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# Business, Energy and Industrial Strategy Committee carbon capture, usage and storage (CCUS) inquiry

# Submission on behalf of UCL Institute for Sustainable Resources (ISR) and the UK Energy Research Centre (UKERC)

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This evidence is a joint submission by the UCL Institute for Sustainable Resources (ISR) and the UK Energy Research Centre (UKERC). These two institutions have worked together closely in the past, including on a report commissioned by the Global CCS Institute, on *The role of CCS in meeting climate policy targets*[1].

UCL ISR generates knowledge in the globally sustainable use of natural resources and trains the future leaders of this field. It provides independent evidence-based research into low carbon and sustainable energy and resource use, and the role of policies in supporting these outcomes.

UKERC carries out world-class, interdisciplinary research into sustainable future energy systems. Our whole systems research informs UK policy development and research strategy. UKERC is funded by The Research Councils UK Energy Programme.

We are submitting evidence because we believe CCUS is likely to have a critical role as part of an overall decarbonisation strategy for the UK – and, perhaps more importantly, for the world. We are keen to take part in the debate as to how this can be achieved.

[1] Hughes, N., Ekins, P., Pye, S., Winning, M., Macrory, R., Milligan, B., Haszeldine, S. and Watson, J. 2017 'The role of CCS in meeting climate policy targets: Understanding the potential contribution of CCS to a low carbon world, and the policies that may support that contribution', a report commissioned by the Global CCS Institute, GCCSI, Australia, http://www.globalccsinstitute.com/publications/report-university-college-london-role-ccs-meeting-climate-policy-targets

## Executive summary

- Current modelling evidence suggests that meeting carbon reduction targets will be at best significantly more expensive, and at worst impossible, without CCUS.
- This is primarily due to its offer of emissions reductions in industrial sectors, and of negative emissions with biomass, rather than as a power sector technology *per se.*
- Attempting to pre-define a cost-reduction trajectory for CCUS in advance is difficult and uncertain.
- Rather, the government should establish a maximum subsidy level at which it would be prepared to contribute to funding CCUS, and commit to fund projects should they reach this level or go below it.
- It should then introduce competitive mechanisms to assist discovery of the lowest cost, similar to the Contract for Difference (CfD) auctions.
- It also needs to support the whole innovation chain, coordinating diverse actors across industry and power sectors, $CO_2$ transmission and storage; supporting research, development and demonstration efforts of shared benefit; taking over whole chain risk; identifying synergies between industrial sectors.
- Although CCUS currently appears to be critical to industry decarbonisation, there are other potential options which may compete with or indeed complement CCUS in the longer term. A bottom-up, granular approach to decarbonisation challenges and opportunities within specific UK industry clusters will yield greater long-term benefits than a single-technology focus on CCUS alone.

## How essential is CCUS for the UK to meet its carbon emission reduction targets to 2050?

1. At a global level, there is strong evidence from energy system and integrated assessment modelling studies, that achieving a stabilisation of global temperature at or below 2°C above pre-industrial levels, would be at best substantially more expensive, and at worst impossible, without CCUS[2,3,4,5]. The importance of CCUS in 2°C scenarios is not primarily due to its use as a low-carbon technology within the power sector, but more significantly due to its use in industrial processes that the models find hard to decarbonise by other means, and to its potential for achieving 'negative emissions' if combined with bioenergy.

2. For the UK, the reasoning for the role of CCUS is similar. CCUS is not crucial to the decarbonisation of the power sector, due to the availability of other low-carbon power options. Indeed, purely considered as a low-carbon power sector technology, CCUS is at a disadvantage to renewables and nuclear in that it is not expected to capture 100% of the emissions from its fuel[6].

3. On the other hand, UK-level modelling suggests that the absence of CCUS has serious implications for the UK's ability to eliminate the residual emissions that persist as a result of the activities of 'hard-to-decarbonise' sectors. Reflecting the global picture, modelling estimates suggest that costs of meeting the UK's 2050 target could almost double

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[2] ibid

[3] Edenhofer et al (2014) *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge UK,: Cambridge University Press.

[4] Peters, G. P., Andrew, R. M., Canadell, J. G., Fuss, S., Jackson, R. B., Korsbakken, J. I., Le Quere, C. & Nakicenovic, N. 2017. Key indicators to track current progress and future ambition of the Paris Agreement. Nature Clim. Change, 7, 118-122.

[5] Dessens, O., Anandarajah, G. & Gambhir, A. 2016. Limiting global warming to 2 °C: What do the latest mitigation studies tell us about costs, technologies and other impacts? *Energy Strategy Reviews,* 13–14, 67-76.

[6] UKERC (2013) *The UK Energy System in 2050: comparing low-carbon, resilient scenarios*, p. 12, Figure 2.3. Available at: http://www.ukerc.ac.uk/publications/the-uk-energy-system-in-2050-comparing-low-carbon-resilient-scenarios.html

without CCUS[7,8]. As such, CCUS appears on the basis of these results to be a crucial part of the UK's most cost-effective pathway towards the 80% target.

4. Although the current legislated target is 80% by 2050, it is possible that developments in climate science combined with emerging outcomes of climate change, could create a case for the UK to aim for greater than 80% reductions. The government has already signalled its intention to ask the Committee on Climate Change for advice on the implications of the Paris Agreement for the UK's long-term target. Going beyond 80% is likely to require near-100% decarbonisation of transport and heat, as well as extensive decarbonisation in industry. If CCUS is a crucial part of the strategy towards 80%, it is likely to be even more so going beyond 80%.

## How should the Government set targets for cost reduction in CCUS? How could CCUS costs be usefully benchmarked?

5. For any emerging low-carbon technology, the government would rightly wish to have a coherent and structured approach for driving down costs. However, predicting the future costs of emerging technologies is challenging, as various governments have found in setting administered subsidies in the context of ongoing technological development and cost reduction of renewables. For the same reason it will be difficult for the government to determine and set appropriate cost reduction targets for CCUS.

6. Furthermore, it is not necessarily clear that a rigid series of cost targets on their own are particularly helpful to driving innovation. What is likely to be more helpful is a well-designed suite of policy measures acting at all stages throughout the innovation chain. A good illustration of the need for this 'systemic' approach to supporting technological

[7] CCC (2015) The fifth carbon budget – the next step towards a low-carbon economy (p. 56). Available at: https://www.theccc.org.uk/wp-content/uploads/2015/11/Committee-on-Climate-Change-Fifth-Carbon-Budget-Report.pdf

[8] ETI (2015) Building the UK carbon capture and storage sector by 2030 – Scenarios and actions. Available at: https://www.eti.co.uk/insights/carbon-capture-and-storage-building-the-uk-carbon-capture-and-storage-sector-by-2030

innovation and cost reduction is provided by the case of offshore wind. The rapid cost reductions seen recently in the UK and other countries are not only due to deployment subsidies. They are also the outcome of a range of policies over time, including capital grants and support for supply chains that have helped that technology to overcome the 'valley of death' between early stage innovation and commercialisation. It is important to bear in mind, however, that CCUS is different to electricity generation technologies such as offshore wind. CCUS is a system in its own right, and requires the integration of capture, transport and storage[9].

7. Nonetheless, a part of such a systemic innovation policy approach will be a clear future-oriented market incentive. Even though costs are uncertain, it is likely to be helpful for government, within the structure of such an incentive, to articulate a maximum subsidy level, at or below which it would be prepared to subsidise CCUS [10]. This would provide crucial 'market pull' by giving industries a clear signal as to what cost level they would need to reach in order to receive a viable income stream. It would also make clear the government's commitment to establishing such a revenue stream. However, it need not tie the government in to providing this exact subsidy level, if, spurred on by competition, consortia are able to deliver CCUS at an even lower cost.

8. Although costs remain uncertain, in the remainder of this answer we review the kind of evidence that could be drawn on to identify a benchmark for a reasonable maximum level of subsidy that the government could be prepared to provide. In later answers we develop further the notion of holistic innovation policy support as it applies in the case of CCUS.

9. A number of studies have estimated possible costs of CCUS in the UK context, focussing on power sector projects. In 2013, the CCS Cost Reduction Taskforce suggested that the

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[9] UKERC (2012) Carbon Capture and Storage: realising the potential? London: UK Energy Research Centre. Available at: http://www.ukerc.ac.uk/publications/carbon-capture-and-storage-realising-the-potential-.html

[10] Lowest cost decarbonisation for the UK: the critical role of CCS. Report to the Secretary of State for Business, Energy and Industrial Strategy from the Parliamentary Advisory Group on Carbon Capture and Storage (CCS). http://www.ccsassociation.org/news-and-events/reports-and-publications/parliamentary-advisory-group-on-ccs-report/

first CCS power projects would cost in the region of £150-200 / MWh, subsequently falling to around £94 / MWh with the development of economies of scale in usage of $CO_2$ transportation and storage infrastructure, and improvements in engineering and financeability[11]. The 2016 Report of the Parliamentary Advisory Group on CCS recommended a set of policies that it argued would address each of these cost reduction opportunities directly, as a result proposing £85 / MWh as a reasonable maximum power sector CCS subsidy level[12]. In line with these estimates, the CCUS Cost Challenge Taskforce in 2018 reported that Summit Power's Caledonia Clean Energy Project would be seeking a Contract for Difference (CfD) at around £80-90 / MWh[13].

10. For industry CCUS the appropriate metric may be the cost of sequestered $CO_2$, in £ / $tCO_2$. One techno-economic analysis of CCUS technologies across various industry sectors found that the costs for the majority of CCUS processes across industries were in the range \$20-\$120 / $tCO_2$, though with fairly large ranges of uncertainty[14]. Costs may be higher in industrial sectors with multiple $CO_2$ point sources within a single facility, requiring multiple capture plants to be fitted. On the other hand, some industrial processes already produce high-purity $CO_2$ streams, and thus would require little or no additional $CO_2$ separation, placing them at the lower end of the cost range for industrial CCUS. Potential sectors of this kind include natural gas processing, ammonia, ethylene oxide and hydrogen production. These could be 'low hanging fruit' for relatively low cost 'first-mover' industries for CCUS[15]. Analysis by Poyry and Teesside Collective explores the costs of implementing CCUS jointly on six existing industrial facilities, involved in fertiliser production, chemicals and fossil fuel processing in the Teesside area. They estimate

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[11] CCS Cost Reduction Taskforce (2013) Final Report. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/201021/CCS_Cost_Reduction_Taskforce_-_Final_Report_-_May_2013.pdf

[12] Lowest cost decarbonisation for the UK: the critical role of CCS. Report to the Secretary of State for Business, Energy and Industrial Strategy from the Parliamentary Advisory Group on Carbon Capture and Storage (CCS). http://www.ccsassociation.org/news-and-events/reports-and-publications/parliamentary-advisory-group-on-ccs-report/

[13] Delivering clean growth: CCUS Cost Challenge Taskforce Report. https://www.gov.uk/government/publications/delivering-clean-growth-ccus-cost-challenge-taskforce-report

[14] Leeson, D., MacDowell, N., Shah, N., Petit, C., Fennell, P.S. (2017) A techno-economic analysis and systematic review of carbon capture and storage (CCS) applied to the iron and steel, cement, oil refining and pulp and paper industries, as well as other high purity sources. *International Journal of Greenhouse Gas Control*, 61, 71-84. Costs are in year-2013 US \$.

[15] ibid

overall abatement costs of £58/$tCO_2$[16]. For comparison they note that this cost is below the Central Scenario 2030 carbon value – currently £79/$tCO_2e$ – given in BEIS' short-term traded carbon values for policy appraisal[17]. Green Alliance suggest that a CCUS industrial cluster in the Humber region in combination with a large power sector project could be delivered at an overall cost of £91/$tCO_2$[18].

11. Such cost-estimates could provide a guide for the government in setting a maximum subsidy level as a starting point for a competitive allocation process.

12. However, due to the variety of different processes involved in industry CCUS, the likelihood of large cost ranges between them, and the likely cost saving benefits of shared infrastructure through clustering, it will also be important to consider carefully how this kind of competitive process can be combined with the kind of cooperative and strategic support which is likely to be necessary to discover the lowest overall costs. We return to these issues in our next answer.

## What would be a realistic level of cost reduction to aim for – and by when?

13. As discussed above, it is a complex task for any government to set cost reduction targets and trajectories. Instead, we have suggested that the government should identify a maximum subsidy level, and then ensure that the right project management and bidding structures are in place to enable the lowest possible cost to be discovered through industry competition.

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[16] Poyry and Teesside Collective (2017) A business case for a UK industrial CCS support mechanism. Available at: http://www.teessidecollective.co.uk/wp-content/uploads/2017/02/0046_TVCA_ICCSBusinessModels_FinalReport_v200.pdf

[17] BEIS (2018) Updated short-term carbon values used for UK public policy appraisal. Available at: https://www.gov.uk/government/publications/updated-short-term-traded-carbon-values-used-for-uk-policy-appraisal-2017

[18] Benton, D. (2015) Decarbonising British industry – why industrial CCS clusters are the answer. London: Green Alliance. Available at: https://www.green-alliance.org.uk/resources/Decarbonising_British_Industry.pdf

14. However, these measures focus purely on the market pull element, and there is much that the government could and should do to support other parts of the innovation chain. For industry CCUS projects there will be the challenge of diverse processes, often with multiple, relatively small $CO_2$ streams, operating under different conditions and with different inputs and outputs. To achieve reasonable economies of scale around CCUS, and to achieve the clustering concept proposed by the CCUS Cost Reduction Taskforce and others[19,20,21], there would need to be some kind of coordinating role similar to that carried out in Industrial Symbiosis programmes, not least of which was the UK's National Industrial Symbiosis Programme (NISP) which was operational between 2005-2009[22]. For both power and industry projects, there might also need to be some coordination of actors along the CCUS chain, from sources, through capture, infrastructure and $CO_2$ injection and monitoring. There may be justification for the government to take over some of the whole chain risk, and for government or a regulated body to exercise some coordination and ownership of shared infrastructure, similar to the role currently played by System Operators in relation to electricity transmission networks. The government or a government body could also play an important role in coordinating the multiple private actors involved in targeting research, development and demonstration projects, to speed up technological progress – the Carbon Trust has acted effectively in this role in other sectors, for example through the Offshore Wind Accelerator[23].

15. We think that such an approach has important advantages compared to that which is being implied by this question – namely, that the government should attempt to identify in advance a cost reduction trajectory and a timescale over which this can or should take place. Recent experiences have shown that attempts to predict future technology costs

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[19] Delivering clean growth: CCUS Cost Challenge Taskforce Report. https://www.gov.uk/government/publications/delivering-clean-growth-ccus-cost-challenge-taskforce-report
[20] Poyry and Teesside Collective (2017) A business case for a UK industrial CCS support mechanism. Available at: http://www.teessidecollective.co.uk/wp-content/uploads/2017/02/0046_TVCA_ICCSBusinessModels_FinalReport_v200.pdf
[21] Benton, D. (2015) Decarbonising British industry – why industrial CCS clusters are the answer. London: Green Alliance. Available at: https://www.green-alliance.org.uk/resources/Decarbonising_British_Industry.pdf
[22] See Case Study: The National Industrial Symbiosis Programme, pp.182-183, in Ekins, P. and Hughes, N. (2017) Chapter 13: National Government. In: Walport, M. and Boyd, I. (eds) *From waste to resource productivity: evidence and case studies.* Government Office for Science. https://www.gov.uk/government/publications/from-waste-to-resource-productivity
[23] https://www.carbontrust.com/offshore-wind/owa/

can be at odds with events, and that this can lead to subsidy costs being higher than necessary, or pressure to revise or scrap policy hurriedly, which has a long-term negative impact on industry confidence in government policy. On the contrary, we suggest that the approach we have outlined will give the government the best possible chance of making CCUS a viable proposition within its subsidy benchmark.

## If CCUS costs do not come down "sufficiently", what alternatives should the Government consider to meet the UK's climate change targets? How might the cost of these compare with CCUS?

16. As discussed at the start of this submission, CCUS looks likely to be an important part of a cost-effective decarbonisation pathway, as the evidence from energy system models is not currently showing an alternative that will meet decarbonisation objectives at lower cost in the absence of CCUS.

17. However, while we would stand by this high-level conclusion, we would also stress the importance of continuing to develop a range of mitigation options in the hard-to-decarbonise heavy industry sectors – that it is, not to see CCUS as a sole solution.

18. The first of these additional strategies should be energy and material efficiency. A global modelling study compares the effect of introducing material and energy efficiency measures into both CCUS and non-CCUS mitigation scenarios, and finds substantial cost reductions in both cases[24]. Energy and material efficiency is thus not so much an alternative, as a vital no-regrets strategy that will reduce costs and increase feasibility of overall carbon mitigation against any technology background.

19. We would also stress the importance of taking a granular and forward-looking view of the various sectors and processes of which heavy industry is comprised. Although the

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[24] Akashi, O., Hanaoka, T., Masui, T. & Kainuma, M. 2014. Halving global GHG emissions by 2050 without depending on nuclear and CCS. *Climatic Change,* 123, 611-622.

message from energy system models appears to be starkly that there is no way of decarbonising industry without CCUS, the authors of one detailed bottom-up review of mitigation options in energy-intensive industry suggest that modelling studies thus far have represented industry 'in an aggregate way that obscures sectoral complexity and capacities to abate', with a common observation being that 'detailed sectoral knowledge of >50% industrial abatement options was vague, incomplete or missing'[25]. The authors' own sector-by-sector review reveals a range of mitigation options, including but not limited to CCUS. Other options include changing the process, fuel or heat source to involve electrification, biomass, hydrogen or synthetic fuels. We suggest it is important to be aware that there could be mitigation options within industry other than CCUS, and that as such there could be benefits to taking a sector-by-sector technology-neutral approach to industry decarbonisation, rather than an approach that pre-determines CCUS as the sole solution for all cases.

20. For example, one techno-economic analysis suggests the DRI-EAF (Direct reduced iron – electric arc furnace) steel production route using low-carbon hydrogen as the reductant, could be more cost-effective in the long term than a blast-furnace with CCUS route[26]. Of course, it might be argued that even here CCUS would have a role as the production route for hydrogen. However, it is also possible that the hydrogen could be produced from low-carbon renewable power at times of excess supply due to low system demand. A joint venture between SSAB, LKAB and Vattenfall is currently working to pilot this system in order to develop 'fossil-free steel'[27]. Similarly 'renewable' hydrogen has also been proposed as means of producing 'Green Ammonia'[28].

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[25] Bataille, C., Åhman, M., Neuhoff, K., Nilsson, L., Fischedick, M., Lechtenböhmer, S., Solano-Rodriguez, B., Denis-Ryan, A., Stiebert, S., Waisman, H., Sartor, O. and Rahbar, S. (2018) A review of technology and policy deep decarbonisation pathway options for making energy-intensive industry production consistent with the Paris Agreement. Journal of Cleaner Production, 187, 960-973

[26] Fischedick, M., Marzinkowski, J., Winzer, P. and Weigel, M. (2014) Techno-economic evaluation of innovative steel production technologies. Journal of Cleaner Production, 84, 563-580

[27] https://group.vattenfall.com/press-and-media/news--press-releases/pressreleases/2017/ssab-lkab-and-vattenfall-form-joint-venture-company-for-fossil-free-steel

[28] Duckett, A. (2018) Green ammonia project set for launch in UK today. Available at: https://www.thechemicalengineer.com/news/green-ammonia-project-set-for-launch-in-uk-today/

21. Other options could include increasing the use of low-carbon electricity. Electric Arc Furnace (EAF) steel production is used for recycling steel. At present, impurities in the steel recycling stream are typically high which limits the ability to use the resulting recycled steel in high-performance applications. However, circular economy measures – such as promoting modular eco-design measures to improve disassembly and separation of materials – by improving the purity of the recycled steel stream, could substantially increase the applications for recycled steel via the EAF route[29], thereby potentially allowing more decarbonisation of steel through electrification.

22. The future costs of such measures may be uncertain. However, given the right incentives technological development could conceivably occur on timescales consistent with decarbonisation objectives. We suggest that it would be worthwhile to keep examining and encouraging a suite of industry mitigation options in tandem with CCUS.

23. We support the CCUS Cost Challenge Taskforce's recommendation on developing industrial 'clusters'[30], and suggest that the options for decarbonisation within each cluster could be developed in a bottom-up granular way, drawing on existing processes and strengths, and identifying suitable mitigation options in each region. An organisation with a role similar to that played by the National Industrial Symbiosis Programme (NISP) may be crucial to support the various commercial participants in identifying synergies and linkages.

24. Although we essentially concur with the CCUS Taskforce and others that CCUS is too important a mitigation tool not to support and develop, we suggest rather than pre-determining CCUS as the sole option for industry decarbonisation, there should be a bottom-up, granular strategy on industry decarbonisation for the UK-specific industrial

[29] Bataille, C., Åhman, M., Neuhoff, K., Nilsson, L., Fischedick, M., Lechtenböhmer, S., Solano-Rodriguez, B., Denis-Ryan, A., Stiebert, S., Waisman, H., Sartor, O. and Rahbar, S. (2018) A review of technology and policy deep decarbonisation pathway options for making energy-intensive industry production consistent with the Paris Agreement. Journal of Cleaner Production, 187, 960-973

[30] Delivering clean growth: CCUS Cost Challenge Taskforce Report. https://www.gov.uk/government/publications/delivering-clean-growth-ccus-cost-challenge-taskforce-report

context. This will no doubt include CCUS, but integrated with other key options like hydrogen, biomass, electrification, and material efficiency / circular economy concepts.