Civil engineering insights into carbon capture and storage

May 2020

Overview

In June 2019, the government passed legislation requiring the UK to achieve net-zero greenhouse gas emissions by 2050.[1] In simple terms, this target requires the UK to balance emissions produced and emissions taken out of the atmosphere by 2050. This can be achieved by a combination of emissions reduction and removal. ICE has previously delivered an insights paper on the net-zero target.[2]

The Committee on Climate Change, in its landmark report *Net Zero – The UK's Contribution to Stopping Global Warming*, highlights the crucial role carbon capture and storage (CCS) needs to play to achieve the net-zero target, stating, 'CCS is a necessity and not an option.'[3] The committee estimates that in 2050 somewhere between 75 and 175 million tonnes of carbon dioxide (CO_2) will need to be removed by CCS annually in order to achieve net-zero. This is because it is unlikely that all sources of greenhouse gases can be eliminated.[4]

CCS is the process of capturing and storing CO_2 before it is released into the atmosphere and escalates climate change. Proponents of the technology argue that CCS could capture up to 90% of CO_2 released by burning fossil fuels in electricity generation and industrial processes such as cement production.[5] CO_2 can also be used to produce commercially marketable products through a process known as carbon capture and utilisation – but this is not the focus of this paper.

Government success in supporting the development of CCS has been varied and the technology has been slow to develop both in the UK and internationally.[6] Notably, two competitions to develop CCS in the UK were cancelled in 2011 and 2015.[7] In 2019, the Department for Business, Energy and Industrial Strategy (BEIS) conducted work on possible carbon capture, usage and storage business models.[8] More recently, the 2020 Budget included a renewed commitment to CCS, with £800 million for a CCS Infrastructure Fund to support the establishment of at least two CCS clusters in the UK. In the Budget, the government also indicated its willingness to use consumer subsidies to support the construction of the UK's first CCS power plant.[9]

Purpose of this paper

The purpose of this paper is to assess what contribution CCS technology could make to mitigating climate change in the UK. The paper will contribute to the development of ICE's forthcoming *State of the Nation 2020* report on the role of the infrastructure sector in achieving the net-zero target. It combines insights from ICE Fellows, industry experts and available published evidence.

[1] GOV.UK (2019) UK Becomes First Major Economy to Pass Net Zero Emissions Law
[2] ICE (2019) Civil Engineering Insights into the UK's 2050 Greenhouse Gas Emissions Net-Zero Target
[3] Committee for Climate Change (2019) Net Zero – The UK's Contribution to Stopping Global Warming
[4] Ibid
[5] Grantham Research Institute on Climate Change and the Environment (2018) What is Carbon Capture and Storage and What Role Can it Play in Tackling Climate Change?
[6] Parliamentary Office of Science and Technology (2018) POSTbrief: Carbon Capture and Usage; ICE (2014) State of the Nation 2014: Infrastructure
[7] National Audit Office (2017) Carbon Capture and Storage: The Second Competition for Government Support; CCS Association (2016) Lowest Cost Decarbonisation for the UK: The Critical Role of CCS
[8] BEIS (2019) Business Models for Carbon Capture, Usage and Storage
[9] HM Treasury (2020) Budget 2020

About carbon capture and storage

CO_2 is produced as a by-product of a number of industrial processes, such as fermentation, cement production and ammonia production, as well as of electricity production from fossil-fuel power stations. CO_2 is a greenhouse gas, and human activities that release CO_2 into the atmosphere are a major cause of climate change.[10] Capturing and storing CO_2 at scale will be necessary for meeting international goals on limiting climate change, as set out in the Paris Agreement and the UK's net-zero target.[11]

CCS is a collection of processes that have gained attention in recent years from industry and policymakers as an essential approach to climate change mitigation. CO_2 can be captured using a number of methods, outlined below:[12]

- **Post-combustion technology** removes CO_2 from gases that result from burning fossil fuels, biomass or chemical processes.
- **Pre-combustion methods** involve converting fossil fuel into a mixture of hydrogen and CO_2 – the CO_2 is stored, while the hydrogen could be used as a low-carbon fuel in power, industry, heating and transport.
- **Oxyfuel technology** produces CO_2 and steam by burning fossil fuels with almost pure oxygen.

Post-combustion and oxyfuel equipment can be fitted to new plants or retrofitted – meaning it can be added to existing power stations that were originally built without CCS technology. For example, a gas-fired power station could be retrofitted with CCS in order to reduce emissions. In contrast, pre-combustion methods require large modifications to existing plants and are therefore more suitable to new builds.[13]

Once the CO_2 has been captured, it is compressed into liquid state and transported by pipeline, ship or road tanker. It can then be pumped underground, usually at depths of 1 kilometre or more, to be stored into depleted oil and gas reservoirs, deep saline aquifers or coalbeds, where the geology is suitable.[14]

No commercial-scale CCS plant has yet been constructed in the UK. But this is a rapidly changing sector. In 2019, there were five CCS facilities in early development: Acorn CCS, Caledonia Clean Energy, HyNet North West, Teesside Collective and a pilot plant at Drax Power Station. Several of these facilities also involve hydrogen production.[15] The CCS Association claims CCS could create 100,000 jobs across the UK by 2030, contributing £6.5 billion to the UK's economy.[16]

The Committee on Climate Change identifies CCS as a policy priority for net-zero, recommending the government takes a lead on CO_2 infrastructure development, with long-term contracts to reward carbon capture plants and encourage investment.[17]

Implementation barriers

While CCS presents opportunities for the UK (explored further in the subsequent section), the development of a domestic CCS industry must overcome several barriers. The greatest of these are commercial, rather than technical.[18] Although much of the associated technology is now well developed, costs of deployment are high and there is little policy incentive to capture and store CO_2.[19]

[10] IPCC (2018) Global Warming of 1.5°C: Summary for Policymakers
[11] Committee for Climate Change (2019) Net Zero – The UK's Contribution to Stopping Global Warming
[12] Grantham Research Institute on Climate Change and the Environment (2018) What is Carbon Capture and Storage and What Role Can it Play in Tackling Climate Change?
[13] Ibid
[14] Ibid
[15] Global CCS Institute (2019) UK Committee on Climate Change Highlights Crucial Role for Carbon Capture and Storage in Achieving a Net-Zero Target in the UK
[16] CCS Association (2020) Economic Importance
[17] Committee for Climate Change (2019) Net Zero – The UK's Contribution to Stopping Global Warming
[18] House of Commons Business, Energy and Industrial Strategy Committee (2019) Carbon Capture Usage and Storage: Third Time Lucky?
[19] Parliamentary Office of Science and Technology (2018) POSTbrief: Carbon Capture and Usage

The Global CCS Institute has identified the policy conditions that are needed to drive CCS development,[20] which largely remain absent in a UK context. They are:

- **placing a value on emissions reduction** (through direct regulation or mechanisms such as carbon certificates and obligations, a carbon tax, a tax credit or enhanced oil recovery)
- **a framework enabling investment** (government capital is often necessary to attract private capital, including direct equity investment, grant funding, tax credits, accelerated depreciation, concessional loans and loan guarantees)
- **infrastructure access and storage** (governments could assist to map CO_2 storage capacity and aid in the identification of suitable sites; governments can also support the build-out of CO_2 pipeline networks to reduce cross-chain risks and enable the establishment of CCS clusters to reduce unit storage costs).

In addition, there are a number of low-probability but high-impact risks which the private sector, at least initially, cannot price or take, or where the risk premium is too costly. These include CO_2-related cross-chain risk, stranded asset risk and insurability of CO_2 storage liability, given the risk (albeit very low) of CO_2 leakage and the lack of an insurance market to cover the specific CO_2 leakage risks.[21] While these risks are not insurmountable, to initially drive the development of a domestic CCS industry, the government will likely need to play a role ensuring risks are appropriately managed and allocated.

Of course, like any other major infrastructure project, CCS in the UK will also need to meet stringent safety standards and environmental management regulation.[22]

Identified benefits

Reducing and removing CO_2 emissions

As outlined above, it is estimated that in 2050 somewhere between 75 and 175 million tonnes of CO_2 will need to be removed by CCS annually in order to meet the UK's net-zero target.[23] Analysis by the Energy Technologies Institute suggests the UK has enough potential capacity to meet the UK's needs for CO_2 storage to 2050 and beyond, with the potential to store more than 78 billion tonnes of CO_2.[24]

When combined with bioenergy technologies (energy created with biomass) for power generation, CCS has the potential to generate 'negative emissions' – effectively removing CO_2 from the atmosphere.[25] The Committee on Climate Change analysis suggests that bioenergy with carbon capture and storage (BECCS) could be an economically viable way to reduce emissions by around 2030. It estimates that by 2050 between 20 and 65 million tonnes of CO_2 each year could be sequestered through BECCS in the UK, equivalent to up to around 15% of current UK CO_2 emissions.[26]

Direct air carbon capture and storage (DACCS) is another technology that is emerging as a solution for removing CO_2 from the atmosphere. While major technological innovations have been achieved over the last decade, DACCS is still widely considered to be a back up for challenging abatement due to cost uncertainties.[27] Irrespective, CCS deployed as part of negative emission solutions offers the potential to make contributions towards achieving the UK's net-zero target.

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[20] Global CCS Institute (2019) Policy Priorities to Incentivise Large Scale Deployment of CCS
[21] CCUS Cost Challenge Taskforce (2018) Delivering Clean Growth: CCUS Cost Challenge Taskforce Report
[22] ICE (2019) Carbon Capture and Storage Briefing Sheet
[23] Committee for Climate Change (2019) Net Zero – The UK's Contribution to Stopping Global Warming
[24] Energy Technologies Institute (2017) Taking Stock of UK CO_2 Storage
[25] Grantham Research Institute on Climate Change and the Environment (2018) What is Carbon Capture and Storage and What Role Can it Play in Tackling Climate Change?
[26] Committee on Climate Change (2018) Biomass in a Low-Carbon Economy
[27] Realmonte, G., et al. (2019) An Inter-Model Assessment of the Role of Direct Air Capture in Deep Mitigation Pathways, *Nature Communications*, 10; Fasihi, M., et al. (2019) Techno-Economic Assessment of CO_2 Direct Air Capture Plants, *Journal of Cleaner Production*, 224: 957–80

Supporting the transition to a low-carbon economy

CCS can be used in both energy generation and industrial sectors, and proponents see it playing a vital role in the move to a low-carbon economy.[28]

Decarbonising electricity

Good progress has been made in decarbonising energy generation in the UK, with emissions falling 53% in the past decade.[29] Much of this reduction has come from a larger proportion of renewable energy in the UK's energy mix.[30]

Renewable energy, such as wind and solar, is likely to be the UK's primary source of electricity in the future. However, these renewable energy sources are intermittent and dependent on the weather. Alongside renewable energy, the UK will likely require more reliable and stable low-carbon power from technologies such as nuclear, hydrogen, hydro, tidal and gas with CCS. Modelling of a future net-zero power generation sector for the National Infrastructure Commission suggests at least 5 gigawatts of gas CCS capacity is needed by 2050.[31]

There is also a range of other technologies that could address the intermittencies inherent in renewable energy, including demand shedding, pumped storage, batteries and cryogenic storage.

Decarbonising energy-intensive industry

For a net-zero future, CCS may become an increasingly important option for many energy-intensive industries, such as the production of steel, cement, chemicals and ammonia. In many cases, CCS is the only technology available today to deeply decarbonise energy-intensive industry, including steel and cement.[32] The ability of CCS to be developed in these sectors could ensure these industries survive in the UK as the economy transitions to net-zero.

Decarbonising hydrogen

The Committee on Climate Change estimates that by 2050 hydrogen production capacity of comparable size to the UK's current fleet of gas-fired power stations will be needed to achieve net-zero.[33] There are roughly 20 methods to produce hydrogen and research is ongoing to make them more cost-effective alternatives to natural gas.[34] The production of low-carbon hydrogen at scale will rely on deployment of CCS.[35] The pre-combustion carbon capture method outlined above can be used to produce hydrogen, which in turn can be used not only to fuel electricity generation and industry but also, in the future, to power vehicles and heat homes with near-zero emissions.[36]

International comparators

According to the Global CCS Institute, in 2019 there were 51 large-scale CCS facilities across the world in various stages of development and operation. The facilities currently operating or under construction will have the capacity to capture and store around 40 million tonnes of CO_2 annually. In addition to the current large-scale facilities, there are 39 pilot and demonstration-scale CCS facilities (operating or about to be commissioned) and 9 CCS test centres globally.[37]

[28] CCS Association (2020) Why CCS?; Committee for Climate Change (2019) Net Zero – The UK's Contribution to Stopping Global Warming
[29] BEIS (2020) Final UK Greenhouse Gas Emissions National Statistics: 1990 to 2018
[30] National Statistics (2020) UK Renewable Electricity Capacity and Generation, July to September 2019
[31] National Infrastructure Commission (2020) Net Zero: Opportunities for the Power Sector
[32] Energy Transition Commission (2018) Mission Possible
[33] Committee for Climate Change (2019) Net Zero – The UK's Contribution to Stopping Global Warming
[34] Parliamentary Office of Science and Technology (2017) Decarbonising the Gas Network
[35] Committee on Climate Change (2018) Hydrogen in a Low-Carbon Economy
[36] CCS Association (2020) Pre-Combustion Capture
[37] Global CCS Institute (2019) Global Status of CCS 2019

It is estimated that globally 12 gigatonnes of CO_2 will need to be removed annually by 2100, to have a high likelihood of limiting global warming to 1.5°C as envisaged in the Paris Agreement.[38] The International Energy Agency forecasts that 2.3 gigatonnes of CO_2 must be stored annually by 2060. Forecasts show we are not on track to deliver this.[39]

CCS technologies have been particularly attractive to economies with rich fossil fuel resources, such as Norway, Canada, Australia, the US and China. The first large-scale CCS project began operating in 1996 at Sleipner in Norway and since then about one million tonnes of CO_2 from natural gas has been captured and stored each year at the site.[40] In contrast, the recently established Gorgon natural gas processing plant off the coast of Western Australia will be the world's largest dedicated geological CO_2 storage facility when it ramps up to full capacity, storing up to 4 million tonnes of CO_2 per year.[41]

Canada is rated first in the Global CCS Institute's global CCS Readiness Index.[42] Canadian governments have committed around CAD $1.8 billion to CCS initiatives over the last few years.[43] A flagship example in Canada is the Shell-operated Quest Project in Alberta. The project captures CO_2 from the manufacture of hydrogen for upgrading bitumen into synthetic crude oil. The CO_2 is transported by a 65-kilometre pipeline and stored more than 2 kilometres underground in dedicated rock formations. Around four years after operations commenced, Quest had captured and stored more than four million tonnes of CO_2, roughly equal to the emissions from about one million cars.[44]

The Alberta Carbon Trunk Line, a 240-kilometre CO_2 pipeline, is expected to come online in 2020. It will offer CO_2 transport services to industry in Alberta, with North West Redwater Partnership's Sturgeon refinery and the Agrium fertiliser plant expected to jointly supply around 1.6 million tonnes of CO_2 annually via the pipeline.[45]

More than half of global large-scale CCS facilities are in the US, with a combined capacity to capture more than 25 million tonnes per annum.[46] Sustained government support, including the CCS-specific 45Q tax credit and further state-based mechanisms, have positioned the US as a global CCS leader. The US is well positioned to maximise CCS opportunities due to the political and economic characteristics of its energy economy, supportive regulatory environment, resource wealth and innovation-driven manufacturing sector.[47]

China leads CCS activity across the Asia Pacific region, with one large-scale facility in operation, two in construction and five in early development. Given that China contributes almost one third of the world's CO_2 emissions, there are big opportunities for the technology in China.[48] Before 2018, China had a broad portfolio of activities focused on CCS through directives and incentives issued by various levels of government. Since then, the Chinese Government has restructured its approach to general environmental management towards a more coordinated approach, combining emissions reductions with air pollution controls, to stimulate new industries and jobs. Still Chinese policies tend to be focused on supporting individual projects (which are not always well publicised), rather than measures to support the CCS industry as a whole.[49]

The public's expectations on climate change mitigation

Given CCS technology's potential, it attracts much attention from the industry, government and the scientific community. However, public awareness of the technology is very low, and studies of the public's opinion have been launched only during the last decade. Given the importance of popular support in the implementation of major infrastructure projects similar to CCS, researchers emphasise the need to focus on issues of social acceptance.[50] New CCS initiatives would

[38] Fajardy, M., et al. (2019) Grantham Institute Briefing Paper No 28: BECCS Deployment: A Reality Check
[39] International Energy Agency (2017) Energy Technology Perspectives 2017
[40] Equinor (2019) Sleipner Partnership Releases CO2 Storage Data
[41] Global CCS Institute (2019) Global Status of CCS 2019
[42] Global CCS Institute (2020) CCS Readiness Index
[43] Natural Resources Canada (2018) Carbon Capture and Storage: Canada's Technology Demonstration Leadership
[44] Shell (2019) Carbon Capture: The Quest for Cleaner Energy
[45] Global CCS Institute (2019) Global Status of CCS 2019
[46] Beck, L. (2020) Carbon Capture and Storage in the USA: The Role of US Innovation Leadership in Climate-Technology Commercialization, *Clean Energy*, 4(1):2–11
[47] Ibid
[48] Global CCS Institute (2019) Global Status of CCS 2019
[49] Global CCS Institute (2018) Carbon Capture and Storage in De-Carbonising the Chinese Economy
[50] Tcvetkov, P., et al. (2019) Public Perception of Carbon Capture and Storage: A State-of-the-Art Overview, *Heliyon,* 5(12)

likely require extensive public communication and engagement efforts from industry and the government, disseminating generic and project-specific CCS information.

A range of opinion polls have explored British perceptions of climate change. A 2019 Opinium poll found that 63% of the British public think they are in a climate emergency and 64% think the government should take action.[51] Similarly, Ipsos Mori polling found that public concern around climate change has reached record levels, with 85% of British adults now expressing concern, which is up from the 82% a similar poll recorded in 2005.[52] That same Ipsos Mori polling found that a majority (55%) of British adults believe that the net-zero target should be achieved before 2050.[53]

Alternatives to carbon capture and storage

While CCS has an important role to play, it should be considered alongside a raft of other emissions reductions measures. To meet the net-zero target, the Committee on Climate Change emphasises the importance of low-carbon fuels such as hydrogen, electrification of transport and heating, societal changes to reduce carbon consumption and land use change. CCS is not a substitute for no-or-low-carbon changes to current carbon-intensive energy generation and industrial processes (e.g. renewable energy or low-carbon cement), but is complementary, to support the transition to net-zero by 2050.[54] Some jurisdictions, such as the Netherlands, do not provide public support for CCS where cost-effective alternatives, such as renewable energy generation, exist.

But it is increasingly clear that reducing emissions is not enough – and we will also need to actively remove greenhouse gases from the atmosphere.[55] In this way, CCS and other greenhouse gas removal technologies have a role as longer-term solutions where suitable low-carbon alternatives cannot be found (e.g. agricultural land use or aviation).

There is a wide variety of approaches for removing greenhouse gases from the atmosphere. In contrast to CCS technologies, many of these processes are natural. Already, vegetation in the UK removes an estimated 28 million tonnes of the UK's 351.5 million tonnes of total CO_2 a year.[56] But greenhouse gas removal methods require resources, like land, energy or water, placing limits on the scale and location of their application, and leading to resource competition between them and with other human activities, such as food production.[57]

Afforestation, reforestation and forest management

As trees grow, they absorb CO_2 from the atmosphere and store it in living biomass, dead organic matter and soils. Afforestation and reforestation – sometimes referred to collectively as 'forestation' – facilitate this process of carbon removal by establishing or re-establishing forest areas.[58] Potentials for carbon removal from forestation vary from 3 to 18 gigatonnes of CO_2 per year, depending on land availability.[59]

Wetland, peatland and coastal habitat restoration

Wetland, peatland and coastal habitat restoration rely on the restoration or construction of high-carbon-density ecosystems as a mechanism for removing CO_2 from the atmosphere.[60] Peatlands and coastal wetlands have been estimated to store between 44 and 71% of the world's land biological carbon.[61] The UK has 0.45 million hectares of salt

[51] Opinium (2019) Two-Thirds of Britons Agree Planet is in a Climate Emergency
[52] Ipsos Mori (2019) Concern about Climate Change Reaches Record Levels with Half Now 'Very Concerned'
[53] Ibid
[54] Committee for Climate Change (2019) Net Zero – The UK's Contribution to Stopping Global Warming
[55] The Royal Society and Royal Academy of Engineering (2018) Greenhouse Gas Removal
[56] ONS (2019) UK Environmental Accounts: 2019; BEIS (2020) 2019 UK Greenhouse Gas Emissions, Provisional Figures
[57] The Royal Society and Royal Academy of Engineering (2018) Greenhouse Gas Removal
[58] Ibid
[59] Griscom, B., et al. (2017) Natural Climate Solutions, *Proceedings of the National Academy of Sciences*, 114(44):11645–50
[60] The Royal Society and Royal Academy of Engineering (2018) Greenhouse Gas Removal
[61] Zedler, J. and Kercher, S. (2005) Wetland Resources: Status, Trends, Ecosystem Services and Restorability, *Annual Review of Environment and Resources*, 30(1):39–74

marsh, 0.8 million hectares of freshwater wetland and between 9 and 15% of Europe's peatland area, 2.7 million hectares, of which 80% is considered to be in poor condition, thus providing restoration opportunities.[62]

Soil carbon sequestration

Soil carbon sequestration is the process of removing CO_2 from the atmosphere by changing land management practices (for example, cropland and grassland management) in such a way as to increase the carbon content of soil. The level of carbon in the soil is determined by a balance of carbon inputs (for example, from litter, residues, roots or manure) and carbon losses (mostly through respiration, increased by soil disturbance).[63] Estimates for the UK potential for soil carbon sequestration are between 1 and 31 million tonnes of CO_2 per year.[64]

In addition to the methods listed above, there are a number of other greenhouse gas removal approaches, including biochar, ocean fertilisation and alkalinity, mineral carbonation, enhanced terrestrial weathering and low-carbon concrete. These methods are at various stages of development and impact the environment in different ways. To be economic and pursued at scale, most greenhouse gas removal requires a suitable price on carbon or other government incentive system.[65] Largescale greenhouse gas removal processes such as CCS are challenging and expensive, and not a replacement for reducing emissions.[66]

About ICE

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For more information please contact:

Alex Hardy, Policy Manager, ICE

policy@ice.org.uk

[62] IUCN Peatland Programme (2011) Commission of Inquiry on Peatlands
[63] The Royal Society and Royal Academy of Engineering (2018) Greenhouse Gas Removal
[64] Smith, P., et al. (2016) Preliminary Assessment of the Potential for, and Limitations to, Terrestrial Negative Emission Technologies in the UK, *Environmental Science: Processes & Impacts*, 18(11):1400–5
[65] The Royal Society and Royal Academy of Engineering (2018) Greenhouse Gas Removal
[66] Ibid