, including impacts on well integrity if pressures exceed tolerances, induced seismicity through increased risk of fault reactivation. Although very unlikely, this may, in extreme cases, lead to increased risks to containment.
  - e. Potential saline water displacement to coastal and onshore potable aquifers.
  - f. Requirement for active pressure management and brine disposal via wells. Associated impact and monitoring requirements building on PML work.

Uncertainty exists in the extent and magnitude of the pressure increase and the specific response of the aquifer and overburden. These uncertainties arise because pressure responses for individual storage sites are largely dependent on the degree of communication within the large sandstone strata. The degree of communication will be determined by the geological structure and heterogeneity at a range of scales and requires a detailed knowledge from a range of datasets. This understanding, at a regional scale, is necessary to inform the risk profiles at each storage site, and enable prediction and therefore optimisation of injection, an understanding of the consequences for individual storage operations, as well as overall capacities to achieve the anticipated UK Carbon Budget 6 injection rates.

2. *Impacts of variable injection rates and Joule-Thompson cooling on infrastructure and injectivity.* As CO<sub>2</sub> is injected at relative low pressures in depleted gas fields, the dense CO<sub>2</sub> expands and cools. This cooling can lead to temperatures that may be below those for which infrastructure and materials within the well were originally designed and are rated. Impacts of this include:
  - a. Excessive cooling may lead to component failure or material damage that may reduce the integrity of the well increasing the risk of leakage.
  - b. It may increase costs as components need to be replaced.
  - c. It may reduce storage volumes as injection rates are reduced to avoid excessive cooling.

Uncertainty remains on the level of cooling, and associated changes in phase of the CO<sub>2</sub> stream that can be safely accommodated during operation. This requires further testing in controlled environments to inform risk assessment and subsequent storage operational costs.

3. *Sufficient storage capacity.* The NSTA's 1<sup>st</sup> CO<sub>2</sub> storage Licence Round has resulted in a significant increase in the number of stores being licensed and is a major step forward in for the UK in developing its storage capacity. It has created a portfolio of potential storage sites, that once permitted, will

provide a huge increase in UK storage capacity. This is very welcome. Simple calculations by BGS indicate that these stores, if all were awarded a storage permit, have sufficient theoretical storage capacity required to achieve Carbon Budget 6 targets. It is worth emphasising that the actual permitted capacities are likely to be significantly lower however, as knowledge of individual stores increases. However, the UK will need many more stores. Current licensed areas can be summarised as mainly a combination of Southern North Sea and East Irish Sea depleted gas fields and aquifer storage in the North Sea. This reflects the maturity of knowledge about these locations. Other regions of the UK Continental Shelf contain geological formations that BGS have identified as offering high potential to increase storage capacity. However, uncertainty remains on the geological characteristics of these formations. To address this, regional geological characterisation is required, similar to that undertaken for oil and gas exploration, as a pre-competitive assessment prior to conducting a licensing round.

4. *Improving understanding of fluid behaviour in the wellbore, the injection infrastructure and the subsurface storage complex to assess consequences for flow assurance and storage efficiency.* Whilst the fundamental migration and trapping processes associated with geological storage of CO<sub>2</sub> are well understood, an improved understanding of fluid behaviour along the full CCS chain would generate improvements in the efficiency and reductions in the uncertainty associated with in the Knowledge gaps include:
- a. Key controls on pressure and buoyancy driven migration following injection.
  - b. Understanding key mechanisms that control in migration assisted trapping.
  - c. Investigating transferability of findings to UK reservoirs and cap rocks.
  - d. How does fluid behaviour change with stream variability? And what are the consequences for flow assurance and injectivity?
  - e. Can we optimise injection strategies to improve performance and reduce infrastructure degradation?

However, these challenges represent opportunities for researchers to collaborate with storage operators to improve existing and develop innovative technologies to reduce costs, improve detection and reliability.