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Scotland's Energy Strategy: The role of carbon dioxide capture and permanent storage

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Authors:
Dr Peter Brownsort, Scientific Research Officer,
Dr Vivian Scott, Policy Officer
Scottish Carbon Capture & Storage

Scottish Carbon Capture & Storage
Edinburgh Centre for Carbon Innovation
High School Yards, Infirmary Street, Edinburgh, EH1 1LZ
Telephone +44 (0)131 651 4647 www.sccs.org.uk

Scotland's Energy Strategy: the role of carbon dioxide capture and permanent storage

A briefing to Scottish Government

This briefing from Scottish Carbon Capture & Storage (SCCS)[1] sets out reasons for Scottish Government continuing to provide positive support for technologies and infrastructure that capture carbon dioxide (CO_2) from emissions and permanently store it in geological formations. Such technologies, collectively known as carbon capture and storage (CCS), are complementary to several options being pursued for decarbonisation of the energy system. Including CCS in Scotland's whole energy-system strategy can make other options more effective and will be needed to extend the 2032 targets to an ambition of a net zero carbon Scotland in 2050.

SCCS believes that Scottish Government should set out a clear ambition to achieve a net zero carbon economy (beyond the energy system) before 2050.

To further this ambition SCCS recommends that Scottish Government takes a twin-track approach to carbon capture and storage:

> *encouraging near-term, smaller-scale developments to maximise the effectiveness of low-carbon energy actions and CO_2 utilisation opportunities;*
>
> *while in parallel taking all necessary steps to secure existing large-scale infrastructure that can form a cost-efficient basis for large-scale industrial CCS applications.*

History – tarred with the wrong brush

Deployment of CCS technology in Europe and the UK has failed to gain traction for many reasons. One key reason is that it has generally been seen as a monolithic technology most appropriate to large, centralised fossil fuel power generation with resulting very high capital costs and contrary to energy-system development toward decentralised solutions. **This need not be the case.**

Vision – right-sized CCS, a new paradigm

For much of the CCS chain it is possible to start with smaller-scale projects, complementary to and right-sized for matching with other decarbonisation actions that are worthwhile in their own right; these can be made more effective in terms of CO_2 emission reduction by coupling with CCS technologies. Examples are given in supporting pages. The economics would be different from large projects, but there are more ways of achieving acceptable costs than only economy of scale.

The seed – storage infrastructure

The geological storage of CO_2 and transport infrastructure for CCS will need to be large-scale eventually, but even this can be built up sequentially from one or more smaller storage "seed projects". Scotland has a huge advantage here with fully characterised offshore storage sites accessible using existing legacy pipelines. These pipelines are strategic national assets; they should be retained and preserved as a low-cost route to storage in the future for Scotland's large industrial emitters, even though they may not be used for initial, small-scale projects. In this way the value of large public investments already made in this infrastructure can continue to be realised through re-purposing. The storage resource in the Central North Sea is of globally significant scale and gives the opportunity for a new industry satisfying the CO_2 storage needs for the UK and northern Europe. This can be served practically by a ship import solution, which also can be built up sequentially and flexibly.

The fruit – more effective decarbonisation solutions

CCS can complement decarbonisation options being considered in the “hard to treat” energy areas of transport, and domestic and commercial heating. It can complement variability in renewable energy systems both by allowing despatchable low-carbon power generation and by enabling bulk-scale energy storage. It can reduce the life-cycle carbon emissions of many liquid or gaseous fuels – both fossil and bio-based. It can help reduce the carbon-footprint of construction and other materials and it provides a decarbonisation solution to industry – both for inherent process emissions and for energy intensive or high temperature heat needs. Coupled with appropriate bio-energy systems CCS can allow carbon-negative energy production, which can be in the form of both heat and electricity.

The missing link – except that it exists

Transport of CO_2 from capture site to storage site is a key link in the CCS chain. Historically, a pipeline-based system has been envisaged for reasons of economy of scale, but resulting in high capital projections and limited flexibility. Again, this need not be the case. Small-scale, modular CO_2 capture and liquefaction units are available and well established where CO_2 utilisation provides a motivation – indeed one currently operates at a distillery in Edinburgh. Transport of liquefied gases by road tanker, including CO_2, is commonplace and a familiar sight in science campuses and industrial areas. Trains can be used for CO_2 transport over longer distances and coastal and international ship transport of CO_2 is established at a small scale in European waters – with existing terminals in the UK. These modular transport options can be built up sequentially until CO_2 transport volumes justify larger-scale infrastructure development.

The prize – economic opportunity while achieving net zero carbon

Scotland needs to decarbonise its energy system, its economy and its society overall. To achieve the ambition of net zero carbon before 2050 we need to deploy all practical means, methods and technologies: CCS is essential to meeting this target. Its basic action of removing CO_2 from emissions or from the atmosphere (by direct air capture or bio-energy plus CCS) is fundamental to achieving net zero carbon. But CCS is more than just one of several technologies to deploy – it can enhance the effect of other low-carbon actions and it can open new opportunities for decarbonisation, such as the use of hydrogen. By complementing other actions CCS helps achieve affordable and socially acceptable decarbonisation of the energy system.

Scotland holds 35% of European geological storage resources suitable for CO_2. This provides a new area of economic opportunity for industry in the North Sea. Scotland can develop new solutions and services in CO_2 management, creating new jobs while making use of existing skills, capabilities and resources.

Recommendations to Scottish Government

For Scotland to achieve its target to decarbonise the whole energy system in a cost-effective way will require CCS to be implemented, and this will bring opportunities at multiple scales and across many sectors. We believe Scotland should extend its ambition further to plan for an overall net zero carbon economy in line with climate change mitigation science, international policy and Scotland's environmental leadership.

SCCS recommends that Scottish Government pursue a "twin-track" approach to CCS. It should promote near-term, small-scale CCS developments to maximise low-carbon actions, including utilisation opportunities. In parallel, it should take immediate action to retain existing large-scale infrastructure, which can provide a cost-efficient solution for future large-scale industrial CCS applications.

Specifically, we recommend that Scottish Government should:

- Retain the National Transmission System No.10 Feeder onshore pipeline, and appropriate North Sea pipelines including the Goldeneye pipeline and borehole infrastructure and the Atlantic pipeline, avoiding their decommissioning and maintaining them in suitable condition to enable conversion for CO_2 re-use;
- Assess opportunities for small-scale CO_2 capture of emissions from biomass, biogas, fermentation, waste and small combined heat and power (CHP) energy processes to give a low-carbon impact multiplier, together with appropriately scaled options for transport and use or permanent storage;
- Assess opportunities for pilot trials of low-carbon heating using hydrogen for conversion of district-scale gas networks, with hydrogen produced by steam methane reforming coupled with CCS;
- Support investigation and development of seed projects for medium-scale CO_2 storage opportunities.
- Support actions leading towards development and commercialisation of larger-scale CO_2 storage operations, including projects involving cooperation with other states around the North Sea.

[1] Scottish Carbon Capture & Storage is a research partnership of British Geological Survey, Heriot-Watt University, University of Aberdeen, the University of Edinburgh and the University of Strathclyde. Its researchers are engaged in high-level research as well as joint projects with industry to support the development and commercialisation of carbon capture and storage as a climate mitigation technology.

Context, opportunities and examples

Global context

- Global climate system warming responds to cumulative greenhouse gas emissions; achievement of climate stability requires net zero emissions.
- UNFCCC Paris Agreement aims to "achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century" (Article 4).
- Progressive climate actors including nations (Sweden – 2045, Norway – 2030), businesses and institutions (University of Edinburgh – 2040) understand this and are advancing net zero emission targets.
- Scotland is recognised as a climate action and low-carbon energy global leader; a net zero ambition is key to ongoing leadership and green economic growth.

Policy context

- Scotland's long-term climate change targets call for a reduction of greenhouse gas emissions of at least 80% of baseline by 2050.
- Core themes in the Scottish Government's emerging Energy Strategy can be summarised as:
    - Decarbonisation of the whole energy system by 2050.
    - Taking a whole system view with a comprehensive policy prescription covering all aspects of supply through to end use of energy in all forms and sectors.
    - Using a localised approach to energy provision, where possible, with supply and demand matched at a local level and with community involvement, wherever appropriate.
- Scottish Government powers on energy are limited, the UK Government reserves powers on energy market design and mix, emissions trading aspects and European relationships.
- The current UK Government is pursuing a power generation strategy of nuclear renewal, coal phase-out, gas generation and offshore wind.
- Scotland's ambition for whole energy system decarbonisation is for a net zero carbon system, meaning surplus zero carbon energy can be traded to offset carbon import.

Energy systems landscape

Power: Power systems are undergoing a revolution, which is still in its early days. Renewable energy systems and energy efficiency measures have already made a substantial impact. Their ongoing expansion has huge potential, particularly when integrated into distributed energy resource systems, including energy storage (with batteries) and "smart" demand management. Distributed energy resources could become the backbone of a decarbonised energy system suggesting a reduced role for large, baseload generation assets in future. However, the need for some baseload generation will not disappear. Challenges include: the rapid pace of change in scale for distributed energy resources and need for support infrastructures; the need for new regulatory and market models; providing for system stability in terms of smoothing intermittency and voltage/frequency control; delivering sufficient transmission and interconnection capacity; providing for inter-seasonal and reserve power storage.

Heat: There are a variety of low or zero-carbon options for low-grade, domestic and commercial heating, including heat pumps (requiring low-carbon electricity), district heating/heat recovery networks (often gas-fuelled CHP systems, which are efficient but not low-carbon), biomass heating systems (a high uptake in Scotland but with resource supply constraints), and potentially geothermal heat networks (appropriate for limited geographical areas). However, for high-grade and large-scale industrial heat demands there is unlikely to be a practical alternative to combustion of fossil fuels. Hydrogen is potentially a hugely valuable heat vector and is gaining attention rapidly. It has different challenges for retrofitting from other systems with the challenge of bulk supply most likely tackled by large-scale production from natural gas using steam methane reformers, which can be zero carbon when combined with CCS. Repurposing the upgraded gas-grid for hydrogen may allow large-scale pilots in Scotland in segregated areas of the grid.

Transport: Deployment of electric vehicles is increasing for light vehicles and their batteries have a potential role in power storage. Development of charging infrastructure for electric vehicles is a challenge, but commercial pathways are known. However, heavy goods vehicles require different systems so hydrogen, if available in bulk at low or zero-carbon intensity, may provide a solution either through combustion engines or fuel cells. Air travel is a further challenge, which may be an appropriate use of liquid biofuels, which otherwise are likely to be constrained through supply chain sustainability issues.

Industry: Apart from the ongoing requirement of fossil fuels for high-grade heat in industry, mentioned above, hydrocarbons will very likely remain key feedstocks for industry as many materials and products are dependent on carbon-based polymers. Additionally, several important industrial processes (iron and steel making, some refinery and some chemicals processes, fertiliser production, cement and lime production) release CO_2 from their fundamental chemical processes, the emissions are inherent to these processes and the products cannot be manufactured without such emissions.

CCS in context with Scotland's Energy Strategy

In contrast to the failed historical model for CCS deployment, a near-term alternative pathway of smaller-scale project investments can be conceived. This would align well with Scottish Government's future energy system ambitions, complementing other low-carbon energy actions and integrating with a distributed energy resources system. This would be a "no regrets" pathway that would complement a parallel, phased development of larger-scale CCS systems.

CCS can complement other low-carbon energy actions in a number of ways – the main ones are listed in the box adjacent. Some are related to national-scale energy systems and industrial strategies and align better with large-scale CCS developments, while others can be applied at small- to mid-scale and can enhance the emission reduction potential of low-carbon developments that are worthwhile in their own right, giving rise to a multiplier effect. Some examples follow.

How CCS complements decarbonisation across the energy system

- Complementing variability in renewable energy systems (RES) – despatchable low-carbon power from e.g. gas generation plus CCS (**Power)**
- Reducing carbon intensity of materials used in RES – CCS on industrial production of steel and cement to avoid inherent process emissions (**Industry**)
- Decarbonising domestic and commercial heat supplies – through use of bulk-scale hydrogen plus CCS (**Heat**)
- Decarbonising surface transport – through use of bulk-scale hydrogen plus CCS – can tackle heavy transport, buses, trucks, potentially shipping (**Transport**)
- Decarbonising domestic and commercial heat supplies – through CCS on district heating/CHP schemes (**Heat**)
- Reducing carbon intensity of transport fuels – through CCS on refinery operations, including bio-refinery operations (**Transport**)
- Allowing carbon negative electricity production – through biomass combustion plus CCS (BECCS) (**Power**)
- Allowing carbon negative liquid fuel production - through bioethanol fermentation (**Transport**)
- Reducing carbon intensity of some natural gas supplies – through CCS on gas separation operations (**Heat**)(**Power**)
- Reducing carbon intensity of biogas – through CCS on gas separation operations (**Heat**)(**Power**)
- Reducing carbon intensity of landfill gas – through CCS on gas separation operations (**Heat**)(**Power**)

Biogas and landfill gas

Both biogas from anaerobic digestion and landfill gas in their crude states typically contain large proportions of CO_2, up to around 50%, as well as the desired methane content. The gas mixtures are generally either combusted directly for heat and power generation, which will give a CO_2-rich flue gas, or they may be upgraded by separating CO_2 to give a higher value bio-methane product of a quality that can be supplied to the gas-grid. These CO_2 streams are usually vented to the atmosphere but they could be captured using established technologies, allowing bio-methane to be a carbon-negative fuel, providing the CO_2 is securely stored. In Scotland in 2014 the fifteen largest landfill sites emitted over 375,000 tonnes of CO_2 (t-CO_2) and eight sewage treatment sites emitted over 165,000 t-CO_2, although not all of this will have resulted from biogas production.[2] Globally, CO_2 separation from fossil natural gas production is the largest source of captured CO_2 for both storage and utilisation;[3] separation from biogas and landfill gas can use the same technology.

Biomass

The use of biomass in Scotland for heat, or combined heat and power, is growing strongly. CO_2 emissions from biomass combustion are not generally the subject of focus, as they are considered largely carbon-neutral. However, the total CO_2 emission from biomass combustion for heat/CHP in 2015 was approximately 1.5 million tonnes (Mt).[4] Capturing and storing a proportion of this would, in effect, represent a negative emission; such negative emission technologies are considered vital to the achievement of stable climate scenarios and Scotland could take a leading role in developing the field. Many biomass combustion installations are of very small scale and may never be appropriate for CCS, but more than half the heat output from biomass in 2015 was from just six larger sites, each with CO_2 emissions estimated in the range 40,000 to 400,000 tonnes CO_2 per year (t-CO_2/yr). giving the potential for mid-scale carbon-negative projects.[2,4]

Fermentation

Another source of biogenic, carbon-neutral CO_2 emission that can be captured to give a carbon-negative effect is the fermentation industry – brewing and distilling. CO_2 capture from fermentation for reuse within the food and drink sector is an established technology that has been used globally for decades, although seems now to be in decline; one continuing Scottish example is a distillery in Edinburgh that captures around 20,000 t-CO_2/yr for its own re-use and for sale.[5] Fermentation in bioethanol production for fuel use is also an established source for captured CO_2, both for industrial use and for geological storage.[6] In Scotland a small number of large grain distilleries emit a total of around 160,000 t-CO_2/yr from fermentation, with individual site emissions estimated in the range 5,000 to 50,000 t-CO_2/yr.[7]

Energy-from-waste

The small number of energy-from-waste facilities existing and under development in Scotland have CO_2 emissions in the 10,000s to small 100,000s t-CO_2/yr range and these could be captured using established technologies. The plans for the Norwegian CCS demonstration projects include CO_2 capture and storage of 300,000 t-CO_2/yr from the energy-from-waste facility serving Oslo.[8]

Heat networks

The use of heat networks plays a key role in Scottish Government's plans for decarbonisation of the heat sector. These include residential heating schemes and institutional, commercial or industrial networks; some involve CHP and a variety of primary energy sources are used. Many existing heat networks involve the use of gas boilers or gas-fuelled CHP systems at scales ranging from sub-megawatt to hundreds of megawatts for industrial systems. Some larger systems have been proposed for regional-scale industrial CCS clusters,[9] while small- to mid-scale systems have so far been largely overlooked for CCS. However, developments in fuel cell technology being trialled in Canada and the USA may provide a cost- and energy-efficient method of capturing CO_2 from smaller gas-fuelled systems. In a pilot project at the University of Calgary a methane-fuelled, high-temperature carbonate fuel cell will be coupled to an existing gas-fuelled 14 megawatt (MW) CHP unit. The fuel cell will generate an additional electrical and heat output (which could reduce demand on the CHP unit or provide extra revenue) while capturing the CO_2 from gas combustion as a pure stream.[10] This technology could be retrofitted to many small to mid-sized gas-fuelled district heat and CHP systems in Scotland.

Hydrogen

Hydrogen has great potential as a low-carbon energy vector if its production is coupled with CCS. Its main advantages will come with low-cost, bulk-scale production and use; small-scale stand-alone projects are less likely. The exception may be for pilot trials, for instance in hydrogen-powered vehicle fleets, or in limited area domestic gas distribution networks. Relatively small-scale hydrogen production plant using steam methane reforming is available and could be coupled with a number of different CO_2 capture technologies. In Japan, the Tomakomai CCS project currently captures 100,000 t-CO_2/yr and injects it for permanent storage close offshore.[11] This CO_2 is captured from hydrogen production at a refinery. The current rate of capture is equivalent to production of approximately 18,200 tonnes of hydrogen per year, which would have a nominal energy value of about 700 megawatt-hours,[12] enough for 50,000 average households in Scotland.[13]

Transport and storage

All these examples of potential smaller-scale carbon capture opportunities need to be matched with appropriately sized CO_2 liquefaction and transport options for this proposed "bottom-up" development of CCS to be deployed; and there needs to be a prospect of a permanent CO_2 storage solution or a viable utilisation market.

Currently, small-scale liquefaction and transport systems are available commercially and in routine use for the production and distribution of liquid CO_2 to the industrial gas and food and drink markets. There are several suppliers of small-scale capture and liquefaction equipment down to a scale of around 20 t-CO_2/day, or 7,300 t-CO_2/yr (roughly the emission from a 2 MW-thermal biomass boiler, suitable for a small commercial or institutional heat network) and one supplier lists plant available down to 3.5 t-CO_2/day, or 1,300 t-CO_2/yr.[14] At the 20 t-CO_2/day scale, one road tanker per day would be sufficient for transport to a logistics hub, which could consolidate volumes for transport by train (currently uncommon) or by ship, which is an established method for CO_2 transport in European waters.[15] Some intermediate storage between transport modes would be required, using surface tanks. Such a transport chain would deliver CO_2 either direct to a storage site or to a pipeline entry point for delivery to the storage site.

Utilisation and storage

Many of the smaller CO_2 capture, liquefaction and transport systems and services available and in operation today form part of the current industrial gas and food-grade CO_2 supply chain. There may be opportunities for sales into this market for further small capture operations, although the market is already well supplied. Increasing interest in carbon capture and utilisation technologies may help to grow this market and build new value opportunities for small CO_2 capture operations. However, few CO_2 utilisation technologies lead to long-term storage of CO_2, as necessary to mitigate climate change, and a permanent storage solution is required to achieve Scotland's net zero carbon ambitions. This indicates the need for strategic investment in a geological storage solution using North Sea resources. This can start as a relatively small-scale operation reusing some existing infrastructure,[16] leading to realisation of a large-scale offshore storage network of national and international significance and a huge opportunity for new economic value from the North Sea region.

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