Executive Summary

June 2016

Actions required to develop a roadmap towards a Carbon Dioxide Utilisation Strategy for Scotland

Grant Agreement nº 424886

This Executive Summary provides an overview of the detailed report *"Actions required to develop a* roadmap towards a Carbon Dioxide Utilisation Strategy for Scotland (2016)", which was commissioned by Scottish Enterprise. It presents a number of carbon dioxide (CO_2) Utilisation opportunities and recommendations for Scotland to explore and develop its potential in this area

Why should Scotland be interested in CO_2 Utilisation?

CO_2 Utilisation or Carbon Capture and Utilisation (CCU) holds out the promise of providing economic activity in Scotland by re-using its CO_2 as a feedstock to create various products. This economic activity has the potential to help Scotland shift to a lower-carbon, more sustainable and more circular economy through better management and re-use of its carbon, and in particular, by helping Scotland to develop its CO_2 resource by giving it a value.

CCU offers the potential to take certain carbon emissions and use them as a feedstock to produce carbon-based products such as inorganic fertiliser, fuels, chemicals and building materials. CCU also offers the potential to store 'surplus' electricity at times of oversupply via the creation of synthetic hydrocarbons. A mixture of hydrogen (produced by electrolysers) and carbon monoxide produced from CO_2 is termed 'syngas', which can be used as a feedstock to create various types of synthetic hydrocarbon fuels via various catalytic routes.

Carbon Capture and Storage (CCS) and the re-use of carbon through CO_2 Utilisation (CCU) should **both** be part of Scotland's overall strategy for CO_2 management. The two avenues are considered to be **complementary**. Both share the potential to be significant future growth areas for Scotland, which will be governed by market developments at a policy level, as well as technological advances and sufficient levels of Government investment in infrastructure. Whilst the applications for CO_2 are varied, the potential near-term demand for CO_2 relative to the scale of supply of Scotland's CO_2 emissions is low, to the extent that CCU **SHOULD NOT** be considered a substitute to CCS when looking to tackle and mitigate the scale of Scotland's CO_2 emissions. CCS and CCU are aiming for very different scales of deployment.

Scottish CO_2 supply versus demand

As shown in Figure 1, in 2014 there were approximately 10 million tonnes of CO_2 emissions from Scotland's large carbon emitters, (those with >10,000 tonnes of CO_2 per year), of which an estimated capture potential of around 4.3 million tonnes has been identified. Of this estimated capture potential, 3.1 million tonnes are located within 50 miles of Grangemouth. This presents a large centralised 'supply' opportunity when compared with the current demand for CO_2 across Scotland, which is estimated at just 200,000 tonnes per year. The existing use of CO_2 is varied and includes the following sectors: Food & Beverage, Chemicals, Pharmaceuticals, Petroleum, Metals, Manufacturing, Construction, and Health Care.

Figure 2 displays a breakdown of the 10 million tonnes of CO_2 per year from the large emitters across various energy and industrial sectors. Most of the CO_2 emissions are derived from fossil carbon sources but there are significant sources of biogenic CO_2 emissions that include the brewing and distilling sector, and bioenergy plants, *i.e.* biomass/waste combustion and anaerobic digestion.

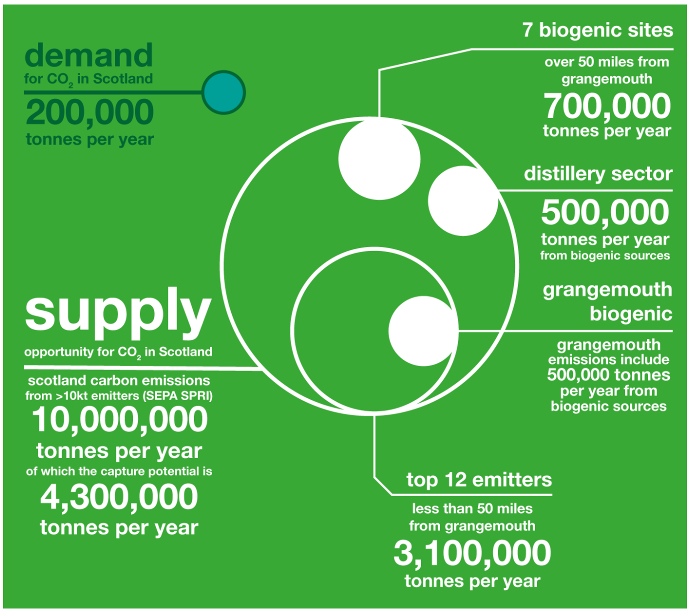


Figure 1

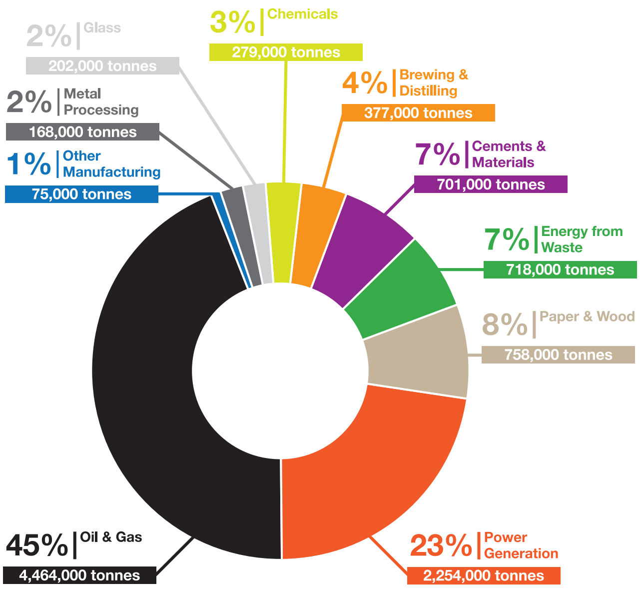
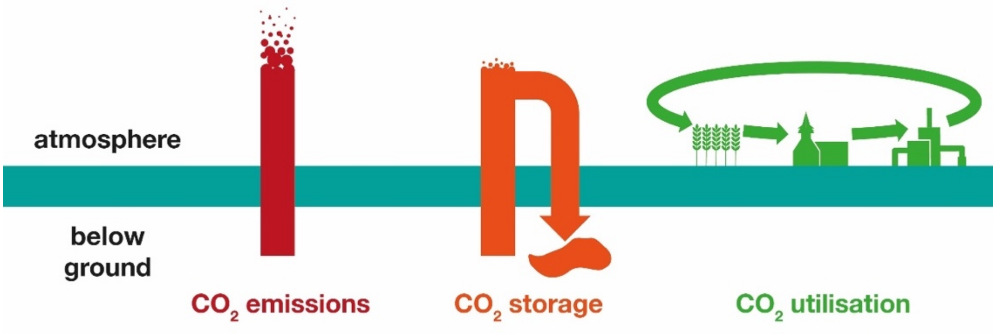


Figure 2

Carbon dioxide (CO_2)

Carbon dioxide is vital to life, but is also a greenhouse gas responsible for climate change, and a major cause of ocean acidification. There are two main types of CO_2: fossil and biogenic. Fossil CO_2 is generated from the combustion of fossil fuels (coal, gas, oil) or from the thermal decomposition of limestone (in types of cement production). If fossil CO_2 is released into the atmosphere it is therefore additional atmospheric CO_2 as the carbon was originally underground (in anthropogenic timeframes). Biogenic CO_2 on the other hand is CO_2 that is generated from a process such as malt fermentation or biomass combustion. The carbon for this originates from a biological source of carbon rather than a fossil source, typically biomass created via photosynthesis that has removed CO_2 from the atmosphere. Biogenic sources of CO_2 are therefore usually considered to be carbon neutral rather than adding to the level of CO_2 in the atmosphere.

*Once CO_2 is generated, it can be **emitted**, **mitigated** or **utilised**.*



In Scotland, the majority of primary **energy** supplies (*including* oil for transport fuels and natural gas for heating) and chemical feedstocks are from fossil derived sources. This is due to the cost and maturity of the supply chains of these in comparison to alternatives. However, the use of fossil sources can be considered to be part of a linear type of economy (**make-use-dispose**), which increasingly is viewed as an unsustainable form of activity. Future economic activity needs to move to a more circular economy (**make-use-recycle**) to become more sustainable, and the capture and reuse of CO_2 could offer a significant opportunity.

Carbon capture and storage (CCS)

Carbon capture and storage is a climate change mitigation process involving the capture of CO_2 from a power station or industrial emissions source (iCCS) before it reaches the atmosphere, its transportation to a storage site, and its injection into deep underground porous geological formations, where it is stored over the long-term. CCS can provide a large scale, mitigation opportunity for major CO_2 emitters near centralised infrastructure and could enable Grangemouth in central Scotland to become one of Europe's major low carbon manufacturing hubs in the future.

CO_2 Enhanced Oil Recovery (CO_2-EOR) could use the captured CO_2 from large emitters such as power stations or industrial sources to yield additional oil from hydrocarbon reservoirs. This technique has been used in the USA for many decades, by using significant levels of CO_2 from natural hydrocarbon gas reservoirs that contain CO_2 as an impurity. Development of CO_2-EOR in Scotland from large industrial sources would have significant infrastructure requirements, which could help the development of iCCS.

Carbon Capture and Utilisation (CCU)

CO_2 Utilisation or CCU provides a way to integrate CO_2 into the circular economy, with CO_2 used as a feedstock to make products such as CO_2-derived fuels, chemical feedstocks or inorganic fertilisers. Many CO_2 Utilisation processes require an input of energy, which should be from a low-carbon source. As the world transitions to products with lower environmental impacts, it will need access to lower impact feedstocks and fuels to create these products. CO_2 Utilisation offers a route to provide the carbon needed for lower impact products (as the carbon is being re-used), but due to the low cost of 'virgin' carbon from fossil fuel sources, there is currently little market pull through.

Scotland's Whisky sector has undergone significant expansion over the last 30 years. This sector produces an historically underutilised by-product in the form of high purity biogenic CO_2 from the fermentation of malted barley and grains. Certain CO_2 Utilisation technologies provide the potential to add value to this resource.

In the medium to long-term, if CCS is able to provide the industrial complexes at Grangemouth with a long-term low-carbon future through world leading low carbon manufacturing, CO_2 Utilisation is likely to find a role to play here too.

Grangemouth

Grangemouth is clearly the location for any longer-term strategic aspiration to create a CO_2 Utilisation hub of scale in Scotland, as the location houses the majority of Scotland's large emitters and has straightforward tie-ins to identified potential CCS infrastructure. Grangemouth is Scotland's largest manufacturing region, with a deep and broad chemical sciences knowledge base and its associated supply chains. Half of the 20 largest Scottish carbon emitters are in the Grangemouth Region, with 12 CO_2 emitters within 50 miles of Grangemouth producing CO_2 with an estimated capture potential of 3.1 million tonnes per year. As Grangemouth develops its potential as an Industrial Biotechnology cluster, there are likely to be synergies and industrial symbiotic opportunities that use CO_2 to provide additional value. The map on the following page displays the location of Scotland's reported onshore large emitting CO_2 sources and highlights some CCU opportunities for Scotland.

Specialist Chemicals

Early stage research in CO_2 derived specialist chemicals is primarily focused on the development of highly efficient catalysts giving faster reaction rates, reduced energy requirements and high product selectivity. Products include linear carbonates, cyclic carbonates and polymers. One major advantage of CO_2 utilisation as a feedstock is its comparative safety when compared to current reagents such as phosgene. Using CO_2 as a renewable feedstock in the production of polymers is an advancing technology. Polyols derived from CO_2 are being used in the production of polyurethane foams for use in furniture and mattresses. Adhesives, resins and fillers derived from CO_2 are also reaching the construction materials market.

CO_2 Derived Fuels

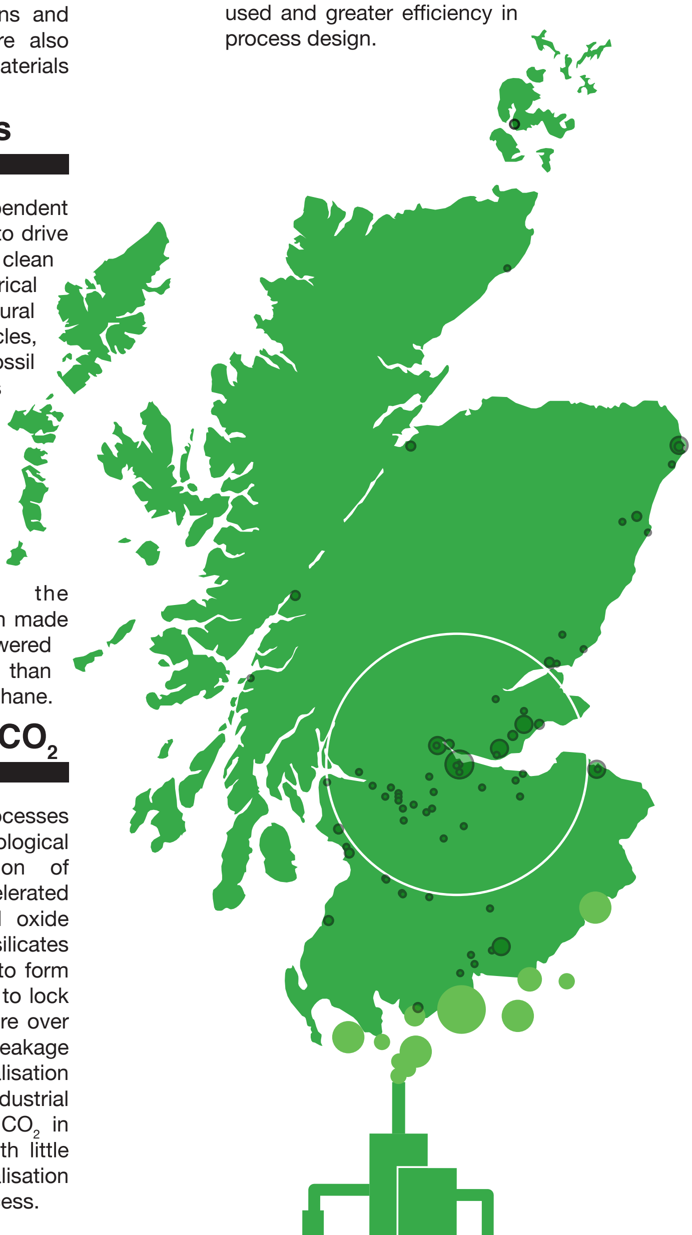
The transport sector is dependent on liquid hydrocarbon fuels to drive combustion engines. New clean technology is enabling electrical vehicles (full and hybrid), natural gas vehicles, fuel cell vehicles, and liquid fuels from non-fossil sources. There are advances in liquid fuels manufacture from biofuels and from gas-to-liquids which transform methane into syngas and then into a range of liquid fuels. Ideally the syngas would be made CO_2 rather than methane as the carbon source and hydrogen made from renewable energy powered electrolysis of water rather than the steam reformation of methane.

Mineralisation of CO_2

Mimicking natural processes normally completed over geological timescales, the carbonation of minerals is based on the accelerated reaction of CO_2 with metal oxide bearing minerals such as silicates of calcium and magnesium to form inert carbonates that serves to lock carbon out of the atmosphere over the long-term in a stable, leakage free manner. CO_2 mineralisation can be completed with industrial CO_2 process emissions or CO_2 in combustion flue streams with little pre-treatment, as the mineralisation step itself is the capture process.

Chemical Feedstocks

The feedstocks for the extensive manufacturing industry centred at Grangemouth predominantly derive from fossil fuels. A number of chemicals and their feedstocks can be derived from CO_2, i.e. methanol, urea, dimethylether, olefins etc. Supercritical and liquid CO_2 is classified as a green solvent and has a role to play in the bulk chemical industry replacing many more hazardous and environmentally damaging solvents, although ultimately the CO_2 will still be released to the atmosphere upon use. However, CO_2 can act as a switch which enables the solvent to change its properties allowing smaller volumes of solvent to be used and greater efficiency in process design.



Inorganic Fertiliser

Scotland currently imports all of its inorganic fertiliser demand. CO_2 can be utilised to produce a pelletised carbonate type fertiliser that can be spread on fields with existing farm machinery. Biogenic CO_2 derived fertilisers align with Scotland's ambition to be a world leader in Green farming by providing a circular use of biogenic carbon coupled with low carbon energy inputs that could also potentially increase the soil organic matter too.

Carbon Capture & Storage (CCS)

CCS involves the capture of CO_2 from a power station or industrial emissions source, transportation to a storage site and injection into deep underground porous geological formations. The North Sea basin is host to several world class offshore locations for the storage of CO_2. The main conceptual difference CCS and CCU is that the utilisation sector see CO_2 as a resource for re-use, whereas the storage sector regards CO_2 as an emission to be sequestered. The main practical difference is one of scale. To provide its primary goal of protecting the atmosphere, worldwide CCS needs to scale up to billions of tonnes of CO_2 per annum to help address the scale of carbon emissions. Over the near term CCU will be limited in its scale, as time is needed to develop products and market size.

CO_2 EOR

Rather than simply capturing and storing CO_2 with little additional economic benefit beyond the CO_2 capture and transport supply chain, Scotland could use the captured industrial and power sector CO_2 emissions to provide a working fluid to enhance oil and gas recovery via CO_2-EOR. The technique would be used to extend the economic life of the North Sea basin by allowing a greater amount of hydrocarbons to be extracted.

Key

10,000 tonnes

500,000 tonnes

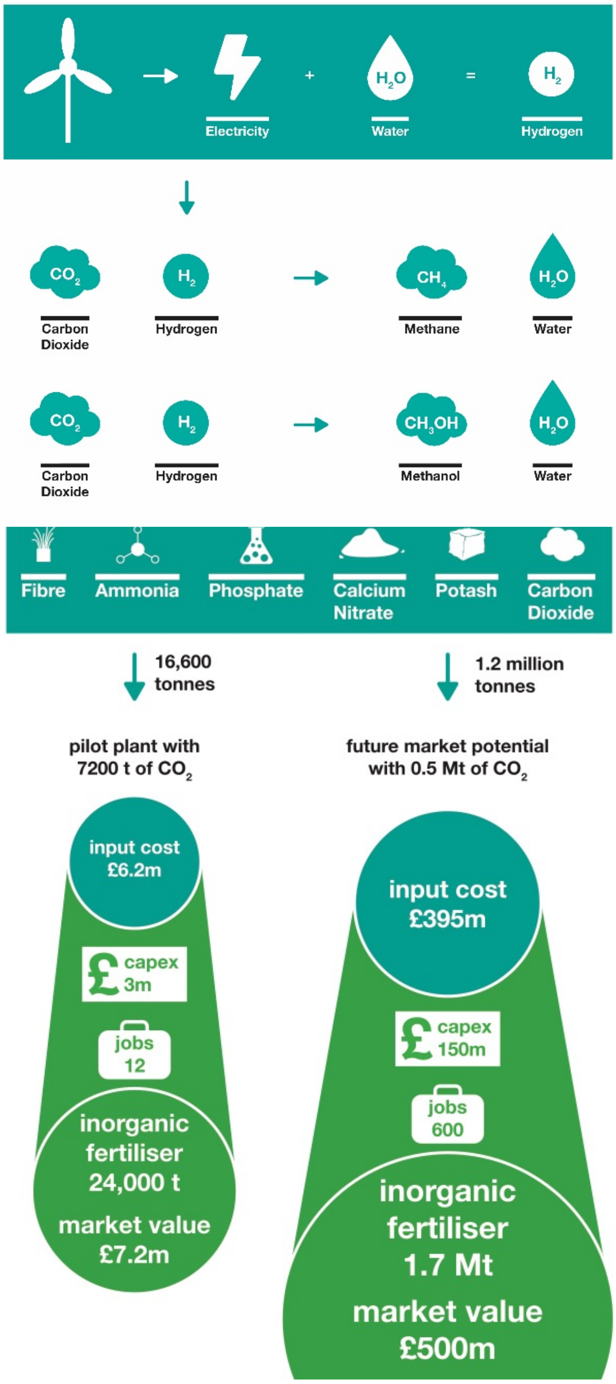
1,000,000 tonnes

50 miles from Grangemouth

Case Study: Inorganic fertiliser

Currently Scotland imports an estimated £200m of fertiliser each year. These imports could be substituted by sustainable inorganic fertiliser produced in Scotland using biogenic CO_2 and renewable ammonia as feedstocks. Using renewable energy to drive the process would significantly help areas like the North East, affected with both soil degradation and increasing renewables curtailment. Using biogenic CO_2 from whisky distillers as an input to this fertiliser process would provide a valuable carbon loop between the food and drink and agricultural sectors. Sustainable inorganic fertiliser saves 6 tonnes of CO_2 for every tonne of fertiliser made in comparison to the conventional approach, and so would also help the Scottish agricultural sector tackle its significant decarbonisation challenge.

When five materials, totalling 16,600 tonnes are combined with 7200 tonnes of CO_2 through a £3m pilot plant run by 12 staff they create 24,000 tonnes of inorganic fertiliser with an estimated market value of £7.2m. When this is extrapolated for the 500,000 tonnes of biogenic CO_2 estimated to be available across the distilling sector, a market valued at £500m could be created, sustaining 600 new jobs and a potentially a new Scottish export of renewable inorganic fertilisers.



CO_2 derived synthetic fuels

With increasing amounts of weather dependent renewable generation there are significant risks that Scotland will have to curtail an increasing amount of renewable electrical generation each year in order to keep the electrical system in balance. Rather than being curtailed, this 'surplus' renewable electricity could instead be used to generate hydrogen through the electrolysis of water. This renewable hydrogen can in turn be combined with CO_2 (either fossil or biogenic) to create synthetic fuels such as methane or methanol. This provides a scalable means to store significant amounts of energy. Synthetic fuels can be created to have local air quality pollution benefits with reduced oxides of Nitrogen (NO_x), Sulphur (SO_x) and particulates as products of combustion.

Importantly, synthetic fuels also offer a way to decarbonise parts of the transport sector such as aviation, which is thought to require the energy density and safety afforded by liquid fuels for the foreseeable future.

Conclusions and recommended actions to develop a CCU Roadmap for Scotland

Scotland is uniquely advantaged for the development of a world leading CO_2 Utilisation sector: an abundance of biogenic CO_2 from the food and drink sector; vibrant CCU, hydrogen and CCS academic communities; progressive Climate & Energy policies and world class renewable energy resources. *If enabled*, Scotland can undertake an evidence based approach to the formation of a national CCU Roadmap, as per key recommendations and further actions detailed within the main study report.

Key recommendations are listed below with further actions and detail available in the full report.

- Appoint person(s) within Scottish Enterprise for further investigation of CCU
- Further identification and mapping of type and tonnage of CO_2 resources including <10,000 tonnes per year emitters
- Commission a market study to identify the current and potential future scale of CO_2 demand in Scotland
- Commission a market study to identify the type, tonnage, value and geographical nature of the inorganic fertiliser demand within Scotland to establish the potential for import substitution with CO_2-derived fertiliser
- Secure funding to co-fund industry to undertake initial CO_2 utilisation assessment studies
- Seek funding for a ClimateXChange fellow to work closely with the Scottish Government's Energy Team to undertake analysis of the potential economic and network benefits of various CO_2 deployment scenarios
- Commission a study to better understand the legislative levers being considered within Europe to advance CO_2 Utilisation or that have an impact on the sector and consider their suitability at a Scottish level
- Promote a demonstration-scale CO_2 Utilisation project competition to accelerate CO_2 Utilisation
- Commission further research focused on CO_2 Utilisation opportunities for Grangemouth
- Organise an annual CO_2 Utilisation conference in combination with CCS, hydrogen and energy storage