Response to:

BEIS Committee Carbon capture, usage and storage (CCUS) inquiry

This is an **Institution of Chemical Engineers** (IChemE) response to the BEIS Committee call for evidence on Carbon Capture, Utilisation and Storage (CCUS). This response was developed by the IChemE's Energy Centre, which brings together chemical engineers with expertise and insight across the energy sector.

IChemE is the global professional membership organisation for individuals with relevant experience or an interest in chemical and process engineering. Founded in 1922, IChemE has grown to its current status of over 40,000 members in around 100 countries.

We are the only organisation to award Chartered Chemical Engineer (CEng) status and Professional Process Safety Engineer. We are also licensed to award the titles Chartered Scientist (CSci) and Chartered Environmentalist (CEnv) to suitably qualified members.

Our Royal Charter and charitable status confers upon us an obligation to advance chemical engineering for the benefit of society as a whole and support the professional development of our membership, which spans a wide range of individuals from industry, regulators, academia and consultancies.

We can call upon our members' expertise in these fields without bias or favour, in order to reach objective advice based on sound science. IChemE welcomes the opportunity to comment on this call for evidence.

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

CCS is essential for the UK to meet its targets for CO_2 emissions reductions by 2050. This has been recognised by the UK's independent Climate Change Committee. Many industries and technologies, such as gas fired heating, international aviation and shipping, and steel and concrete production, cannot be sufficiently decarbonised or replaced with renewables in time to meet that target. CCS offsetting must be introduced at points of CO_2 production such as biofuel systems and various industrial processes, as well as for the hydrocarbon fuels that will remain in use for power generation during the 'energy transition' in the coming decades.

CCS, combined with process efficiency optimisation, is the only realistic option for addressing the decarbonisation of manufacturing processes in which the emission of CO_2 is an inherent part of the production methods; primarily cement, petrochemicals, iron and steel, and refining. This is noted in the 2015 Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050 reports commissioned by then Departments of Energy and Climate Change (DECC) and Business, Innovation and Skills (BIS). This showed that CCS could be the single largest contributor to decarbonisation, contributing 37% of the total reduction[1] by 2050 relative to a 2012 base year in their 'Max Tech' scenario. Hydrogen is increasingly considered to be a favoured option for decarbonising commercial and domestic heating (for example, the Leeds H21 project) and some transport, for which the most economic decarbonised production route at the large scale required is steam methane reforming (SMR) coupled to CCS.

Fewer than 50% of global Integrated Assessment Models (IAMs) achieve the COP21 target of 1.5-2 °C above pre-industrial levels upon which the UK targets are based.[2] The Fifth Assessment Report of the IPCC (2014) highlighted that the IAMs achieving the target that do not use CCS are on average 138% more expensive than those which incorporate it, and that delaying CCS implementation in 2030-50 could increase the costs of future action by up to 44%[3]. The cost to the UK alone of not implementing CCUS has been estimated at £30-50bn by 2050.[4] This speaks to the necessity of CCS for achieving long term cost-effectiveness. CCS will not compromise, defer or slow the introduction of renewable energy sources, but will complement them by helping to decarbonise the CO_2 emissions which are difficult to avoid for reasons of engineering or economics.

IChemE has recently published 'A Chemical Engineering Perspective on the Challenges and Opportunities of Delivering Carbon Capture and Storage at Commercial Scale' which considers in detail the need for CCUS and the policies required to achieve it.[5]

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[1] Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050 – Cross-sector Summary (2015) (http://bit.ly/2IABqjF)
[2] Fuss et al., 2014. Betting on negative emissions. *Nature Climate Change*. (http://bit.ly/2IFqvfg)
[3] Fifth Assessment Report, IPCC (2014) (http://bit.ly/2Kg2D0F)
[4] Future Electricity Series Part 1: Power from Fossil Fuels, Policy Connect (http://bit.ly/2KvaZh2)
[5] A Chemical Engineering Perspective on the Challenges and Opportunities of Delivering Carbon Capture and Storage at Commercial Scale. IChemE Energy Centre. (2018) (http://bit.ly/2lLgDRb)

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

Government targets for CCUS cost reduction

While there are many developing technologies in the pipeline which may over the next few decades make a contribution to reducing the overall costs of CCUS, in the short-term the major cost reductions needed to make CCUS commercially viable in the UK will arise from other sources, in particular from:

a) New business models that share risk between government and the private sector and enable reductions in the cost of capital
b) A stable and supportive policy environment that both increases business confidence and encourages investment
c) Building multiple CCUS projects at large scale (several Mt CO_2 pa) to benefit from the economies of scale and from learning by doing, where experience from the process industries sector shows that the nth plant can cost typically 50% of the first build

It is expected that such measures could reduce the costs of CCUS by 50-60% compared to previous demonstration plants or 'first-of-a-kind' (FOAK) installations. Below are specific examples and suggestions for applying these three cost-reduction principles.

New business model options could include:

- Separating the transport and storage infrastructure (T&S) from capture.
- The government as well as industry having a stake in transport and storage infrastructure, providing a network (or hub) into which multiple CO_2 generators can feed and share the T&S costs. This is one example of reducing cross-chain risk. This also encourages the growth of clusters of CO_2 generators and users to stimulate local low-carbon industries.
- Government taking on some of the risk which industry will find difficult to bear, at least initially; e.g. publicly funded transport networks, government taking on long-term CO_2 storage risks and liabilities.
- Establishing new funding models equivalent to Contracts for Difference (CfD) in the electricity sector for providing security to investors that they will obtain a return from CCUS applied in different sectors. For example, applying CfD to CCUS gas power plants, an equivalent system for hydrogen used for heating (from SMR with CCS), or an obligation system for industrial plant CCUS.

Aspects of a stable and supportive policy environment could include:

- Incentives for companies to locate to CCUS hubs.
- Tax credits for storing CO_2, similar to the successful 45Q measure in the US.
- Raising the carbon floor price to realistic levels to encourage CCUS rather than emissions.

Delivery of multiple large-scale CCUS projects essentially leads to engineering optimisation. This could involve:

- Adopting a systems approach to the whole integrated capture-transport-storage chain; e.g. optimising location of CO_2 sources and capture sites and storage sinks; optimising transport networks in relation to committed and future feeder plants.
- Linked to this, optimising energy, utilities and materials/feedstocks efficiencies.

In summary, important areas for the reduction of cost (and risk to companies) are the reduction of cross-chain risk associated with operating a CCS system, and the long-term liability associated with CO_2 storage. The extent to which the government will act as insurer of last resort for CCS projects, including the long-term socialisation of risks, cannot be underestimated.

While the major cost reductions in the initial phase on commercial CCUs installation will come from the above approaches, further cost reductions (maybe ~20%) will come in the medium to long-term from technology improvements. In the CCS process, the separation of CO_2 from the source can account for up to nearly 90% of the additional overall cost of CCS being applied to power generation. This is therefore the most important factor to focus on for technical cost reduction. The government should assess and support novel capture technologies, particularly those which are in the small-medium scale demonstration stage (TRL 4-7). Technology selection criteria to consider are:

- minimum of 90% capture rate
- capability to deliver cost of capture < £30 per tonne of CO_2
- for power, less than 35% increase in cost of electricity based on a reference plant without a capture facility
- for decarbonised products in general (electricity, heat, transport fuel, cement, steel, solid CO_2 utilisation products such as lime-based building aggregates or polymers), a target cost increase of less than consumers might be prepared to pay for decarbonised products

The government can further encourage innovation by reaffirming its commitment to existing decarbonisation targets and increasing the cost of carbon on a yearly basis. The government can go some way to addressing the current slow progress of the CCS market by supporting the new business approaches and policy environment described above in the short-term and applied research business development incentives for improved capture and storage approaches to bring high impact options to TRL 8-9 in the longer-term (post 2030).

Benchmarking of CCUS costs

CCUS cost reduction may be benchmarked against what has been achieved for renewables using similar approaches. Offshore wind, for example, where the costs have come down dramatically over the past few years. Where there are alternatives to fossil fuels plus CCUS (as there is in the power sector), there are appropriate benchmarks in the strike prices for electricity agreed in CfDs for wind and nuclear, against which the current consensus of achievable costs of <£80/MWh for Combined

Cycle Gas Turbines (CCGT) with CCS can be measured. In the case of industrial processes producing CO_2 there are no alternatives to CCUS and therefore no appropriate established benchmarks for decarbonised products.

The process of CO_2 capture and removal has been practiced for many years in gas exploration to limit the CO_2 content of distributed gas. This is a potential benchmark for the capture technology. Similarly, the practice of transporting pressurised CO_2 is well established for Enhanced Oil Recovery (EOR) projects in North America, from which capital expenditure and operating costs may be benchmarked. The government should concentrate its support on analysing the storage of CO_2 in offshore reservoirs, as this cannot yet be accurately benchmarked.

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

The exact value for cost reduction depends on many different factors being addressed. Some calculations may only account for capture. It is important that a standardised system of measuring cost of CCS is agreed. The cost of transport, infrastructure and storage should also be considered. Crucial factors are the resulting cost of the decarbonised product to the consumer, the premium consumers are willing to pay for decarbonised products, and the incentives governments will offer. This applies not just in the context of electricity, but also heating, hydrogen fuel, cement and steel, or petrochemicals.

A systems approach reveals a great many factors where unpredictable technological innovation might impact the cost of CCS. The variation in the nature of industrial sources means that some CCS projects might already have costs 80% lower than those currently in use in the power sector. Furthermore, cost may depend on the application of industrial ecology principles can be applied in the grouping of CO_2, transport and storage hubs, and utilisation points. This is particularly well illustrated by the potential of Calcium Looping CCS products as a feedstock for then-decarbonised cement production.

For electricity generation, any cost reduction target must take into account the ongoing technological development, future carbon pricing, load factor, and the cost improvements which come with experience. Based on the Government's own assessment, gas-fired CCGT with CCS will have to achieve levelised costs of electricity (LCOE) of £75-£90/MWh to be competitive as a flexible non-intermittent source.[6] Our estimate, based on BEIS figures, suggests a realistic target figure for the entire capture, transport and storage process would be £40-£50 per tonne of CO_2 by 2030. A reduction in capture cost of around 50% should be achievable within the same time frame.

[6] BEIS Electricity Generation Costs (2016)
(http://bit.ly/2KlBBVu)

Caution is urged when setting costs; different technologies and different industries face different issues. One approach would be to not set a specific target for cost reduction but provide a level playing field for all fossil and renewable processes. This can be achieved through an agreed cost for carbon.

There are several promising technologies which could reach maturity and full-scale commercialisation in the period of 2025-2030. These technologies passing the 'valley of death' and therefore allowing us to meet cost reduction targets will be dependent on the government providing a steady policy for the future with a clear regulatory outline and adequate financial support. Specifically, emerging second-generation CCS technologies of note are:

- Ionic Liquids (ILs)
- Water-lean solvents
- Carbonic anhydrase enzyme-based technology (CO_2 Solutions)
- Flexible co-ordination polymers (FCPs)
- Metal-organic frameworks (MOFs)
- Membrane technologies
- Molten carbonate fuel cells
- Combined power and carbon capture plants e.g. Allam cycle (NET Power)

Attention and support should be given to these technologies to accelerate their development, allowing them to be at the commercial demonstration scale by 2030. This could be done through a combination of UKRI funded R&D and technology watch through programs such as the Energy Systems Catapult. It is estimated that such new technologies could bring the cost of capture down to less than US$10 per tonne of CO_2 captured by 2050.

The UK has previously embarked on CCS projects such as Peterhead and White Rose. It is important the lessons from these are considered when determining a cost reduction target.

4. 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?

The UK is likely to struggle to meet its target for total CO_2 emissions, without CCS regardless of power generation strategy. This is as a result of industrial CO_2 emissions from energy-intensive processes such as steel and cement production. CO_2 targets can only be met if alternative materials or reduced emission production methods (such as will be tested at the Swedish HYBRIT plant) are rapidly developed and adopted. Where CO_2 is a by-product of the process, alternative decarbonisation routes are unlikely. In time, industrial process energy requirements could be met by either renewable electricity or use of hydrogen for heating.

For power generation without CCS, significant investment in nuclear and renewable energies may be required, to skip over the transition via gas which is the assumed orthodoxy. Options for large-scale power generation include nuclear, pumped hydro, and tidal power, as there are no obvious large-scale energy storage options available to resolve the intermittency issues with renewables such as wind and solar. Investment in the development and deployment of grid-scale energy storage is essential for the long-term reliance on renewables.

One strategy which may enable an easier transition without CCS retrofitting of existing CO_2 sources is the use of Allam Cycle CCS technology in new build natural gas-powered plants (a technology which cannot be retrofitted). NET Power in the US have begun testing Allam Cycle technology at a potentially zero-emission plant which produces high-purity CO_2 at no extra cost compared to unabated gas. In this case, no further investment is required to begin CO_2 separation and the technology produces decarbonised electricity and economically competitive compared to natural gas combined cycle (NGCC) power plants.

Additionally, we would caution against the assumption that the cost of the currently in-use technologies reflects ‘the’ cost of CCS. Other novel technologies such as CO_2 Solutions’ enzymatic technology and post-combustion capture using Molten Carbonate Fuel Cells (MCFC) present alternative or complementary options which may have distinct cost-effectiveness profiles.

Development and deployment of CCS at commercial scale is important for countries such as the UK to meeting obligations to reduce CO_2 emissions. CCC and IPCC models show that relying on renewables and nuclear options alone is likely to be 40-50% more expensive, with an additional cost to the UK of £30-40bn pa by 2050. However, there are risks and a long-term commitment is required. Investment in CCS is needed as part of a wider energy strategy to decarbonise the energy intensive industries (such as steel and structural cement) and develop large-scale energy storage solutions to support renewable energy technologies.