Action Plan – Carbon Capture and Utilisation Sector Innovation

Final Plan

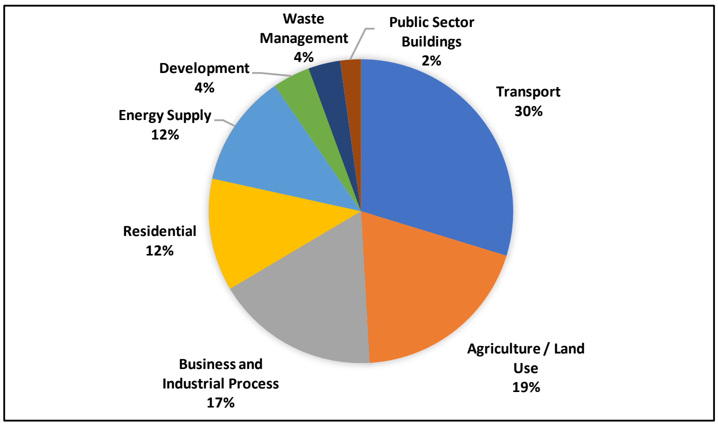
Scottish Enterprise

29th August 2019

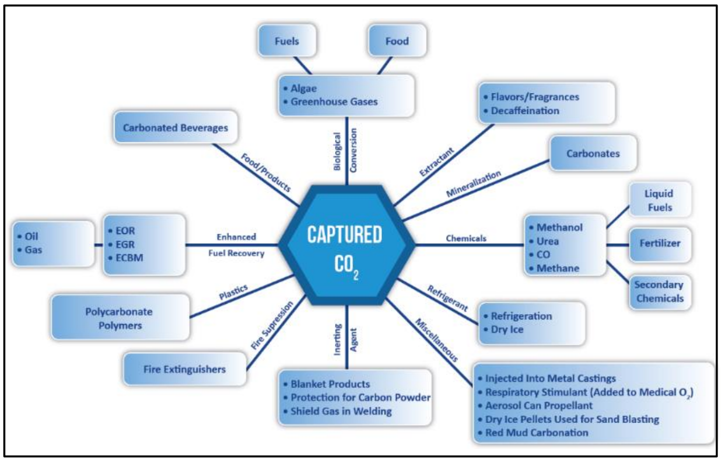
J3124/SE

Executive Summary

We are facing unprecedented challenges from global warming as a result of greenhouse gas emissions. Yet these challenges catalyse opportunities to develop innovative sustainable manufacturing processes, that in turn can support the creation of new business models. This action plan has been developed in the context of the Scottish Government's Net Zero emissions commitment for 2045 and the Just Transition Commission, which is advising Scottish Ministers on how to reach this goal. It has the vision of positioning Scotland as an innovation driven cluster and international leader in innovation and adoption of carbon capture and utilisation (CCU). It addresses innovation, but recognises that policies supporting other aspects, such as fiscal incentives and regulation, are also required. Scottish Enterprise and Falkirk Council, as partners in the EU-funded Interreg project, Northern Connections, have identified specific opportunities for Scotland's industries to work with European partners to realise CCU.



Scotland emitted around 50 million tonnes of greenhouse gases in 2017, of which 8.5 million tonnes (17%) were attributable to business and industrial processes. Falkirk Council is responsible for over 3.6 million tonnes of these emissions. It is also the hub of chemical manufacturing in Scotland. This presents a massive opportunity to link concentrated emissions with solution providers.



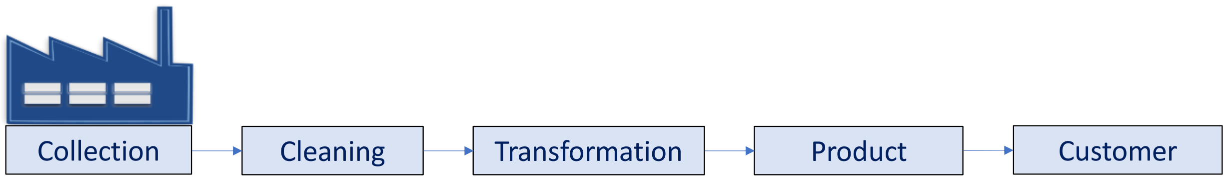
Over 80% of all emissions were carbon dioxide (CO_2). CO_2 can be converted into products such as: commodity chemicals, that are required for the manufacturers of numerous products including polymers and pharmaceuticals, biofuels, construction materials, foodstuffs for human consumption and feed for animals. It can, in some situations, simply be supplied as a gas for use in industrial processes.

Traditional chemical routes can produce a number of these products but often require large amounts of energy. Newer, industrial biotechnology (IB) approaches offer a potentially more attractive solution as they require less energy but need to be validated at commercial scale.

In Scotland there is appetite amongst the larger industrial emitters to tackle this challenge. There are also a growing number of research groups, innovation centres and innovative companies that offer solutions. These include:

- Research Centre for Carbon Solutions at Heriot Watt University
- Carbon Capture Group at the University of Edinburgh
- IBioIC, the industrial biotechnology innovation centre
- Carbon Capture Machine, a spin-out from the University of Aberdeen, which is developing a mineralisation process for CO_2
- Doosan Babcock which has developed a system for CO_2 capture from power plants
- Ingenza, an innovative SME developing IB processes that could better use CO_2
- NiTech, an innovative SME developing continuous process technologies that use CO_2
- Xanthella, an innovative SME developing photobioreactors for microalgae growth, which also requires CO_2
- Drochaid, a private research and development company carrying out chemical research (including novel catalysts)

However, the value chain linking these organisations and the scale of activity at each stage is, currently, weak in Scotland compared to other nations.



A range of initiatives are required to resolve this, including:

- Public and private investment to further develop and validate new technologies at commercial scale, recognising that new innovation need not necessarily come from the domestic base
- Fiscal incentives such as tax relief and public procurement, to encourage the development and commercialisation of technologies and products using captured CO_2
- Regulatory changes, such as mandating the inclusion of a minimum amount of material made from captured CO_2 in specific products

Specific opportunities for Scotland include:

- The production of biofuels that can be blended in Grangemouth to meet sustainability targets, e.g. for aviation fuels which Petroineos supplies to Scottish airports. Unlike road transport, aviation will require liquid fuels for the next several decades
- Growth of microalgae to produce feed that can supply the significant aquaculture industry in Scotland and displace imported soyameal

This action plan proposes a number of activities to deliver on its vision:

- **The Northern Connection Interreg project** – its Living Lab activity offers early opportunities for collaboration with European partners
- **Feasibility studies** to understand the optimum approach and potential solutions for those emitters with a desire to adopt CCU technologies
- **Demonstration facility** to evaluate different technology solutions in real-world scenarios, increasing confidence in emitters that these will work and not adversely affect their operations

- **Innovation competition** to deliver specific solutions, with well-defined outcomes, to a required demand
- **Sector innovation network** to provide leadership and a focal point for CCU in Scotland and help inform future policy

With regards to the above activities, the Falkirk and Grangemouth Growth Deal is submitting an outline business case in Autumn 2019 to both Scottish and UK governments for funding that includes investing in demonstration scale facilities for CCU technologies, as well as creating a supportive, collaborative environment for technology companies, emitters and others in the value chain.

In addition to these specific activities, cost effective energy will be needed. CO_2 is a stable molecule and energy is required to convert it to other chemicals. Often these reactions require hydrogen, which can be produced cleanly through the electrolysis of water, another energy intensive process.

If this opportunity is successfully developed, it will not only contribute significantly towards Scotland's ambition to be net zero carbon by 2045, it will also establish sustainable manufacturing businesses, and develop technologies and products that can be exported across the globe. As a result, it will help create new business models, jobs and economic prosperity, with analysis suggesting that between 7,000 and 45,000 jobs could be associated with combined carbon capture utilisation and storage (CCUS) by 2030. Furthermore, it could establish Scotland as the international destination of choice for other innovative companies seeking to demonstrate and commercialise their CCU technologies. Failure to seize this opportunity will mean that other nations will take the lead and will most likely result in manufacturing companies moving operations from Scotland to avoid punitive emissions regulations if there are no viable CCU solutions.

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1 Introduction

Carbon capture and utilisation (CCU), the processes that convert industrially emitted or airborne carbon dioxide (CO_2) into chemicals, fuels and materials, is considered to have the potential to make a significant contribution to the mitigation of CO_2 emissions. It is estimated[1] that, in the long term, it could transform between 1 and 2 giga tonnes per annum of CO_2 (2.5 and 5% of global CO_2 emissions) into commercially viable products. CCU is, therefore, considered an attractive approach to support government commitments on greenhouse gas emissions and as a raw material for sustainable manufacturing.

Scottish Enterprise (SE) and Falkirk Council (FC) have recognised the potential of CCU and are seeking to understand current CCU activities, identify attractive CCU development opportunities and identify actions to develop initiatives that will support development opportunities across Scotland and, more specifically, at Grangemouth. As part of developments at Grangemouth, both organisations are partners in the European Union funded Interreg North Sea Region Northern Connections project[2]. Their main role is to identify early stage or potential collaborative CCU projects in Scotland that would benefit from alternative or new technologies, services or processes to help better inform implementation or introduce improvements in the projects. To achieve this, North Sea region businesses will be invited to propose solutions to the challenges identified in the Scottish projects.

This document presents the results and recommendations of a study to identify the priority actions to encourage CCU developments in Scotland and to support SE and FC's work in the Northern Connections project. The sector innovation system approach[3] was used to:

- Develop a plan to accelerate the development and adoption of CCU technologies in Scotland
- Specifically focus on value chain opportunities that can feature at a Living Lab event as part of the Northern Connections programme
- Develop an action plan to implement the options identified

The study focused specifically on CO_2 and the approach had three key stages*:*

1. Value chain analysis to map out the specific opportunity, detailing the focus of technology and establishing the position of Scottish companies in the value chain
2. Analyse the innovation system around the value chain and specific opportunities
3. Facilitate an industry and stakeholder workshop with a focussed agenda on the specific opportunity, the challenges identified and development of an action plan

The first two stages of the methodology included in depth consultation with industry and other stakeholders and many of these individuals also attended the workshop. Those organisations that participated in the study are listed in Appendix A. We acknowledge the input of all organisations and thank all individuals involved for their contributions.

The work was carried out between February and July 2019.

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1 Novel Carbon Capture and Utilisation Technologies, group of Chief Scientific Advisor, European Commission, May 2018, referencing The Changing Paradigm of CO_2 Utilisation, Aresta et al, Journal of CO_2 Utilisation, 3-4, 2013, 65-73

2 www.northsearegion.eu/northern-connections

3 A methodology developed by Scottish Enterprise and previously tested for biorefining and subsea vehicle opportunities, to help Scottish Enterprise and stakeholders develop plans to accelerate industry involvement and adoption

2 Context

2.1 Addressing Net Zero Carbon Targets

Addressing climate change is clearly defined as a key priority at both a national and global level:

- The Scottish Government has defined world-leading targets of net-zero greenhouse gas emissions by 2045, at the latest, and a carbon neutral country by 2040[4]
- The Just Transition Commission[5] is advising Scottish Government Ministers on developing an environmentally and socially sustainable economy
- The UK Government has recently committed to a net-zero greenhouse gas target by 2050 following the recommendations of its advisory Committee on Climate Change[6]. This is a significant change to its previous target, defined in 2008 to reduce carbon emissions by at least 80% by 2050
- The European Union has also defined a target of net-zero greenhouse gas emissions by 2050 and has published[7] a long-term strategic vision to achieve this

Governments and industries are under increasing pressures to mitigate carbon emissions and deliver against these targets as climate change has become a more mainstream public issue recently, catalysed by the international youth movement against climate change, initiated by Greta Thunberg, the BBC's David Attenborough climate documentary and the Extinction Rebellion protests.

Evidence collated in this study clearly highlights a major change in company commitment to addressing emissions and climate change.

4 https://www.gov.scot/news/climate-change-action-1/
5 https://www.gov.scot/groups/just-transition-commission/
6 Net Zero – The UK's Contribution to Stopping Global Warming, Committee on Climate Change, May 2019
7 A Clean Planet for all. A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy, European Commission, 28th November 2018

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2.2 Emissions in Scotland

Greenhouse gas emissions in Scotland were 50.1 million tonnes ($MtCO_2e$) in 2017, as follows[8, 9]:

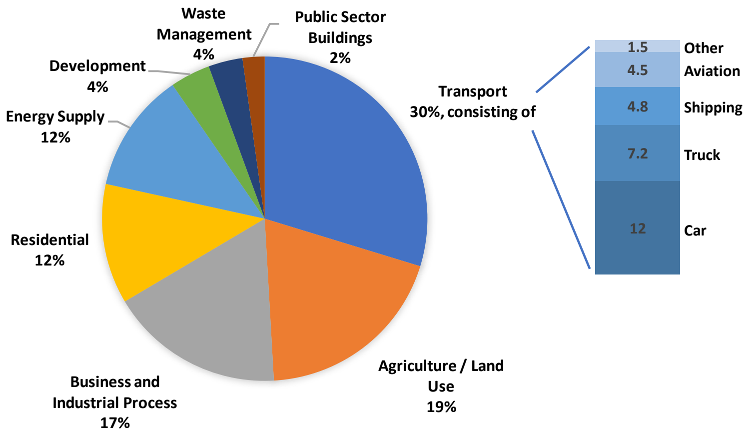

Figure 1: Greenhouse Gas Emissions in Scotland by Source, 2017

This highlights the small share of overall CO_2 emissions in Scotland attributed to industry: 17% compared with 30% from transport and 19% from agriculture and land use. When the positive impact of the forestry sector is considered, this leads to net emissions of 40.5 $MtCO_2e$, a reduction of 3.3% from 2016 and 46.8% from 1990 figures. CCU can further reduce net emissions across other sectors through sustainable manufacture of chemicals and fuels.

8 Scottish greenhouse gas emissions 2017, Scottish Government, 11th June 2019, see https://www.gov.scot/publications/scottish-greenhouse-gas-emissions-2017/pages/3/

9 Scottish Transport Statistics, No 37, 2018 Edition, National Statistics, 2018, see https://www.openaccessgovernment.org/uk-worlds-first-net-zero-carbon-cluster/55711/

The focus of this study is industry, and reported release of CO_2 by sector, and by weight, can be presented as shown below.

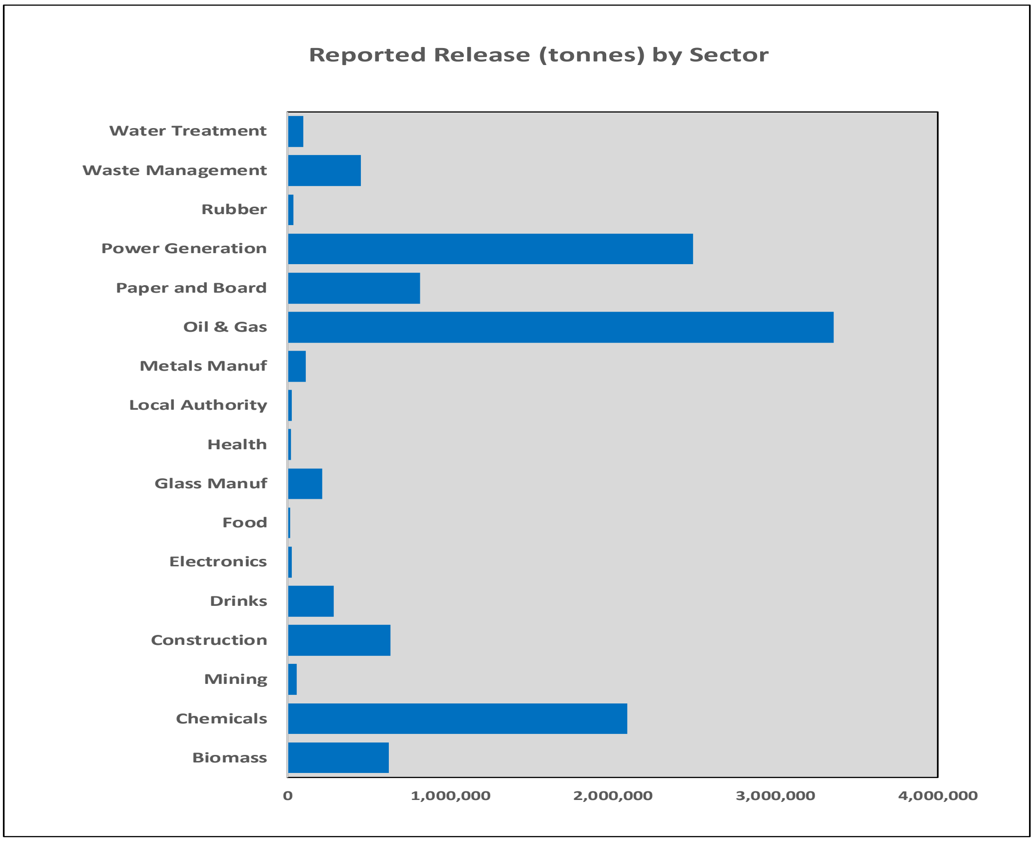

Figure 2: Reported CO_2 Emissions by Industry Sector (2017) [10]

This data covers a total of 80 sources across these sectors with emissions above reporting thresholds. The combined output is over 11.3 million tonnes. The full list of sources is included in Annex 1. Falkirk, one of Scotland's 32 local authorities, which includes Grangemouth, was responsible for over 3.6 million tonnes.

In comparison, the demand for CO_2 in Scotland is estimated to be around 200,000 tonnes per annum[11].

Of course, reported data excludes emissions from a wide range of smaller industrial sites in the above sectors, that may be potentially interesting for siting CCU plants.

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10 https://www.sepa.org.uk/environment/environmental-data/spri/

11 Actions Required to Develop a Roadmap Towards a Carbon Dioxide Utilisation Strategy for Scotland, Report for Scottish Enterprise, Peter Styring et al, 28th June 2017

(footnote continued)

2.3 Valorising CO_2

There are a number of potential uses for captured CO_2, as shown below[12].

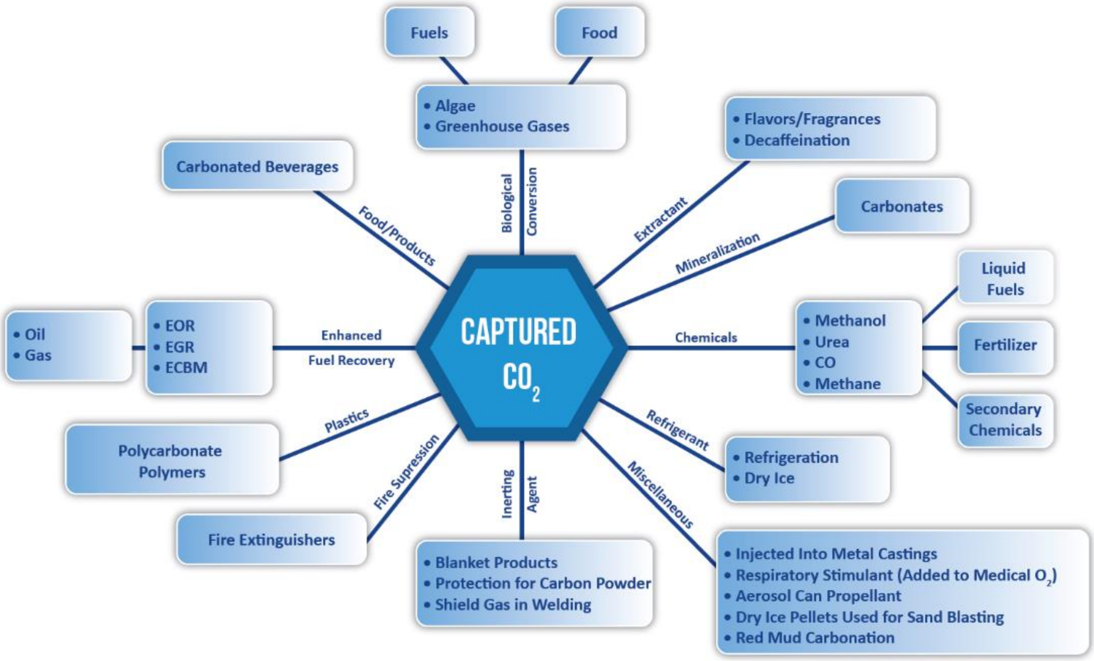

Figure 3: Potential Applications for Captured CO_2

There are also a wide range of valorisation technologies that are being developed. Examples of these were summarised in a previous Optimat study for Scottish Enterprise[13] and are listed in Annex 2.

12 US Department of Energy's National Energy Technology Laboratory
13 Industrial Biotechnology Research within Circular Carbon, Optimat report for Scottish Enterprise, May 2018

3 The Current Situation

3.1 The CCU Value Chain in Scotland

Analysis of the CCU value chain in Scotland is summarised below. The full value chain report is included as Annex 1.

3.1.1 The CCU Value Chain Model

A generic CCU value chain model, focusing on the transformation of CO_2 from industrial sources into primary products was developed as shown below:

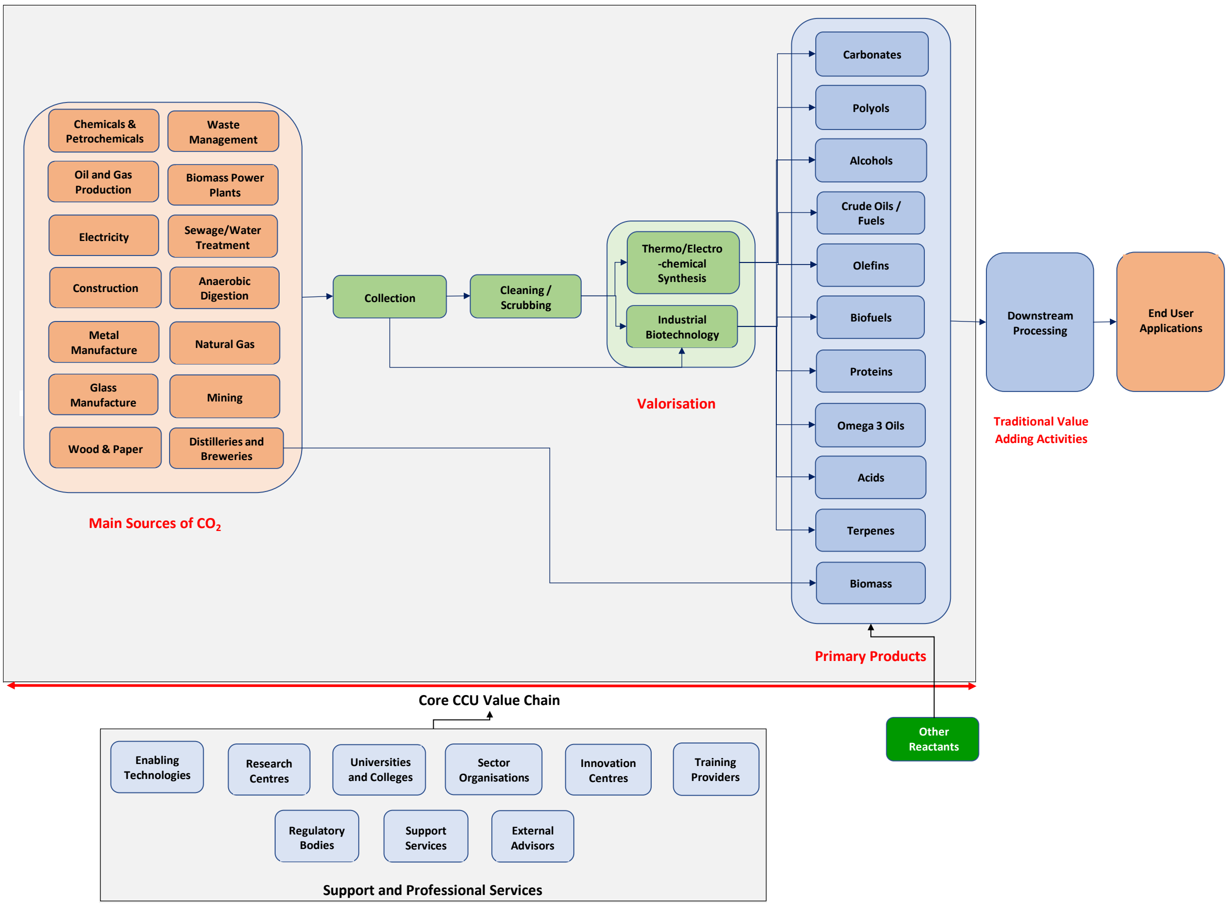

Figure 4: CCU Value Chain Model

It must be recognised, however, that the value chain for emissions from specific sources will be specifically structured to accommodate the different characteristics of emitted gas (e.g. volumes, purity, etc.).

3.1.2 CCU Market Opportunities

CCU market opportunities can be segmented as follows:

a) Chemicals

The production volumes and market value of numerous chemicals and other products that could be manufactured from CO_2 is significant, as indicated in the table below (N.B. this is non-exhaustive, it reflects the range of the most common products). These are predominantly commodity chemicals supplied to global markets. Further processing of several of the commodity chemicals will be carried out to produce higher value, speciality chemicals, but these activities are considered to be outside the CCU supply chain. In addition to converting CO_2 into these products, it can be captured and used directly (following appropriate cleaning) for a range of applications including the carbonation of drinks, inert environments for the packaging of products (such as food) and as a supercritical solvent.

Product	Demand	Production Levels	Market Value
Methanol[14]	Global – fuel and feedstock	110Mt	$55B
Butanol[15]	Global – feedstock, solvent and also fuel	>1.5Mt (1997)	$9.9B (2020)
Butadiene[16]	Global – synthetic rubber (tyres), feedstock	~16Mt	$33.5B (2024)
Dimethyl ether[17]	Global – fuel and propellant	~5Mt (2014)	$9.7B (2020)
PHA[18]	Global – packaging and replacement of other fossil-fuel derived plastics	Limited ~100Kt (but growing)	$93.5M (2021)
Terpenes[19]	Global – feedstocks, fuels	Large for natural terpenes	$688.54M (2022)
Olefins[20]	Global – feedstocks	~4.3Bt (2016)	$12.58B (2025)
Polyols[21]	Global – feedstock, e.g. for polyurethanes	1.74Mt (2021)	$4.71B (2021)
Microalgae	Global – biomass can be used for aquaculture feed, and be further processed for fuels and to extract other chemicals	83.6Mt (2017)[22]	$100B (2017)[23]
Carbonates[24]	Global – construction materials	Millions of tonnes	$70.46B (2025)

Figure 5: Global Market Demand, Production Levels and Market Values for Various Chemicals, Fuels and other Products that Can Be Produced by Processing CO_2

14 http://www.methanol.org/the-methanol-industry/
15 https://www.prnewswire.com/news-releases/global-n-butanol-market-analysis-2015-2017-and-forecasts-to-2020---growing-butyl-acrylate-manufacturing-industry-is-a-key-market-driver-300581967.html
16 https://www.researchnester.com/reports/1-3-butadiene-market-global-demand-analysis-opportunity-outlook-2024/447
17 https://www.marketsandmarkets.com/PressReleases/dimethyl-ether.asp
18 https://www.marketsandmarkets.com/PressReleases/pha.asp
19 https://www.qyresearchgroups.com/report/global-terpenes-market-research-report-2017-d-49
20 https://www.prnewswire.com/news-releases/global-1258-alpha-olefin-market-analysis-2014-2017-with-forecasts-to-2025-300594287.html
21 https://www.marketsandmarkets.com/Market-Reports/green-and-bio-polyols-market-1175.html?gclid=CjwKCAjw8r_XBRBkEiwAjWGLlDCVLh2EH64AJVYjav6RWBIv3UCWF1TSWSI82aex1SFxG5R_0L-rORoCD90QAvD_BwE
22 http://www.fao.org/in-action/globefish/fishery-information/resource-detail/en/c/338597/
23 http://salmonbusiness.com/algae-based-feed-company-researchers-eye-billion-dollar-market/
24 https://www.zionmarketresearch.com/report/carbonate-minerals-market

(footnote continued)

We have identified a number of companies across the globe that are developing processes for the valorisation of CO_2, which indicates that this is an area of great interest to different economies. Most of these, however, are still pre-commercial, highlighting that this is a relatively young market with opportunities for co-development and for new entrants.

The volumes of CO_2 and tonnages of final products required to make opportunities viable will vary depending on the volumes and quality of CO_2 produced and the specification required to meet market demand, both of which will impact the complexity of the processing required. At this stage, however, due to the lack of CCU activities it is difficult to quantify the volumes required for viability.

b) Biofuels

Similarly, the global biofuels market is significant, with predictions[25] that it will grow to be valued at $218.7 billion by 2022, an annual growth rate of 4.5% for the period from 2017 to 2022

c) Niche products

There a numerous, smaller scale opportunities in the food, feed and construction markets. Further, these have very positive links to high growth sectors in Scotland, such as aquaculture.

3.1.3 The CCU Value Chain in Scotland

Current value chain activity in Scotland can be summarised as follows:

- As indicated in Section 2.2, above, there are numerous sources of CO_2 in Scotland, with a high concentration of emissions in the Grangemouth area, but little activity to collect the emitted gas. One company, North British Distillery, was identified as the only organisation that has operated a significant CO_2 valorisation activity in Scotland (although this is currently offline). Although there is evidence that other companies have expressed some interest, no other projects of scale were identified. The scale of that activity is small compared to the current level of Scottish demand and very small compared to Scottish industrial emissions.
- As a result, there is very limited other activity and capacity in the value chain. Key areas of activity identified are:
  - CO_2 Capture: Doosan Babcock
  - CO_2 Transport: BOC /Air Liquide (linking to North British Distillery)
  - Valorisation: Carbon Capture Machine, a university spin-out, based in Aberdeen, developing mineral carbonation processes
  - Enabling technology: Xanthella – developers of photobioreactors
Ingenza – development of IB process technology
NiTech – development of continuous process technologies
  - Industrial research Drochaid - chemical research company

There is also a range of relevant university expertise and industry support organisations that are active in the development and support of CCU.

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25 Biofuels Market Size Will Reach USD 218.7 Billion by 2022, Globally, Zion Market Research, 9th January 2018

3.1.4 CCU Value Chain Development Opportunities and Challenges

Two types of CCU development opportunity have been identified:

- Large-scale manufacture of commodity chemicals and fuels
- Smaller, niche market opportunities that align with Scottish circular economy activities

It is considered that the manufacture of commodity chemicals and fuels is very challenging, due to the process economics and value chain development issues.

The development of a portfolio of value chain collaborations that would enable valorisation of CO_2 to address local niche market opportunities is considered more attractive. These may include:

- Distillery – industrial biotechnology company – fish feed producers
- Distillery – gas company – direct use, in a similar way to North British Distillery's activity
- Biomethane plant – gas company – direct use, exploiting the volumes of CO_2 generated in producing gas for injection into the grid

Further developments of any of these opportunities will be dependent on a CO_2 emitter being motivated to valorise its output.

Despite these opportunities for development of the CCU value chain in Scotland, a number of challenges were identified in pursuing these opportunities. These, predominantly, relate to

- Investment risk
- The lack of evidence of the financial and environmental benefits of CCU
- CCU is not core business for any sector or group of companies
  The lack of a "natural home" for CCU development - discussions with stakeholders have tried to address "who should be driving CCU in Scotland". While the chemical sector is a key player, it is clear that the opportunity is far broader than this. In this context, there is a new CCUS network being formed (NECCUS[26]), that will coordinate activities along the UK's North Sea coast, which may take on this role.

These are business / commercial rather than innovation issues, but there are opportunities for innovation interventions to overcome these. This is discussed further in Section 4 of this report.

26 https://neccus.co.uk/

3.2 The CCU Innovation System

Analysis of the CCU innovation system in Scotland is summarised below. The full innovation system analysis report is included as Annex 2.

The various types of innovation support that are available to capture, process and utilise carbon dioxide (CO_2) emissions in Scotland were reviewed. The analysis was structured around an innovation systems model, as shown opposite, with the provision of support in each of the five parts of the model assessed.

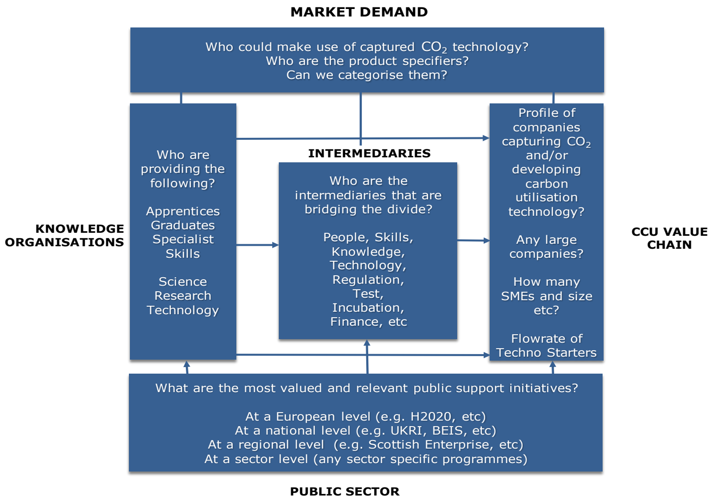

Figure 6: Innovation System Model

Key points noted are:

- There are a number of generic and technology specific funding schemes that will support CCU. The specific schemes tend to be more limited in terms of budget and availability (i.e. set call deadlines), although funding of up to £170 million from the Industrial Research Challenge Fund (ISCF) to develop a zero-carbon manufacturing cluster by 2040[27] is noted.
- Scotland has a strong research capability, in both universities and the private sector. The largest university groups (at Heriot Watt and Edinburgh universities) are also research leaders at a UK level.
- Numerous intermediate organisations support the CCU value chain, but their activities are typically part of a wider technology (e.g. IBioIC) or sectoral (e.g. Chemical Sciences Scotland or the Scotch Whisky Research Institute) remit.

These three facets of the innovation system suggest a strong eco-system to support Scottish companies wishing to develop CCU.

- Value chain actors are the private sector organisations that finance innovation, namely companies and financial organisations that support business research and development (BERD).
- The market demand part of the innovation system model is not strongly linked to other aspects of the value chain, particularly in Scotland at the moment, due the immaturity of the value chain.

A review of the situation elsewhere indicates that:

- There are numerous company specific or collaborative projects to develop CCU technologies, with several developed to higher TRLs.

27 https://www.openaccessgovernment.org/uk-worlds-first-net-zero-carbon-cluster/55711/

These projects are typically supported by a combination of private and public sector funding, but, as already highlighted, there has been little commercialisation of these technologies. A number are listed in Annex 2.

- Development of CCU clusters in Europe is driven by the European Union Strategic Energy Technology (SET) plan[28] but is at an early stage.
  Early cluster development is focusing on infrastructure rather than innovation and industry cluster development.
  The immaturity of CCU cluster development activities elsewhere in Europe means that there are limited high value transferable lessons for Scotland.
- Fiscal incentives, particularly in the USA, have encouraged and supported CCUS activity. The US Government has offered financial incentives[29] for CCUS since 2008. It has recently enhanced these to encourage private sector investment in carbon capture. Tax credits of $35 (for CCU) or $50 (for CCS) per metric tonne of CO_2 captured will be available for 12 years of operation for CO_2 producing industries that commence construction of CCUS facilities by 2024. These recent enhancements have increased the tax credit per tonne and removed the earlier cap (75 million metric tonnes) on the amount of CO_2 produced that would qualify for tax credits.

The evidence collated in this study indicates that the existing innovation system, particularly to support low – mid TRL activities is considered to be relatively strong, based on the range of funding sources available, academic capability and the community of intermediary organisations.

The key issues for companies are strongly linked to business / commercial issues, specifically:

- The lack of existing value chain activity and, thus, best practice examples
- There are no regulatory or legislative drivers
- The apparent/perceived investment risk
- A lack of evidence of the business / financial case for CCU
- CCU is not core business for emitters
- A lack of ownership of CCU development

These six issues collectively lead to inertia. Addressing them is critical to develop CCU.

- Limited funding mechanisms to support the demonstration of CO_2 utilisation
- The complexity of the public support infrastructure

These are business / commercial rather than innovation issues, as already highlighted, and they underline a reluctance / lack of commitment of those companies emitting CO_2 to act to mitigate emissions. This is an understandable position as there is no current driver for action. Innovation interventions can, as already highlighted, help address these issues.

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28 https://ec.europa.eu/energy/en/topics/technology-and-innovation/strategic-energy-technology-plan

29 Implementation of Recent Amendments to the 45Q Carbon Sequestration Tax Credit, The National Law Review, May 3rd 2019, https://www.natlawreview.com/article/implementation-recent-amendments-to-45q-carbon-sequestration-tax-credit

These issues, together with those raised during the value chain analysis were discussed with industry and stakeholders at a half day workshop and a number of innovation interventions were validated. These are discussed below.

4 The Opportunity for Scotland

Based on the research and analysis carried out, it is considered that:

- There are significant opportunities to develop CCU activities in Scotland. These include:
  - Production of biofuels that can be blended in Grangemouth to meet sustainability targets, e.g. for aviation fuels that Petroineos supplies to Scottish airports. Unlike road transport, aviation will require liquid fuels for the next several decades
  - Microalgal growth to produce feed that can supply the significant aquaculture industry in Scotland, displacing imported soyameal
- There are a number of factors that will support development. These include:
  - Supportive government Net Zero Carbon targets
  - The Scottish Government's low carbon economic strategy
  - A strong and growing commitment to mitigating carbon emissions in industry
  - An internationally recognised research capability
  - A growing cohort of innovative technology companies
  - A strong industry support infrastructure
  - A range of established mechanisms to support innovation
- There is the potential for Scotland to become a leading international cluster for CCU innovation and industry development

Considering the wider opportunities for CO_2 mitigation, it should be noted that a recent study by the University of Strathclyde on combined carbon capture utilisation and storage (CCUS) suggests that this could support between 7,000 and 45,000 jobs by 2030, and between 22,000 and 105,000 by 2050[30].

There are however, as indicated in the section above, a number of challenges to overcome if businesses are going to commit to invest in carbon mitigation technologies. These predominantly relate to addressing business risk.

The subsequent sections of this report define the actions that SE and FC can jointly take to encourage development of CCU in Scotland. However, it must be clearly recognised that this goes beyond stimulating innovation, there is a need for further government intervention to catalyse and support business investment. This may be in the form of market incentives or regulatory drivers. It is essential that the CCU community develops the evidence base that enables supportive government action as part of its future strategy.

[30] The Economic Opportunity for a Large Scale CO2 Management Industry in Scotland http://www.evaluationsonline.org.uk/evaluations/Search.do?ui=basic&action=showPromoted&id=689

5 CCU Sector Development Options

5.1 Innovation System Development Options

The results of the analysis carried out, including in-depth engagement with industry and key stakeholders and analysis of best practice in other sectors, identified the following innovation system development options:

- ***"Living Lab".*** Scottish Enterprise (SE) and Falkirk Council (FC), the Scottish partners in the Northern Connections project, are identifying early stage or existing collaborative CCU projects in Scotland that would benefit from identifying alternative/new technologies, services or processes to help better inform implementation or introduce improvements.
- ***Feasibility studies.*** These desk-based studies are important to assess and understand potential technologies for a given situation, identify and select the optimum technology, define the scope of the investment and potential partners, prepare an initial techno-economic analysis and assess, understand (and make) the business case for investment. This activity would precede demonstration activities.
- ***Demonstration scale facility.*** This is considered the core intervention to catalyse CCU activity. This facility will enable evaluation of CCU technologies in a realistic pseudo-industrial emission environment, increased confidence in specific technologies by obtaining evidence of performance in industrially relevant situations and completion of more detailed techno-economic analysis. This facility would need to be sufficiently flexible to accommodate a range of different technology platforms, as specified by interested companies. It would also need to have the required monitoring and control equipment so that the performance of different systems could be accurately monitored.

  The ***Falkirk and Grangemouth Growth Deal*** is currently working up a strategic business case for funding that includes investing in demonstration scale facilities for CCU technologies, as well as creating a supportive, collaborative environment for technology companies, emitters and others in the value chain. The outcome of the growth deal bid will be known by March 2021 and full business cases will then be produced by March 2022.
- ***Innovation competition***. The establishment of a competition to develop attractive technologies that would convert CO_2 into viable products. Such a competition would offer the opportunity for the research and innovation community to propose ideas for CO_2 valorisation, with funding made available to those that are most attractive. This approach has been used successfully elsewhere (e.g. NRG COSIA Carbon XPRIZE[31])
- ***Sector Innovation Network.*** A CCU focused organisation that will bring together organisations interested in CCU, provide leadership, establish a forum for knowledge sharing and raising issues regarding CCU, and influencing government

These were validated at the industry and stakeholder workshop.

Development and implementation of these interventions are addressed in this action plan.

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31 https://carbon.xprize.org/prizes/carbon

5.2 Wider Intervention Needs

The development of CCU, however, cannot be driven by innovation interventions alone. It is important that there are wider, political and policy interventions to catalyse change. Critical actions identified are:

- Clarity and leadership
  It is important that the Scottish Government sets a clear agenda and strategy for mitigation of carbon emissions. A strategic roadmap to achieving the targets for a zero-carbon economy is lacking.
  Addressing this will provide a framework within which Scottish companies can operate.
  It is important, however, that the Scottish Government does not act in isolation in a way that affects the competitiveness of Scottish companies. It would be logical for a Europe wide approach to be developed, rather than individual nations acting in isolation.
- Development of market pull
  A key catalyst for the development of CCU would be the introduction of market incentives for products utilising captured carbon. For example:
  - Public procurement of products utilising captured carbon
  - Tax relief on products using captured carbon, applying to both domestic and export markets

  We believe that such interventions would be compatible with existing frameworks and would be preferable to tariffs and regulations, which, as indicate above, would be detrimental to Scottish industry competitiveness.
- Investment in necessary linked infrastructure
  Effective CCU requires, in most cases, access to cost effective (low cost) hydrogen and energy and parallel investment in these resources are necessary

It is expected that the sector innovation network proposed in Section 5.1 would take an active, leading role in engaging with key stakeholders to establish a supportive policy framework for the development of CCU.

6 Vision, Objectives and Strategy

6.1 Vision

In the context of the Scottish Government's Net Zero commitment for 2045, the vision of this action plan is to

"position Scotland as an innovation driven cluster and international leader in innovation and adoption of carbon capture and utilisation"

6.2 Objectives

The key objectives for this action plan are:

- Living Lab
  - Confirmation of one to two potential Scottish Living Lab collaborative projects by October 2019
  - Circulation to Northern Connection partners of an invitation to express interest in the potential Scottish Living Lab projects by November 2019
  - Hold Living Lab event to engage with overseas partners in January 2020
- Feasibility Studies
  - Set-up of a feasibility study programme by March 2020 with funding to assess the feasibility of 10 company specific opportunities
  - Carry out 4 feasibility studies per annum from March 2020
- Demonstration Facility
  - Complete a business case for the demonstration facility by March 2020 which will be part of the Falkirk and Grangemouth Growth Deal
- Innovation Competition
  - Define the scope to run such a competition in Scotland by December 2019
  - Develop competition scope, rules and timetable by June 2020
  - Launch competition by December 2020
- Falkirk and Grangemouth Growth Deal
  - Define the opportunity to support the demonstration facility by March 2020
- CCU Sector Network
  - CCU sector network set-up by March 2020
  - Initial programme of activities published in April 2020
  - CCU sector network engages with all relevant established organisations by June 2020

6.3 Strategy

These objectives will be achieved through the following strategies:

- Establishing a steering group of SE, FC and key company representatives to oversee implementation of this plan
- Utilising the relationship between SE and FC and the Northern Connections project to drive implementation of Grangemouth based activities

- Utilising the Falkirk and Grangemouth Growth Deal
- Exploiting established public sector support schemes to address relevant objectives, e.g.
    - SE R&D grant scheme to support the innovation competition
    - SE Network Integrator funding resource to establish and run the sector innovation network
    - Industrial Strategy Challenge Fund (ISCF) to support larger scale innovation

7 Action Plan

7.1 Living Lab

This activity will be delivered as part of the Northern Connection programme (2016 - Dec 2020).

Through the Living Labs activity, regional sustainable energy projects and plans are presented to the programme partners to involve businesses around the North Sea in solving project challenges and present a pool of new innovative technologies and services to help address these. The event will increase transnational innovation collaboration.

Scottish Enterprise / Falkirk Council will proceed, within the scope of the Northern Connections Interreg project, to promote specific CCU challenges in Scotland with all project partners. This will require the organisation and hosting of a Living Lab event in Scotland on 30th & 31st January 2020 with all relevant information regarding the Living Lab challenges and the event published on the project website.

The CCU Living Lab in Scotland activities include:

- Identify 1-2 feature projects for the Living Lab event – September
- Define project/s challenges to attract solution providers from North Sea Region – early October
- Define criteria for selection of potential solution providers – end October
- Invitations to partners to recruit businesses – end of October

Typically, a Living Lab event will consist of

- Day 1:
  - Keynote speakers – CCU experts from Scotland
  - Featured project/s owner presentations
  - CCU focused workshops
  - 1-1 meetings – solutions providers and project owners
  - Solutions pitches
- Day 2:
  - Visits to relevant projects

There are Living Lab participation opportunities for owners of featured projects, solutions providers and companies wishing to host visits.

Key participants are expected to be

- Scottish companies with an interest in setting up demonstrator projects
- Scottish companies with existing CCU activities looking to expand or improve existing processes/services
- Relevant sector / technology organisations
- Academic and research organisations

Expected outputs are:

- Provisional commitment to set-up international collaborative CCU innovation opportunities and projects
- Increased knowledge transfer
- Development of a number of international technology linkages

- Further dialogue to inform CCU innovation themes within the Growth Deal
- Knowledge sharing
- New B2B collaborations across CCU transnational supply chains
- New transnational collaborations with academia

7.2 Establish and Operate Feasibility Study Funding Programme

As described above, this programme will support desk-based studies to assess and understand potential technologies to process emissions from a defined industrial plant, identify and select the optimum technology (which may be from domestic or overseas source), define the scope of the investment and potential partners, prepare an initial techno-economic analysis and assess, understand (and make) the business case for investment. As such it will provide the initial evidence base for companies to justify innovation and technology demonstrator projects.

The programme draws on the experience of Pale Blue Dot Energy and its work to catalyse and develop CCU projects, some of which have been funded by the Zero Waste Scotland (ZWS) Circular Economy Business Support Programme. However, in the context of this initiative it is felt that Scottish Enterprise and Highlands and Islands Enterprise support would be more appropriate, as this will not be restricted to SMEs alone, unlike the ERDF-supported ZWS scheme.

It is envisaged that 20 projects, at a cost of £15,000 to £20,000 each, will be supported over a five-year period. With the additional costs of setting up and managing the programme, a total project budget of around £500,000 will be required.

Key activities are:

- Design the scope of the programme
  The detailed objectives, scope, expected activities and outcomes of the programme will be defined. It is expected that this will be completed by key public sector organisations and organisations that may have a role in delivering the programme.
- Identify funding options
  It is assumed that the projects carried out will be funded by the public sector at an appropriate intervention rate. For example, we understand that the Zero Waste Scotland Circular Economy Business Support Programme provides 100% of the costs of projects carried out.
  Discussions with both SE and HIE to assess the options for a focused CCU support programme will be a priority. If this is not a practical option, then other public sector funding options will need to be investigated.
- Make the case for, and secure, funding
  This will be completed once the optimum funding route has been identified. A proposal for funding will be developed as required by the identified funding organisation.
- Formalise programme structure, rules, etc.
  The way the programme will be structured, how companies can apply for funding, the eligibility rules, intervention rate, application process and selection of successful proposals will be defined.
  This activity will provide all the details required to launch the programme.
- Identify and recruit programme manager

A decision will have to be made regarding programme management. Will the programme be managed internally by the funding organisation or will it be outsourced? If it is going to be outsourced, a procurement process will need to be completed.

- Launch programme
  The programme will be launched by the funding organisation, following its typical approach. This may include a launch event. It is also expected that details of the programme will be circulated to all relevant industry, business, sector and technology bodies and, as a result, the programme will be promoted to all companies that may be interested in the programme.
- Initiate first projects
  It is expected that the first projects will be initiated within 2 to 3 months of the launch of the programme. This is considered a reasonable time for interested companies to prepare proposals and for these to be reviewed, following the selection process defined.
- Deliver four projects per annum
  A target of completing four projects per year has been proposed. This modest target has been set to reflect
  - The current embryonic stage of development of CCU in Scotland
  - The potential for the development of sectoral projects (e.g. in the whisky industry) where the output will have relevance to a number of companies
- Annual review of programme outcomes
  A review will be carried out each year of the programme management and the outcomes of individual projects. This will identify:
  - Options to enhance the delivery of the programme
  - Evidence that projects completed are catalysing further investment in CCU innovation and demonstration projects. If this is not the case, the continuation of the programme will need to be considered

7.3 Develop Demonstrator Facility

This facility will enable:

- Evaluation of CCU technologies in a realistic pseudo-industrial emission environment,
- Increased confidence in specific technologies by obtaining evidence of performance in industrially relevant situations, and
- Completion of more detailed techno-economic analysis.

It will need to be sufficiently flexible to accommodate a range of different technology platforms, as specified by interested companies. It will also need to have the required monitoring and control equipment so that the performance of different systems can be accurately monitored.
It is expected that it will be established in Grangemouth.

The main activities to develop this facility are:

- Define the scope / remit of the centre
  The purpose, remit, scale and potential cost of the centre (as defined above) will be refined. This will be achieved by
  - Engaging with potential companies in Scotland to identify their needs

  - Reviewing the interest of relevant technology organisations (domestic or overseas) in participation in the centre
  - Assessing international best practice demonstration facilities in other technology areas

  This will provide a much more detailed "specification" for the centre and what it should offer to companies.
- Establish an industry steering group
  The purpose of this steering group, consisting of industry and stakeholder representatives is to provide industry insights into the development of the centre.
  This group should be involved in reviewing the output of the above activities and in guiding the ongoing development of the centre, ensuring it retains a strong industry relevance.
  We would expect that this would be a small steering group, consisting of around six key players.
- Define links to existing / emerging infrastructure
  It is important that this centre is not developed in isolation and that it is closely linked to other relevant sectoral and innovation infrastructure, including
  - Other developments in Grangemouth
  - The emerging biobased chemical manufacturing centre for which funding is currently being pursued

  A mapping of the linkages between these, and other centres, will be carried out.
- Assess funding options
  CCU innovation and demonstration is being proposed as part of the "Business" theme of the Falkirk and Grangemouth Growth Deal Strategic Business Case. Heads of Terms for the Falkirk and Grangemouth Growth Deal should be agreed by March 2020 and at that time; it will be known whether this project is going forward. There will then be a full business case produced before March 2021.

7.4 Develop and Run an Innovation Competition

The value of an innovation competition is that the research and business communities are asked to demonstrate solutions to one or more issues based on well-defined outcomes. The approach and technology utilised are secondary to this goal. This could be tailored to achieve a number of desired outcomes, such as:

- Addressing specific emissions that are relevant to Scotland, e.g. from distilleries, from petrochemical plants
- Delivering specific volumes of CO_2 capture and utilisation based on the emissions profile in Scotland
- Delivering products at a certain volume/price that are relevant to Scottish supply and value chains
- Addressing emissions at specific scales and/or of an intermittent nature

The key activities are:

- Assess best practice / transferability to Scotland

A number of other competitions have been defined including the NRG COSIA Carbon XPRIZE, the Virgin Earth Challenge[32] and BEIS CCUD innovation competition[33]. These will need to be studied to understand costs and timelines involved, and relevance to the Scottish landscape. It is expected that a committee will be established to oversee the competition. This will be led by SE and include other key public sector organisations, such as HIE, ZWS, and SIB. It will use the information from this and other studies, and direct discussion with other competition organisers to identify optimum approaches, sources of funding for the competitions and lessons learned.

- Define / confirm optimum approach
  The competition committee will use the above analysis to confirm the optimum approach with the wider industry and stakeholder community (ideally the network described in Section 7.5) through an invited workshop. This should focus on competition objectives, eligibility and assessment of entrants, and nature and size of the prize(s). This ensures that the competition is fit for purpose and will attract suitable entries. At this point, initial discussions should take place with potential funders of the competition, which could include the public sector, philanthropic organisations (e.g. Gates Foundation), investors and banks.
- Define scope, rules, timetable
  The outcomes of the workshop will be used to finalise the competition structure, including its specific scope and objectives, eligibility rules, entry process, number of phases/rounds if appropriate (and criteria to progress between phases/rounds), support to be provided to entrants, the structure and level of prizes, and timetable from competition announcement to its completion.
- Seek funding
  Based on this, options for funding the competition will be sought from the sources described above. This could be a joint prize pot. Once this has been finalised, the competition committee should be expanded to include representatives of all those contributing to the prize pot.
- Identify / recruit competition manager
  At this stage a competition manager should be appointed or recruited to manage the day to day running of the competition. This could be an internal or external appointment. The competition committee will provide support to this individual.
- Launch competition
  The competition will be launched by the funding organisation(s) and should include a launch event and wide media programme. It is also expected that details of the competition will be circulated to all relevant industry, business, sector and technology bodies with the result that all relevant potential entrants should be made aware of it.
- Deadline for competition entries
  It is expected that the deadline for competition entries should be at least one if not two months after the competition announcement, dependent on how complex the entry requirements are and the timing of the competition announcement (e.g. if it falls within holiday periods).
- Review entries

32 https://www.virginearth.com/
33 https://www.gov.uk/government/publications/carbon-capture-and-utilisation-demonstration-ccud-innovation-programme

All entries should be reviewed by the competition manager to determine whether they meet entry requirements. Those that do, should be reviewed and ranked by the competition committee or their representatives, against the different competition objectives.

- Select / support winning bids
  If support is to be offered to entrants, and this is limiting, then those that rank highest need to be offered places first. If this is not the case, then all entrants that pass entry requirements should proceed according to competition rules.

7.5 Establish and Run Sector Innovation Network

The Sector Innovation Network will provide cluster leadership through bringing together organisations interested in CCU, establishing a forum for knowledge sharing and discussing issues regarding CCU, and using this resource to help inform government policy.

The activities to develop and establish the network are:

- Confirm network remit / objectives / scope
  These are defined in earlier sections of this action plan, based on the research carried out and the input of key stakeholders. These should be confirmed through
    - Development of a detailed "straw model" of the network
    - Testing and validation / enhancement of the straw model with key stakeholders
- Identify funding options
  It is assumed that the network will require executive resource to function in an effective manner, deliver value to the CCU cluster and effectively engage with government. Funding will be required to cover the costs of this resource.
  The Scottish Enterprise network integrator support scheme is a very relevant funding option. Further, it is understood that this scheme can currently access partial European support.
  Alternatively, the Advancing Manufacturing Challenge Fund (AMCF) could be an option. This provides funding to public sector, academic and third sector organisations to support SMEs to take advantage of innovation opportunities.
  It should be confirmed whether these are appropriate funding options or if there are more suitable alternatives.
- Pursue funding
  The preferred funding option should be pursued, as required by the specific requirements of the scheme.
- Recruit interim / permanent executive
  Once funding is in place, an executive to manage and run the network should be recruited. This individual should demonstrate the relevant background and skills to effectively deliver all aspects of the role.
  This individual may operate independently or be part of an existing organisation that has a very strong affinity with CCU and the sectors that are part of the CCU value chain.
  This recruitment exercise will follow the requirements of the funding scheme.
- Establish network
  The network will be established by key stakeholders and industry representatives to coincide with the recruitment of the executive resource.

A small steering group of industry representatives will be established to support the executive resource.

Linkages will be made with key sector and technology organisations (e.g. IBioIC, CSS, SIBDG, SWA, SWRI, etc) to ensure that the network is effectively linked to relevant organisations.

- Confirm initial activities

  An initial one-year activity plan, defining the priority actions of the network will be developed jointly by the executive resource and the steering group. It is expected that this will include regular events to build the CCU community.
- Recruit industry members

  This will be a core part of the activity plan. Members from all sectors that have high CO_2 emissions, together with technology companies, representatives of the research community and key stakeholders should be pursued to become member organisations.
- Raise profile with key stakeholders

  The importance of engaging with government and other key organisations to raise the profile of CCU, promote its CO_2 mitigation potential, present the barriers to development and highlight options to incentivise CCU developments has been highlighted.

  A programme of actions to complete these tasks should be a core part of the network's activities from day 1.
- Define annual activity plan

  An updated activity plan should be prepared by the network executive on an annual basis. In this way emerging priorities can be pursued and key issues arising addressed.

7.6 Project Plan

These activities are illustrated in the following three-year project plan. It is assumed that each individual activity will pursue continued funding, based on the outputs and impacts achieved in the final year of this plan.

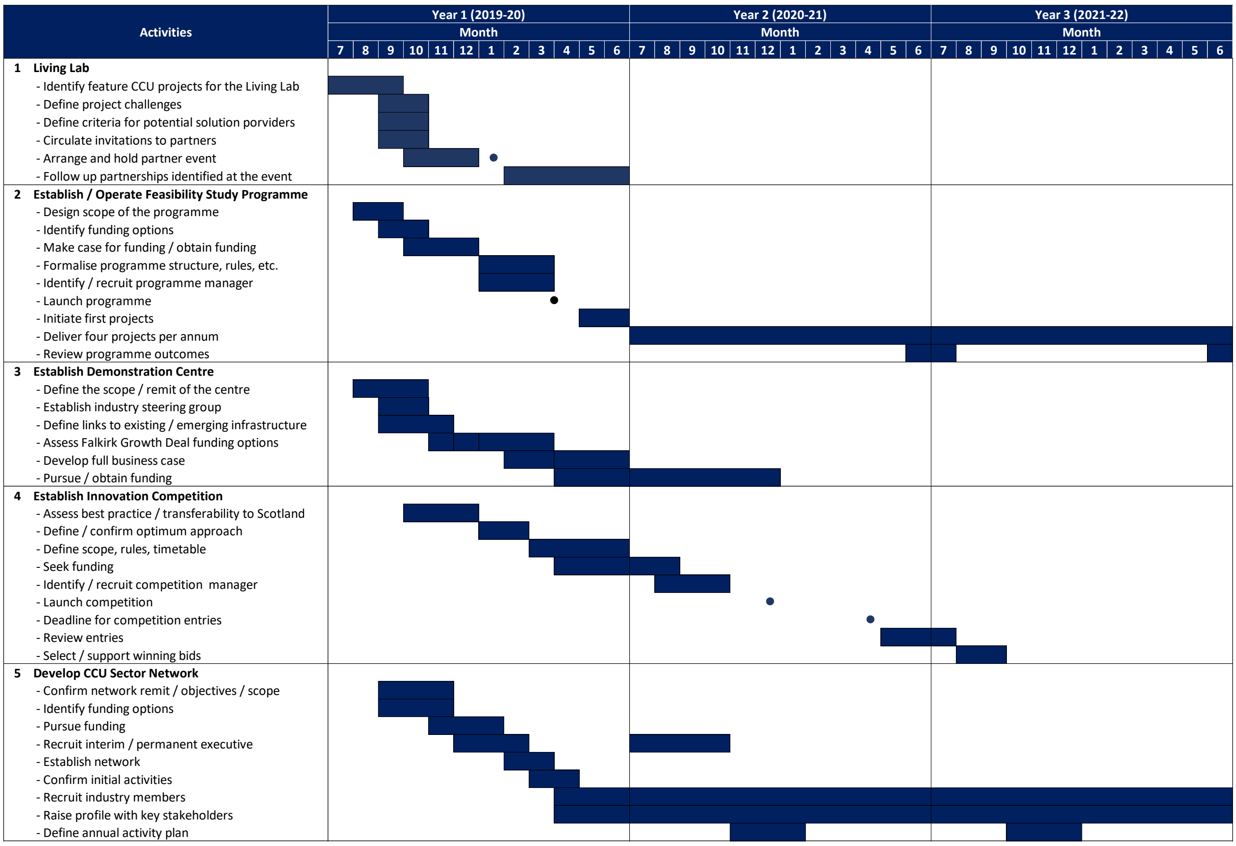


Figure 7: Project Plan

8 Costs and Resources

Costs for all activities, broken down by type of cost, are show below:

	Resources		
Activities	**Existing SE / FC Project Commitment**	**Additional Public Agency Resources**	**External Costs (£)**
1 Living Lab			
- Identify feature CCU projects for the Living Lab	✓		
- Define project challenges	✓		
- Define criteria for potential solution providers	✓		
- Circulate invitations to partners	✓		
- Arrange and hold partner event	✓		
- Follow up partnerships identified at the event	✓		
2 Establish / Operate Feasibility Study Programme			
- Design scope of the programme		5	
- Identify funding options		5	
- Make case for funding / obtain funding		4	£10,000
- Formalise programme structure, rules, etc.		5	£10,000
- Identify / recruit programme manager		5	
- Launch programme		5	
- Initiate first projects		10	
- Deliver four projects per annum		10	£112,500
- Review programme outcomes		10	
3 Establish Demonstration Centre			
- Define the scope / remit of the centre		10	
- Establish industry steering group		5	
- Define links to existing / emerging infrastructure			£10,000
- Assess Falkirk Growth Deal funding options		5	
- Develop full business case			£25,000
- Pursue / obtain funding		25	
4 Establish Innovation Competition			
- Assess best practice / transferability to Scotland		5	£10,000
- Define / confirm optimum approach		5	£5,000
- Define scope, rules, timetable		10	
- Seek funding		10	
- Identify / recruit competition manager		10	
- Launch competition		5	
- Deadline for competition entries			£50,000
- Review entries		10	
- Select / support winning bids		10	
5 Develop CCU Sector Network			
- Confirm network remit / objectives / scope		5	
- Identify funding options		5	
- Pursue funding		10	
- Recruit interim / permanent executive		10	
- Establish network		5	
- Confirm initial activities		5	
- Recruit industry members		5	£112,500
- Raise profile with key stakeholders		10	
- Define annual activity plan		10	
TOTAL		**234**	**£345,000**
		£117,000	**at £500/day**

Figure 8: Estimated Costs

This shows a total cost of £462,000 over a three-year period to deliver the action plan. This consists of:

- £117,000 of public agency staff time, based on a cost of £500 per day
- £345,000 of external (consultancy / contract) costs to deliver key aspects of the action plan.

It also assumes that:

- SE and FC already have committed budget for delivery of the Living Lab project
- Funding for the innovation competition comes from other, existing sources, for example SE's R&D grant scheme
- Subcontract costs (e.g. to manage programmes and networks) are costed at £50,000 per annum. This includes personnel costs and associated expenses.

9 Expected Outcomes and Impacts

A logic model for the potential impact of this action plan can be presented as follows:

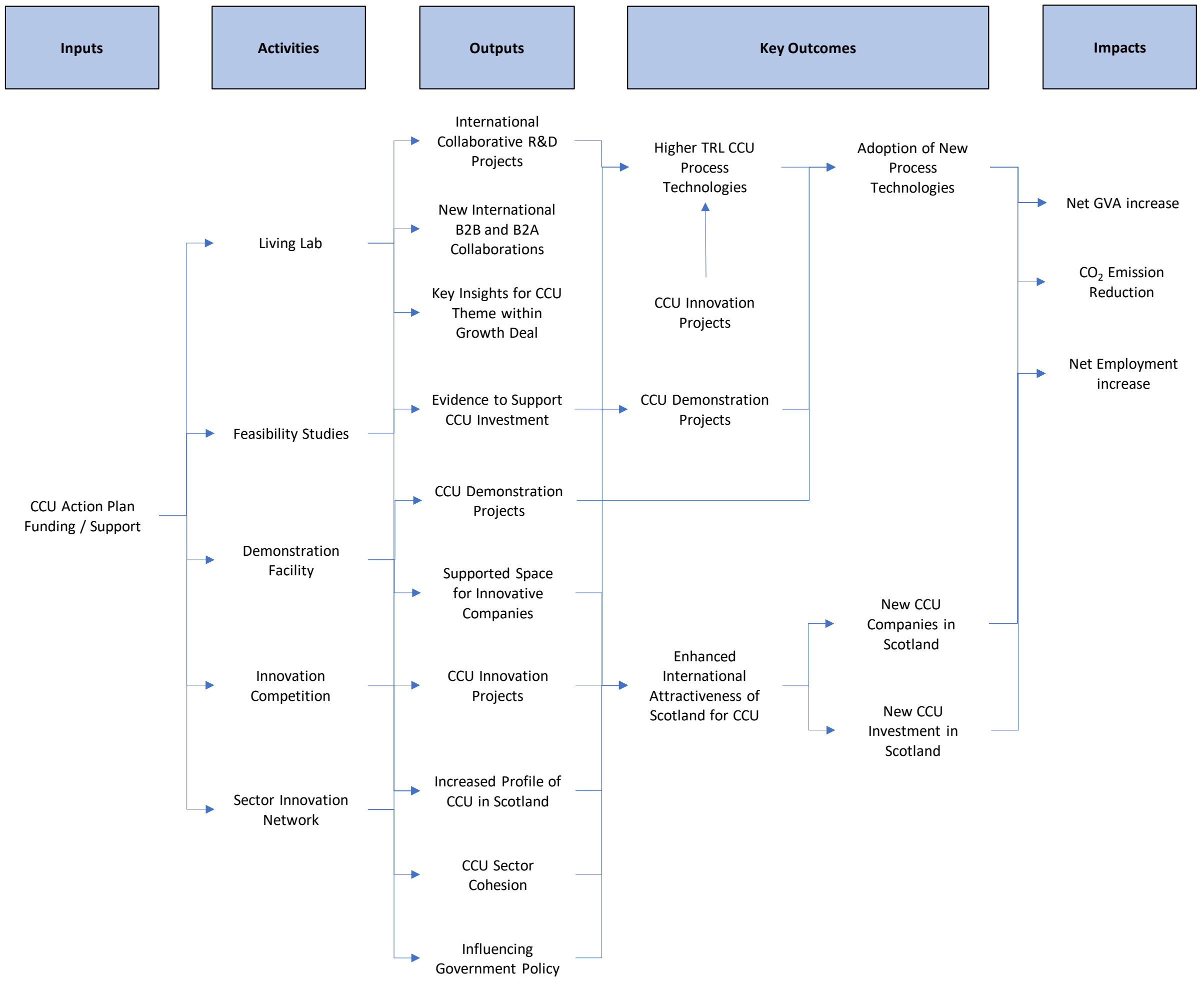


Figure 9: Logic Model

Expected outputs and outcomes are:

- Twenty CCU feasibility projects within 5 years
- Over ten CCU innovation and demonstration projects within 5 years
- Adoption of CCU by more than five companies within 5 years
- A proactive and effective CCU cluster organisation
- Over five new CCU companies in Scotland within 5 years

As a result, the main impacts arising are:

- Recognition of Scotland as an innovation driven leader in CCU
- An increase in international collaboration opportunities for Scottish businesses and research organisations
- Increase in the size of the CCU sector in Scotland (in terms of companies and skilled jobs)
- Increase in the GVA of the CCU sector in Scotland

Appendices

Appendix A: Stakeholders and Companies Participating in this Study

Company	Project Participation		
	Value Chain Consultation	Innovation System Consultation	Workshop
Argent Energy	●		
BEIS		●	
Birmingham University		●	
Brockwell Energy			1
Calachem		●	2
Carbon Capture Machine		●	
Chemical Sciences Scotland	●		1
Diageo		●	1
Doosan Babcock		●	1
Drochaid Research Service Ltd	●	●	1
DSM		●	1
Falkirk Council	●		1
Heriot Watt University	●	●	
IBioIC		●	
INEOS Olefins & Polymers UK Ltd		●	1
Ingenza Ltd	●	●	1
James Hutton Institute		●	
North British Distillery			2
Pale Blue Dot Energy	●	●	1
Petroineos Manufacturing (Scotland) Ltd		●	1
Scotch Whisky Research Institute	●		
Scottish Carbon Capture & Storage		●	
Scottish Enterprise	●●●●		6
Scottish Hydrogen and Fuel Cell Association	●	●	
TUV SUD National Engineering Laboratory		●	1
University of Strathclyde		●	1
Xanthella		●	
Zero Waste Scotland			1
	13	20	24

Annexes

Annex 1:
Sector Innovation System Approach: Carbon Capture and Utilisation Value Chain Report

Final Report
Scottish Enterprise
8th May 2019

J3124/SE

Executive Summary

The ***Sector Innovation System Approach*** is being used in this study to identify options to support the development of carbon capture and utilisation (CCU) in Scotland, specifically focused on opportunities that can be linked to the EU Northern Connections INTERREG project and develop an action plan to implement the options identified. This report addresses the first of three stages of the approach, specifically the analysis of the CCU value chain in Scotland. It focuses on carbon dioxide (CO_2) emissions in Scotland and its potential uses. It adheres to the principle discussed at the earlier meeting that a core focus of the work is to develop activities that utilise CO_2 emissions in Scotland, rather than demonstrate what can be done with CO_2 using commercially available gas.

The analysis indicates that there are numerous sources of CO_2 in Scotland, with a high concentration of emissions in the Grangemouth area, but little activity to collect the emitted gas. One company, North British Distillery, was identified as the only organisation operating a significant CO_2 valorisation activity in Scotland. Although there is evidence that other companies have expressed some interest, no other projects of scale were identified. As a result, there is very limited other activity and capacity in the value chain. Key areas of activity identified are:

- CO_2 Capture: Doosan Babcock
- CO_2 Transport: BOC /Air Liquide (linking to North British Distillery)
- Valorisation: Carbon Capture Machine, a university spin-out, based in Aberdeen, developing mineral carbonation processes
- Enabling technology: Xanthella – developers of photobioreactors
  Ingenza – development of IB process technology
- Industrial research Drochaid - chemical research company

There is also a range of relevant university expertise and industry support organisations that are active in the development and support of CCU.

Significant scope for development of the CCU value chain in Scotland was identified, but a number of barriers to this development were identified. These, predominantly, relate to

- Investment risk
- The lack of evidence of the financial and environmental benefits of CCU
- CCU is not core business for any sector or group of companies
- The lack of a "natural home" for CCU development - discussions with stakeholders have tried to address "who should be driving CCU in Scotland". The common conclusion is that it should be the chemical sector, but there is no apparent appetite for this.

It is considered that the development of a portfolio of value chain collaborations that would enable valorisation of CO_2 is the most attractive short-term opportunity. These may include:

- Distillery – Xanthella – fish feed producers, based on some early activity identified
- Distillery – gas company – direct use, following the North British Distillery model
- Biomethane plant – gas company – direct use, exploiting the volumes of CO_2 generated in producing gas for injection into the grid

Further developments will be dependent on an emitter of CO_2 being motivated to valorise its output. This will also be addressed in the next part of the study.

Table of Contents

Prepared By: Iain Weir and Mark Morrison	**Date:** 8th May 2019
Approved By: Deborah Creamer	**Date:** 9th May 2019

1 Introduction

1.1 Context

The ***Sector Innovation System Approach*** is being used in this study to identify options to support the development of carbon capture and utilisation (CCU) in Scotland, specifically focused on opportunities that can be linked to the EU Northern Connections INTERREG project and develop an action plan to implement the options identified.

The approach was previously piloted in the biorefining and subsea vehicles sectors by Scottish Enterprise and Optimat. It has three key stages*:*

1) Use value chain analysis to map out the specific opportunity, detailing the focus of technology and establishing the position of Scottish companies in the value chain
2) Analyse the innovation system around the value chain and specific opportunity
3) Facilitate an industry and stakeholder workshop with a focussed agenda on the specific opportunity, the challenges identified and development of an action plan

This value chain report describes the work carried out in the first of these stages. The other two stages will be addressed in subsequent reports.

1.2 Study Scope

This study focuses on the output of carbon dioxide (CO_2) in Scotland and its potential uses, as defined in our inception report. It adheres to the principle discussed at the earlier meeting that a core focus of the work is to develop activities that utilise CO_2 emissions in Scotland rather than demonstrate what can be done with CO_2 using commercially available gas.

Carbon capture and storage (CCS) is outside the scope of the study.

In Scotland CO_2 emissions over a threshold of ten million kg p.a. (ten thousand tonnes) are reported to the Scottish Environment Protection Agency (SEPA) and the data is publicly available through the Scottish Pollutant Release Inventory (SPRI)[1]. Published data for 2017, the most recent year available can be summarised as shown opposite[2].

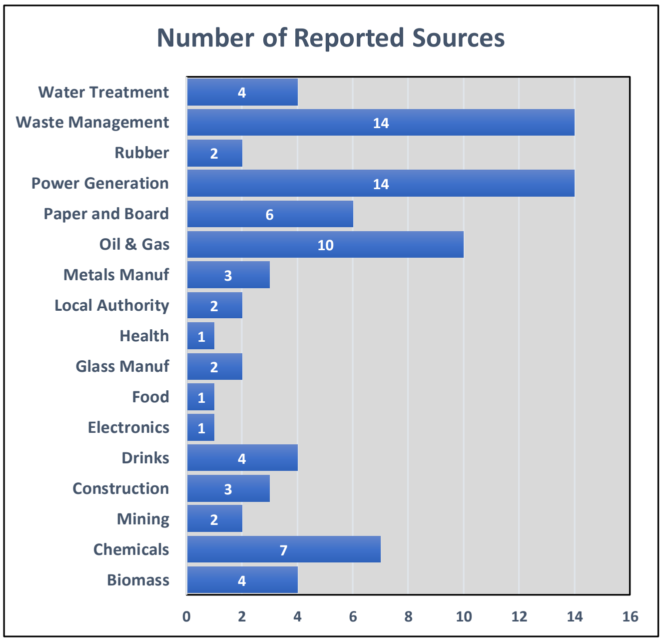


Figure 1: Number of Reported CO_2 Emissions by Sector (2017)

1 https://www.sepa.org.uk/environment/environmental-data/spri/
2 The full list of those companies where emissions are above the threshold is included in Appendix 1A.

Reported release of CO_2 by sector, and by weight, can be presented as follows:

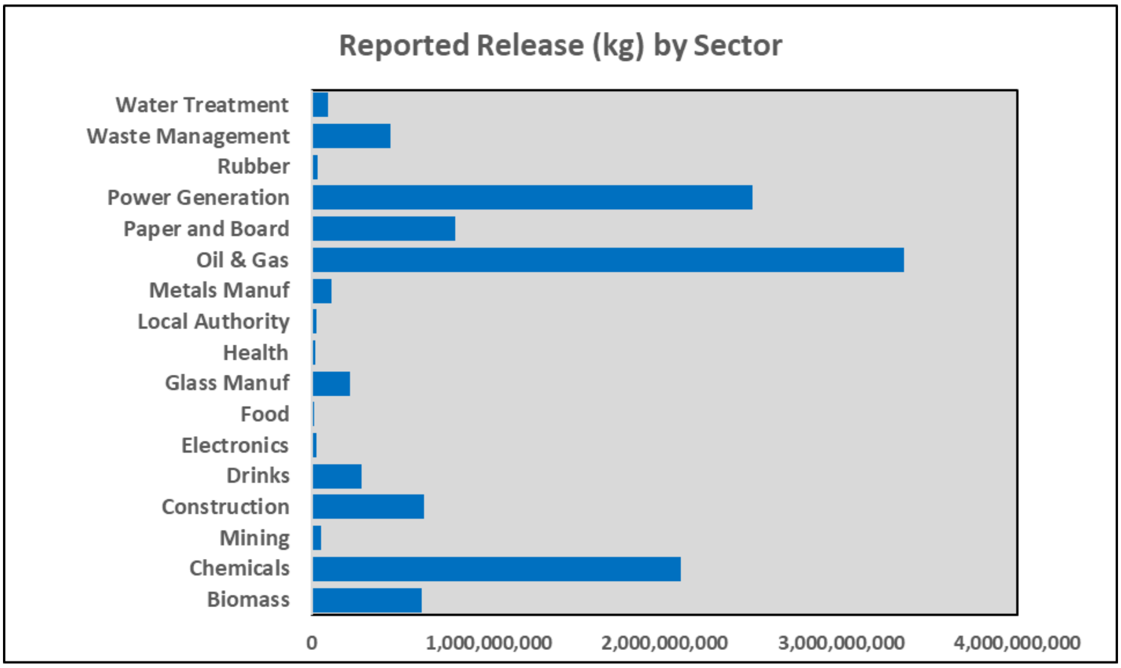


Figure 2: Tonnage of Reported CO2 Emissions by Sector (2017)

This covers a total of 80 sources across these sectors. The full list of sources is included in Appendix 1A. We note that one of these sources, Michelin, in Dundee, has announced its closure since publication of these figures.

Of course, reported data excludes emissions from a wide range of smaller industrial sites, in the above sectors that are potentially interesting for siting CCU plants.

The sectors listed above, therefore, offer a robust foundation on which to build CCU value chains.

As also highlighted in the inception report, the composition of CO_2 from different sources varies significantly, from quite pure to quite contaminated. As a result, the processing steps that are required, the valorisation processes that can subsequently be used and the potential uses that can be exploited can all vary significantly.

Our assessment of the value chain considers this full range of options. However, we do not include

- Supporting value chains ("side chains") that may be necessary to produce other reactants to valorise CO_2
- Activities to add value to outputs from CO_2 valorisation (i.e. known chemicals, materials or fuels manufactured using established processes)

1.3 Methodology and Approach

The study methodology was presented in the inception report. Key activities in developing the CCU value chain were:

- Desk research to develop a value chain structure and to identify organisations active in this value chain
- Stakeholder consultation to

   - Validate the value chain structure
   - Confirm the activities of the organisations identified
   - Identify any additional relevant organisations that should be included
- Discussions with emitters / representative stakeholders to consider their appetite in for CCU.

Those that participated in the consultations are listed in Appendix 1B.

2 The CCU Value Chain

The generic value chain developed for CCU is presented as follows:

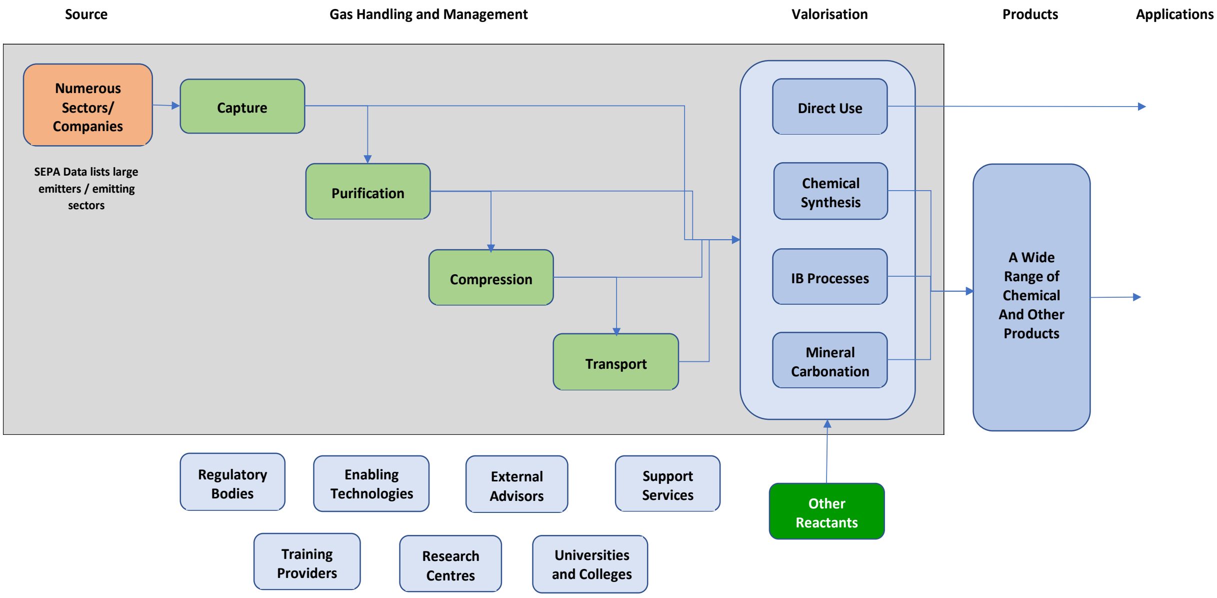


Figure 3: CCU Value Chain Structure

This value chain structure is based on a review of the literature[3] and discussions with key stakeholders.

Typically, downstream products / applications were highlighted in the project inception report and discussed at the subsequent project team meeting.

This figure shows that the CCU value chain (in the grey-shaded area)

- Spans activities from the source of emission to valorisation (either direct use or as a basic product that can be further processed to produce a wide range of chemicals)
- Depends on a range of technologies, experts and support services (light blue boxes)
- Excludes the wide range of different “reactants” that are necessary (e.g. hydrogen) to transform the basic valorised products into other products.

[3] For example, Holistic Assessment of Carbon Capture and Utilization Value Chains, Pieri et al, Environment, 2018, 5, 108, 25th Sept 2018 and Actions required to develop a Roadmap towards a Carbon Dioxide Utilisation Strategy for Scotland, University of Sheffield, June 2017.

(footnote continued)

This generic figure highlights the different stages in the value chain. However, depending on a number of factors, particularly the purity of the CO_2, the target end use and the proposed valorisation strategy, then the number of steps in a specific value chain will vary. For example:

- CO_2 from distilleries typically has a very high purity and can be used in downstream applications with limited further processing. For example, it is understood that CO_2 collected at North British Distillery in Edinburgh is supplied into the soft drinks industry with little processing.
- Industrial biotechnology based valorisation processes typically can accommodate a higher level of impurities than chemical processes[4].

This value chain, as shown in the figure above has been used to assess Scottish capability in carbon capture and utilisation.

3 CCU Capability in Scotland

Current capability in Scotland in CCU is shown in the table below:

			Gas Handling & Mgt				Valorisation				End Use		Value Chain Support Actors						
Company	Town/City	Source	Capture	Purification	Compression	Transport	Chemical Synthesis	IB Based Synthesis	Mineral Carbonation	Direct Use	End Product	End Use	Enabling Technology	Expert Advice	Support Services	Regulatory Bodies	University and Colleges	Research Centre	Training Provider
North British Distillery	Edinburgh	1		1															
Doosan Babcock	Renfrew		1																
Xanthella	Oban							1											
Carbon Capture Machine	Aberdeen								1										
A. G. Barr	Cumbernauld									1									
Coca Cola	East Kilbride									1									
Pale Blue Dot Energy	Banchory													1					
Heriot Watt University	Edinburgh																1		
Edinburgh University	Edinburgh																1		
Aberndeen University	Aberdeen																1		
SEPA	Stirling															1			
IBioIC	Glasgow																	1	
Drochaid	St Andrews																	1	
Scottish Carbon Capture and Storage	Edinburgh																1		
Scotch Whisky Research Institute	Edinburgh														1				
Scotch Whisky Association	Edinburgh														1				
SHFCA	Edinburgh														1				
Scottish Carbon Capture and Storage	Edinburgh														1				
Ingenza	Roslin												1						

Figure 4: Current CCU Capability in Scotland

This shows that current activity is very limited. This is discussed further below.

3.1 Industry Activity

Current industrial activity in CCU in Scotland can be summarised as follows:

- ***North British Distillery*** in Edinburgh has been identified as the only active carbon capture site in Scotland. It has been capturing around 4 tonnes of CO_2 per day from its fermentation processes for around 30 years[5], purifying the gas, then compressing and storing it. The CO_2 is then sold to

4 Industrial Biotechnology Research within Circular Carbon, Optimat report for Scottish Enterprise, May 2018
5 http://www.sccs.org.uk/news/470-carbon-capture-in-the-heart-of-the-city

industrial gas suppliers (i.e. Air Liquide and/or BOC) which then sell to carbonated drinks manufacturers in Scotland (AG Barr and Coca Cola).

- Due to their links to North British Distillery, ***Air Liquide and/or BOC*** can also be considered to be part of the value chain (Note: AG Barr and Coca Cola, as end users are outside the value chain).
- ***Doosan Babcock*** set-up a post combustion plant test facility[6] in 2010. It includes solvent scrubbing technology to capture CO_2 from coal fired gas flues. To date, we have not been able to verify the current status of this capability.
- ***Xanthella*** has developed a range of photobioreactors where CO_2 can be used as an input in the culture of microalgae. It is understood that Xanthella is engaging with a distillery to use its CO_2 emissions to grow microalgae. The microalgae produced could be further processed for fish feed, where the current Scottish supply chain is dependent on imported biomass.
- ***Carbon Capture Machine*** (CCM UK) is a spin-out from the Chemistry Department at the University of Aberdeen. Established in 2017, it has developed technology to transform CO_2 into precipitated calcium carbonate and magnesium carbonate, two species that can then be used in a range of industrial and construction applications. The company has been successful in winning the NRG Cosia Carbon XPrize which will enable it to demonstrate its technology. It is currently establishing a 1,000 tonnes per annum CO_2 demonstrator in Wyoming and is keen to establish a similar demonstrator in Scotland. The site, however, must offer a range of conditions to meet CCM-UK's needs.
- ***Pale Blue Dot Energy*** is a management consultancy that is active in CCU and CCS project development. It is actively involved in (leading) the Acorn Project focusing on CCS and is trying to develop a number of CCU projects.
- ***Ingenza*** is a leading company in the development and use of industrial biotechnology for chemicals, biologics and pharmaceuticals manufacturing. They are actively involved in the development of technologies to valorise CO_2.
- ***Drochaid*** is a private research centre with in-depth research in catalysis and process chemistry. It is currently carrying out and developing a number of projects based on CO_2 utilisation.

3.2 The Scottish Innovation Infrastructure

There are a number of players in the CCU innovation infrastructure in Scotland. There are core strengths in academia and world leading research being carried out within universities. Specific areas of expertise are presented in the following table[7].

6 http://www.carboncapturejournal.com/news/doosan-babcock-test-facility-officially-opened/2750.aspx?Category=a

7 Collated from a number of sources, including http://www.sccs.org.uk/, https://www.abdn.ac.uk/ncs/profiles/f.p.glasser and university webpages

University	Department/Group	Key Contact	Brief Description
University of Aberdeen	Department of Chemistry	Prof Fredrik Glasser	Expertise in materials science, materials chemistry and solid-state science and its applications. Specific focus on cements.
University of Glasgow	School of Geographical and Earth Sciences	Dr John MacDonald	Capture of atmospheric CO_2 by inorganic wastes
Heriot Watt University	Research Centre for Carbon Solutions (RCCS) / Centre for Innovation in Carbon Capture and Storage (CICCS)	Professor Mercedes Maroto-Valer	A range of capabilities and facilities covering carbon capture, CO_2 transport, CO_2 sequestration for mineral carbonation, utilisation for solar fuel production and assessment of environmental aspects of CO_2 release.
University of Edinburgh	School of Engineering	Professor Vasileios Koutsos Dr Daniel Friedrich	Carbon capture and separation processes applied to a range of sources of CO_2 Adsorption process modelling that can be applied to carbon capture processes and to the separation of gases in these situations
University of Strathclyde	Centre for Energy Policy	Professor Karen Turner	Macroeconomic modelling of energy with specific experience of carbon capture and storage.

Figure 5: Scottish Academic Capabilities in CCU

It is understood that a full mapping of academic expertise has already been carried out for Scottish Enterprise[8], but this dataset was not reviewed in preparation of this report.

These academic capabilities are supported by a number of more generic facilities[9] that may be relevant to CCU research and innovation, including:

- University of Aberdeen
  - High Pressure/High Temperature Test Facility
- Institute for Petroleum Engineering, Heriot-Watt University
  - Centre for Enhanced Oil recovery and CO_2 Solutions
  - Flow Pressure Test Facility
  - Chemical looping – CFB & Bubbling Bed
- University of Edinburgh
  - Membrane Characterisation
  - Solid Absorbent Characterisation
  - High Pressure/High Temperature Multiphase CO_2 Flow Rig

8 Actions required to develop a Roadmap towards a Carbon Dioxide Utilisation Strategy for Scotland, University of Sheffield, June 2017

9 https://www.etp-scotland.ac.uk/Portals/57/document%20library/theme%20group%20material/CCS2pagerFinal.pdf

- Doosan Babcock
    - Carbon Capture Test Facility
- National Engineering Laboratory
    - National Flow Measurement Test Facility

A number of these are linked via Scottish Carbon Capture & Storage (http://www.sccs.org.uk/) and / or the Energy Technology Partnership (https://www.etp-scotland.ac.uk/Home.aspx).

More generally, Scotland's universities have a strong track record in chemistry and industrial biotechnology that could be applied to the valorisation of CO_2. The collective capabilities in chemistry of seven universities are encompassed within the ScotCHEM[10] umbrella and several of IBioIC's nineteen academic partners[11] offer relevant industrial biotechnology expertise.

3.3 Other Relevant Infrastructure

A number of other organisations that are working to support CCU development / innovation in Scotland have also been identified. These include

- ***Scottish Hydrogen and Fuel Cell Association*** (SHFCA), a sectoral organisation that "promotes and develops Scottish expertise in fuel cells and hydrogen technologies" (http://www.shfca.org.uk/)
- ***IBioIC***, the Industrial Biotechnology Innovation Centre (http://www.ibioic.com/)
- ***SEPA,*** the Scottish Environmental Protection Agency (https://www.sepa.org.uk/)
- ***Zero Waste Scotland*** which funds a number of projects through its Circular Economy Business Support Programme such as:
    - Assisting Carbon Capture Machine to find a UK location for a 1ktpa demo plant (as detailed above)
    - A 700tpa CO_2 stream as part of a broader coproduct development strategy (Central Belt)
    - A 110ktpa CO_2 stream and ash from a bioenergy plant (NE Scotland)

There are also a number of different types of external advisors and support organisations that could apply their expertise to CCU as it develops. These include, for example, organisations with expertise in engineering, health and safety, risk management, etc. However, due to the current embryonic stage of CCU development in Scotland there is not a strong driver for these organisations to become involved.

4 Mapping Scottish Capability on the Value Chain

The companies and organisations active in the CCU value chain in Scotland, as summarised above, can be presented as follows:

10 https://www.scotchem.ac.uk/
11 http://www.ibioic.com/who_we_are/academic_partners/d35/

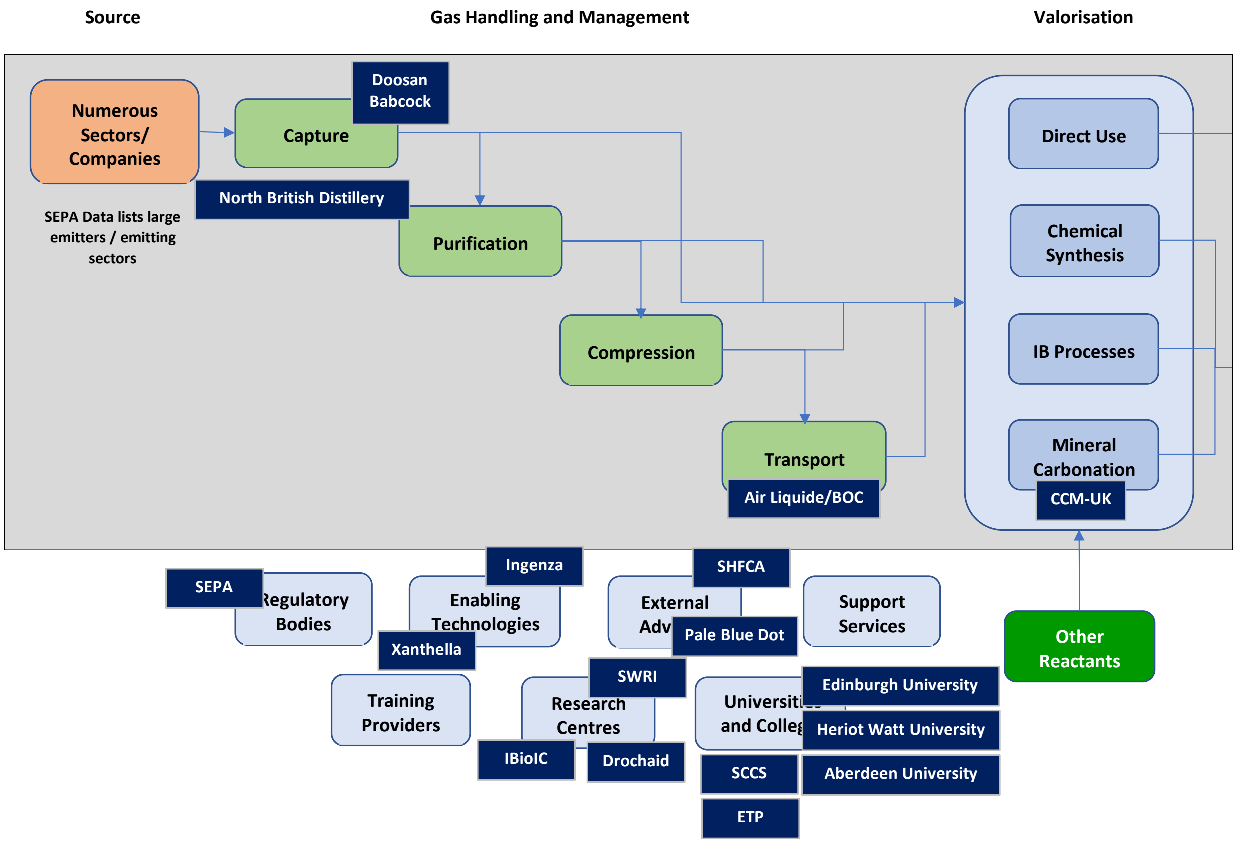


Figure 6: Mapping Scottish CCU Capability

This highlights the limited number of companies across all parts of the core value chain.

5 The Potential for Future Development

We believe that there is significant potential to develop the CCU supply chain in Scotland. A number of potential product opportunities have already been identified[12], together with a discussion on the relative attractiveness of CCU and CCS.

In terms of sources of CO_2, Figure 1 highlighted 80 companies across a number of sectors that are emitting CO_2 at volumes that require reporting. There are also a number of smaller emitters across these sectors that should be considered. For example, there are over 120 distilleries in Scotland and although only three must report CO_2 emissions, a number of others could form the basis of a CCU value chain. Discussions with stakeholders have identified a number of companies that would be interested but have not yet taken any action. The reasons for this are discussed in the following section.

There are a number of innovative small companies, in addition to those listed in Section 3.1, that could develop processes to utilise CO_2. These include:

- Celtic Renewables — New microbial strains and process technologies for the production of fuel drop-ins and other chemicals
- MiAlgae — Algal culture for fish feed

[12] Actions required to develop a Roadmap towards a Carbon Dioxide Utilisation Strategy for Scotland, University of Sheffield, June 2017

- Scottish Bioenergy Algal production from photobioreactors
- T2 Energy Algal production from photobioreactors

There are also a number of companies that could ***potentially*** use products from CO_2 valorisation processes. These include:

Company	Sector	Potential interest?	Use
3F BIO	IB	algal extract	Protein for food production
Apple Biofuels	Basic Chemicals	methanol	Production of drop-in fuels
Argent Energy	IB	methanol, butanol, dimethyl ether	Production of drop-in fuels
Biomar	Agritech	algal extract	Fish feed
Calachem	Speciality Chemicals		Intermediates for chemical synthesis
FMC	Pharmaceutical Services	algal extract	Algal extracts for therapeutics
GSK (Irvine)	Pharmaceutical Services	Small organic molecules	Intermediates for chemical synthesis
Ineos	Basic Chemicals	methanol, higher carbons	Fuels/intermediates for chemical synthesis
Kilco	Agritech	algal extract	Food & feed production
MacFarlan Smith (Johnson Matthey)	Pharmaceutical Services	small organic molecules	Intermediates for chemical synthesis
Marine Biopolymers	IB	algal extract	Therapeutic/cosmetic use
Prasinotech	IB	algal extract	Algal extracts for therapeutics
Royal DSM	Pharmaceutical Services	small organic molecules	Intermediates for chemical synthesis
Sigma Aldrich	Pharmaceutical Services	variety of organic molecules	Intermediates for chemical synthesis
Sustainable Project Partners Ltd	IB	algal extract	Production of drop-in fuels
Syngenta	Agritech	small organic molecules	intermediates for chemical synthesis
Versalis	Basic Chemicals	methanol, butadiene	Plastics

Figure 7: Companies in Scotland that could Potentially Use Products from CO_2 Valorisation Processes (reproduced from previous Industrial Biotechnology in Circular Carbon Study)

With developments in other CCU technologies (e.g. CCM-UK) this list could be extended to include companies from a number of other sectors, including building products and construction.

6 Key Barriers

Discussions with key stakeholders and companies have identified the following barriers to the development of CCU:

- The apparent investment risk
  Our research has indicated that a number of companies are aware of the potential to capture and valorise CO_2 but have not committed to proceed with the idea. A key issue is the lack of

tangible evidence that underlines the business proposition. As a result, there is an unwillingness to proceed without sufficient evidence / confidence that it will be a positive investment.

- The lack of evidence of the financial and environmental benefits of CCU
  We have already highlighted that there is only one active CO_2 capture and utilisation in Scotland and few elsewhere in the UK and Europe. This does not provide a body of evidence to support others to make an investment decision. For example, although there are case studies available describing North British Distillery's commitment to CCU, details of the financial case for it are not accessible.
- It's not core business for any sector or group of companies
  We have highlighted the range of businesses that emit CO_2 and could invest in CCU (or, in some cases, CCS). Most companies, however, will prioritise investment in their core business. Additionally, such a non-core activity would be considered a distraction for existing staff.
- The lack of a "natural home" for CCU development
  Discussions with stakeholders have tried to address "who should be driving CCU in Scotland". The common conclusion is that it should be the chemical sector, which is the most obvious sector to be centrally involved in synthesising CO_2 and exploiting the resultant products in relevant markets. But companies in the sector, whether sources of gas or potential participants further down the value chain, are not showing any interest. We believe that this reflects the production focus, limited innovation and lack of local autonomy within the larger chemical companies. Smaller companies, that demonstrate opposing characteristics have different barriers, namely the lack of resources to invest in developing the technology.

The lack of any regulatory or legislative driver could be described as an additional barrier.

For example, the following active opportunities were identified by stakeholders during recent interviews:

- A biomethane operation with 6ktpa of >98% pure biogenic CO_2 (NE Scotland)
- A grain distillery with 20ktpa of high purity biogenic CO_2 (Central Belt)
- A biomethane operation with 10ktpa of >98% pure biogenic CO_2 (Central Belt)

However, in all cases there is a strong reluctance to proceed.

The key challenge is, therefore, to find mechanisms to persuade emitters of CO_2 to commit to CCU, either individually or in partnership with others.

Initiatives, focusing on the innovation landscape, that we consider are likely to address this challenge and overcome these barriers will be assessed and identified in the next stage of the project, the innovation systems analysis.

7 Opportunities for Grangemouth

As already highlighted, a key aspect of this study was to identify potential innovation or demonstration projects that could be developed in Grangemouth as part of the Northern Connections project. This has been addressed by reviewing evidence from previous studies and discussing with key stakeholders. Potential options identified to date are:

- Establishment of a Carbon Capture Machine demonstrator at Grangemouth. We understand that some of the requirements for this may be challenging to deliver, but that several stakeholders are considering this.
- Projects in the central belt (distillery and biomethane plant), but although relatively close, these are obviously not in Grangemouth.

8 Prioritisation of the Value Chain Gaps to be Addressed

As shown in Figure 6, there a very few players in the value chain. Activities are limited and unconnected. Essentially there are a small number of unconnected activities rather than an established, emerging or even embryonic value chain.

The analysis carried out indicates that focusing on specific parts of the core value chain is not the most useful option. We consider that the development of a portfolio of value chain collaborations that would enable valorisation of CO_2 would be more beneficial in the short term. These may include:

- Distillery – Xanthella – fish feed producers
- Distillery – gas company – direct use
- Biomethane plant – gas company – direct use

Further developments would be dependent on an emitter of CO_2 being motivated to valorise its output. Development of a value chain that was suited to this emitter would need to be developed. This may be based on

- Exploiting existing or developing Scottish technology (e.g. from Xanthella, Ingenza, Drochaid, or others)
- Encouraging inward investment – examples of technologies available (at a range of TRLs) were listed in a previous Optimat study[4].

It is expected that development of these opportunities will be encouraged by an enhanced innovation support system. The options to do this will be addressed in the following part of the study.

Appendices

Appendix 1A: List of Reported Sources

Registered Company Name (Site Name)	Site Company Name	Sector	Total Release
Petroineos Manufacturing Scotland Limited. Petroineos Manufacturing Grangemouth Refinery	PO Box 21 Bo'ness Road Grangemouth FK3 9XH	Oil & Gas	1,638,305,000
SSE Generation Limited. SSE Gen Peterhead Power Station Peterhead	Boddam Peterhead Aberdeenshire AB42 3BZ	Power Generation	950,295,137
ExxonMobil Chemical Ltd. ExxonMobil Chemical Limited Mossmorran	Fife Ethylene Plant Mossmorran Cowdenbeath KY4 8EP	Chemicals	892,964,122
Grangemouth CHP Ltd. Grangemouth CHP Boness Road Grangemouth	Bo'ness Road Grangemouth Falkirk FK3 9XQ	Power Generation	689,035,000
Tarmac Cement & Lime Limited. Tarmac Ltd Dunbar Plant E. Lothian	Dunbar Plant Oxwell Mains Dunbar East Lothian EH42 1SL	Construction	601,447,000
INEOS Chemicals Grangemouth Limited. INEOS Chemicals Grangemouth Ltd Grangemouth	BO'NESS ROAD GRANGEMOUTH FK3 9XH	Chemicals	495,915,365
RWE Markinch Limited. RWE Markinch Limited Glenrothes	RWE Markinch Limited MARKINCH GLENROTHES KY7 6GU	Biomass	472,000,000
Ineos Infrastructure (Grangemouth) Limited. INEOS Infrastructure (Grangemouth) Ltd	1 Inchyra Road Grangemouth FK3 9XB	Chemicals	456,930,862
E.ON UK Plc. E.ON UK Plc Stevens Croft Power Station	Stevens Croft Power Station Johnstonebridge Lockerbie DG11 1HD	Power Generation	411,519,260
Shell UK Limited. Shell UK Ltd St Fergus Gas Plant	St Fergus Gas Plant Peterhead Aberdeenshire AB42 6WJ	Oil & Gas	340,827,607
Ineos FPS Limited. INEOS FPS Ltd Kinneil Terminal Grangemouth	INEOS FPS Limited Kinneil & LPG Terminals Grangemouth FK3 9XH	Oil & Gas	310,885,154
Norbord Europe Limited. Norbord Europe Ltd Station Rd Cowie	Station Road Cowie FK7 7BQ	Paper and Board	305,919,467
UPM-Kymmene (UK) Limited. UPM-Kymmene (UK) Ltd Ayrshire	Caledonian Paper Mill Meadowhead Road Shewalton Irvine KA11 5AT	Paper and Board	278,258,500
Total E & P UK Limited. Laggan - Tormore Shetland Gasplant	Laggan - Tormore Shetland Gas Plant Shetland ZE2 9JN	Oil & Gas	239,202,543
ENGIE FM Limited. Sullom Voe Terminal Shetland	EnQuest NNT Ltd Sullom Voe Power Station Mossbank Shetland ZE2 9TU	Oil & Gas	229,284,430
Shell UK Limited. Fife NGL Plant Cowdenbeath	Mossmorran P O BOX 16 Cowdenbeath Fife KY4 8EL	Oil & Gas	197,088,860
William Grant & Sons Distillers Ltd. Girvan Dist Grangestone Ind Est Girvan	Ladywell Avenue Grangestone Industrial Estate Girvan South Ayrshire KA26 9PT	Drinks	155,795,187
O - I Manufacturing UK Ltd. O-I Manufacturing UK Ltd Glasshouse Loan Alloa	O-I Manufacturing UK Ltd Glasshouse Loan Alloa FK10 1PD	Glass	146,155,270
Repsol Sinopec Resources UK Limited	Flotta Oil Terminal Flotta Stromness Orkney KW16 3NP	Oil & Gas	144,205,632

Wood Group UK Limited. Sage Gas Terminal St Fergus Peterhead	North Pittenheath Road St Fergus Peterhead Aberdeenshire AB42 3EP	Oil & Gas	123,508,000
Norbord Europe Limited. Norbord Ltd Morayhill Inverness	Morayhill Inverness IV2 7QJ	Paper and Board	121,887,380
DSM Nutritional Products (UK) Ltd. DSM @ Drakemyre Chemical Works Dalry	DRAKEMYRE DALRY NORTH AYRSHIRE SCOTLAND KA24 5JJ	Chemicals	118,788,000
EPR Scotland Limited. EPR Scotland Ltd Westfield Biomass Plant Fife	Westfield By Cardenden Fife KY5 0HR	Biomass	112,273,000
National Grid Gas Plc. Aberdeen Compressor Station Garlogie	Garrick Garlogie Westhill Aberdeenshire AB32 6US	Power Generation	90,362,859
National Grid Gas Plc. Bathgate Compressor Station (Site 2)	Gowanbank Quarry Gowanbank Avonbridge Falkirk FK1 2JY	Power Generation	89,912,970
MVV Environmental Baldovie Ltd. MVV Baldovie Incinerator Dundee	Forties Road Baldovie Industrial Estate Dundee Angus DD4 0NS	Waste Mgt	88,350,000
Simec Lochaber Hydropower 2 Ltd. Liberty Lochaber Aluminium Lochaber Smelter	Lochaber Smelter North Road Fort William Highland PH33 6TH	Metals	85,169,436
SSE Generation Limited. SSE Generation Lerwick P/Station Shetland	Gremista Industrial Estate Gremista Road Lerwick Shetland ZE1 0PS	Power Generation	77,509,000
Enquest NNS Limited. Sullom Voe Terminal	Mossbank Sullom Voe Shetland ZE2 9TU	Oil & Gas	77,320,000
Diageo Distilling Limited. Cameronbridge Dist Windygates Leven	Windygates Leven Fife KY8 5RL	Drinks	76,010,000
Arjo Wiggins Fine Papers Ltd. Stoneywood Mill Bucksburn Aberdeen	Stoneywood Terrace Stoneywood Bucksburn Aberdeen AB21 9AB	Paper and Board	73,595,000
Ardagh Glass Limited. Ardagh Glass Portland Place Irvine	1 Portland Place Irvine Industrial Estate Irvine Ayrshire KA12 8LW	Glass	68,038,898
PX Limited. PX Ltd St Fergus N. Sea Terminal Aberdeen	St Fergus Peterhead Aberdeenshire AB42 3EP	Oil & Gas	59,278,557
National Grid Gas Plc. National Grid N. Sea Gas Terminal Peterhead	National Grid Gas Terminal St Fergus Peterhead Aberdeenshire AB42 3EP	Power Generation	55,992,158
Versalis UK Limited. Versalis UK Ltd Grangemouth	Boness Road Grangemouth Falkirk FK3 9XE	Chemicals	55,600,000
Smithkline Beecham Limited. SmithKline Beecham Ltd Irvine	Shewalton Road Shewalton Irvine North Ayrshire KA11 5AP	Chemicals	55,183,000
SMW Limited. SMW Ltd Daldowie RDF Plant	Broomhouse Uddingston South Lanarkshire G71 7RX	Waste Mgt	47,162,942
FCC Waste Services (UK) Limited. Greengairs L/F Meikle Drumgray Rd Airdrie	Meikle Drumgray Road Greengairs Airdrie North Lanarkshire ML6 7TD	Waste Mgt	45,410,000
Veolia Water Outsourcing Limited. Edinburgh Sewage Treatment Works Leith	Marine Esplanade Seafield Road Edinburgh Midlothian EH6 7LU	Water Treatment	42,000,000
Viridor Waste Management Ltd. Viridor WasteDunbar L/FOxwell Mains, Dunbar	South Quarry Oxwell Mains Dunbar East Lothian EH42 1SW	Waste Mgt	40,700,000
Suez Recycling & Recovery Ltd. Stoneyhill Environ Pk Peterhead Aberdeen	Stoneyhill Environmental Park Stoneyhill Peterhead Aberdeenshire AB42 0PR	Waste Mgt	37,300,000

The North British Distillery Company Limited. North British Dist Wheatfield Rd Edinburgh	9 Wheatfield Road Gorgie Edinburgh EH11 2PX	Drinks	34,819,000
GLASGOW CITY COUNCIL. GCC Cathkin L/F Cairnmuir Rd East Kilbride	Cairnmuir Road East Kilbride South Lanarkshire G73 5RG	Waste Mgt	33,400,000
Patersons of Greenoakhill Ltd. Greenoakhill LF Site Mount Vernon	Hamilton Road Mount Vernon Glasgow G71 7SG	Waste Mgt	31,900,000
Kier Minerals Ltd. Greenburn Surface Mine Auchincross Farm	Auchincross Farm Nr New Cumnock East Ayrshire KA18 4QR	Coal	29,055,038
Barr Environmental Limited. Barr Environ Auchencarroch L/F Jamestown	Auchencarroch Road Jamestown Alexandria West Dunbartonshire G83 9EY	Waste Mgt	28,960,000
GNI (UK) Limited. Beattock Compressor Station Dumfries	Lochmaben Road Beattock Dumfries and Galloway DG10 9RL	Power Generation	27,671,997
North Lanarkshire Council. Auchinlea L/F Site Bellside Cleland M/well	Carlisle Road Bellside CLELAND North Lanarkshire ML1 5LR	Waste Mgt	27,240,000
Energen Biogas Limited. Energen Biogas Ltd Cumbernauld	2 Dunnswood Road Wardpark South Cumbernauld G67 3EN	Biomass	26,836,002
Alpheus Environmental Limited. Alpheus WWTP at Glaxosmithkline	SmithKlineBeecham Shewalton Road Irvine KA11 5AP	Water Treatment	25,630,000
Hargreaves Surface Mining Limited. House of Surface Water Mine New Cumnock	NEW CUMNOCK AYRSHIRE KA18 4QS	Coal	23,918,072
Texas Instruments (UK) Ltd. Texas Instruments (UK) Ltd Greenock	Larkfield Industrial Estate Earnhill Road Greenock Renfrewshire PA16 0EQ	Electronics	23,487,051
Egger (Barony) Limited. Egger (UK) Ltd Barony Rd Ayr	Barony Road Auchinleck Cumnock Ayrshire KA18 2LL	Paper and Board	23,034,678
Michelin Tyre Plc. Michelin Tyre PLC Baldovie Rd Dundee	Baldovie Road Dundee DD4 8UQ	Tyres	22,140,000
GNI (UK) Limited. GNI (UK) Ltd Brighouse Bay Compressor Station	Brighouse Bay Compressor Station Kirkcudbright DG6 4TR	Power Generation	21,048,398
Veolia Energy & Utility Services UK PLC. Veolia CHP Plant Earls Road Grangemouth	CalaChem Earls Road Grangemouth Falkirk FK3 8XG	Power generation	19,506,000
Barr Environmental Limited. Barr Environ Garlaff L/F Skares Rd Cumnock	Skares Road Garlaff Cumnock East Ayrshire KA18 2RB	Waste Mgt	18,680,000
Greater Glasgow Health Board. Queen Elizabeth University Hospital Glasgow	1345 Govan Road Glasgow G51 4TF	Health	18,397,000
Superglass Insulation Limited. Superglass Insulations Ltd Stirling	Thistle Industrial Estate Stirling FK7 7QQ	Construction	18,167,215
Penspen Limited. Penspen Limited Drungans Dumfries	Dalbeattie Road Drungans Cargenbridge Dumfries & Galloway DG2 8LT	Power Generation	17,994,663
Suez Recycling & Recovery UK Ltd. SITA Binn Landfill Binn Farm Glenfarg	Binn Farm Glenfarg Perth and Kinross PH2 9PX	Waste Mgt	16,300,000
Shetland Islands Council. Lerwick Energy Recovery Plant Shetland	Green Head Lerwick Shetland ZE1 0PY	Power Generation	16,115,000
Kelda Water Services (Grampian) Ltd. Nigg WWTW Aberdeen	Coast Road Nigg Bay Aberdeen AB12 3LT	Water Treatment	16,000,000

Tennent Caledonian Breweries UK Limited. Tennent Caledonian Breweries UK Ltd	Wellpark Brewery 161 Duke Street Dennistoun Glasgow G31 1JD	Drinks	14,909,508
Dundas Chemical Company. Dundas Chemical Co Mosspark Dumfries	Mosspark Brasswell Dumfries and Galloway DG1 4PH	Chemicals	14,778,544
GFG P15 Limited. Liberty Steel Dalzell Park St Motherwell	Park Street Motherwell North Lanarkshire ML1 1PU	Metals	14,720,000
National Grid Gas Plc. Kirriemuir Compressor Station Forfar	Forestmuir Road Kirriemuir Forfar Angus DD8 3TP	Power Generation	14,606,187
Veolia Energy & Utility Services UK PLC. Dalkia Utilities Services Chirnside Duns	Chirnsidebridge Chirnside Duns Berwickshire TD11 3JW	Power Generation	14,419,000
HILLHOUSE QUARRY GROUP LIMITED. Hillhouse Quarry - Mobile Plant	Hillhouse Quarry Group Limited Hillhouse Quarry Troon KA10 7HX	Construction	13,947,228
Angus Council. Restenneth Landfill Site Montrose Rd Forfar	Montrose Road Forfar Angus DD8 2RL	Local Authority	13,670,000
Fourstones Paper Mill Co Limited. Fourstones Paper Mill Co Ltd Sapphire Mill	Sapphire Mill Glenwood Road Leslie Fife KY6 3AB	Paper and Board	13,369,276
Gates (U.K.) Limited. Gates Power Transmission Heathhall Dumfries	TINWALD DOWNS ROAD Heathhall Dumfries and Galloway DG1 1TS	Rubber	13,146,643
UNITED BISCUITS LTD. United Biscuits Ltd Glasgow	720 Tollcross Road Glasgow G32 8YD	Food	12,481,000
FCC Environment Limited. Oatslie Sandpit L/F Cleugh Rd Midlothian	Cleugh Road Roslin Midlothian EH25 9QN	Waste Mgt	11,940,000
Wyman Gordon Ltd. Wyman Gordon Ltd Livingston	Houstoun Road Houstoun Industrial Estate Livingston West Lothian EH54 5BZ	Metals	11,874,186
Glasgow City Council. Summerston Landfill Site Balmore Road	BALMORE ROAD GLASGOW G23.	Local Authority	11,300,000
Catchment Tay Limited. Hatton STW By Hatton Farm Arbroath	By Hatton Farm Arbroath Angus DD11 2PJ	Waste Mgt	11,000,000
Scottish Water. Meadowhead Sewage Treatment Works Irvine	Meadowhead Road Shewalton Irvine North Ayrshire KA11 5AP	Water Treatment	11,000,000
Viridor Waste Management Ltd. Rigmuir Landfill Site East Kilbride	Rigmuir Landfill Site off A726 Strathaven Road East Kilbride G75 0QZ	Waste Mgt	10,500,000
Earnside Energy Limited. Earnside Energy Ltd Glenfarg	Composting & Anaerobic Digestion Binn Farm Glenfarg Perth PH2 9PX	Biomass	10,497,500

Appendix 1B: Organisations Consulted

We acknowledge the contribution of the following organisations in this value chain analysis.

- Argent Energy
- Chemical Sciences Scotland
- Drochaid
- Falkirk Council
- Heriot Watt University
- Ingenza
- Pale Blue Dot Energy
- Scottish Enterprise
- Scottish Hydrogen and Fuel Cell Association
- Scottish Whisky Research Institute

Annex 2:
Sector Innovation System Approach – Carbon Capture and Utilisation Innovation System Report

Final Report

Scottish Enterprise

31st July 2019

J3124/SE

Executive Summary

The ***Sector Innovation System Approach*** is being used in this study to identify options to support the development of carbon capture and utilisation (CCU) in Scotland, specifically focused on opportunities that can be linked to the EU Northern Connections INTERREG project, and to develop an action plan to implement the options identified. This report addresses the second of three stages of the approach - the analysis of the CCU innovation system in Scotland. It reviews the various types of innovation support that is available to capture, process and utilise carbon dioxide (CO_2) emissions in Scotland. The analysis was structured around an innovation systems model (see Figure 1), with the provision of support in each of the five parts of the model assessed. Key points noted are:

- Scotland has a strong research capability, in both universities and the private sector. The largest university groups (at Heriot Watt and Edinburgh universities) are also UK leaders
- Numerous intermediate organisations support the CCU value chain, but their activities are typically part of a wider technology (e.g. IBioIC) or sectoral (e.g. Chemical Sciences Scotland or the Scotch Whisky Research Institute) remit
- Value chain actors are the private sector organisations that finance innovation, namely companies and financial organisations that support business research and development (BERD)
- The market demand part of the innovation system model is not strongly linked to other aspects of the value chain, particularly in Scotland at the moment, due the immaturity of the value chain

A review of the situation elsewhere indicates that:

- There are numerous company specific or collaborative projects to develop CCU technologies, with several developed to higher TRL levels. These projects are typically supported by a combination of private and public sector funding
- Development of CCU clusters in Europe is driven by the European Union Strategic Energy Technology (SET) plan but is at an early stage. Early cluster development is focusing on infrastructure rather than innovation and industry cluster development

It is considered that the immaturity of CCU cluster development activities elsewhere in Europe means that there are limited high value transferable lessons for Scotland.

The research and consultation completed in this study indicates that the existing innovation system, particularly to support low – mid TRL activities is considered to be relatively strong, based on the range of funding sources available, academic capability and the community of intermediary organisations. The key issues for companies are strongly linked to business / commercial issues, specifically:

- The lack of existing value chain activity and, thus, best practice examples
- There are no regulatory or legislative drivers
- The apparent/perceived investment risk
- A lack of evidence of the business / financial case for CCU
- CCU is not core business for all emitters
- A lack of ownership of CCU development

These five issues collectively lead to inertia. Addressing them is critical to develop CCU.

- Limited funding mechanism to support the demonstration of CO_2 utilisation

- The complexity of the public support infrastructure

These are business / commercial rather than innovation issues, as already highlighted, and they underline a reluctance / lack of commitment of those companies emitting CO_2 to act to mitigate emissions. This is an understandable position as there is no current driver for action. Innovation interventions can, however, help address these issues. Based on the engagement with key stakeholders and analysis of best practice in other sectors, the following innovation interventions are identified:

- ***"Living Lab".*** Scottish Enterprise (SE) and Falkirk Council (FC), the Scottish partners in the Northern Connections project, are identifying early stage or existing collaborative CCU project in Scotland that would benefit from identifying alternative/new technologies, services or processes to help better inform implementation or introduce improvements in the project.
- ***Feasibility studies.*** These desk-based studies are important to assess and understand potential technologies for a given situation, identify and select the optimum technology, define the scope of the investment and potential partners, prepare an initial techno-economic analysis and assess, understand (and make) the business case for investment. This activity would precede demonstration activities
- ***Demonstration scale facility.*** This is considered the core intervention to catalyse CCU activity. This facility will enable evaluation of CCU technologies in a realistic pseudo-industrial emission environment, increased confidence in specific technologies by obtaining evidence of performance in industrially relevant situations and completion of more detailed techno-economic analysis. This facility would need to be sufficiently flexible to accommodate a range of different technology platforms, as specified by interested companies. It would also need to have the required monitoring and control equipment so that the performance of different systems could be accurately monitored.
- ***Innovation competition***. The establishment of a competition to develop attractive technologies that would convert CO_2 into viable products. Such a competition would offer the opportunity for the research and innovation community to propose ideas for CO_2 valorisation, with funding made available to those that are most attractive. This approach has been used successfully elsewhere (e.g. NRG COSIA Carbon XPRIZE – see https://carbon.xprize.org/prizes/carbon)
- ***Falkirk Growth Deal***. We understand that this opportunity is under development and could be used to fund infrastructure such as the demonstration scale facility for CCU technologies, as well as creating a supportive, collaborative environment for technology companies, emitters and others in the value chain
- ***Sector Innovation Network.*** A CCU focused organisation that will bring together organisations interested in CCU, provide leadership, establish a forum for knowledge sharing and raise issues regarding CCU and lobby government

The development and implementation of these interventions are addressed in the ***action plan for development of CCU in Scotland***, which is currently being prepared for SE and FC.

The development of CCU, however, cannot be driven by innovation interventions alone. It is important that there are wider, political and policy interventions to catalyse change. Critical actions identified are:

- Clarity on the direction of travel - it is important that the Scottish government sets a clear agenda and strategy for mitigation of carbon emissions. This will provide a framework within which Scottish companies can operate
- Development of market pull. A key catalyst for the development of CCU would be the introduction of market incentives for products utilising captured carbon
- Investment in necessary linked infrastructure. Effective CCU requires, in most cases, access to cost effective (low cost) hydrogen and energy and parallel investment in these resources are necessary

These other interventions will also be addressed in the ***action plan for development of CCU in Scotland***. Further, it is expected that the proposed sector innovation network will have a key role in raising these wider issues in the relevant forums.

optimat

Table of Contents

Prepared By: Iain Weir and Mark Morrison	**Date:** 30th July 2019
Approved By: Deborah Creamer	**Date:** 31st July 2019

1 Introduction

1.1 Context

The ***Sector Innovation System Approach*** is being used in this study to identify options to

- Develop a plan to accelerate the development and adoption of CCU technologies in Scotland
- Specifically focus on value chain opportunities that can be linked to the EU Northern Connections INTERREG project
- Develop an action plan to implement the options identified

The approach was previously piloted in the biorefining and subsea vehicles sectors by Scottish Enterprise and Optimat. It has three key stages***:***

- Use value chain analysis to map out the specific opportunity, detailing the focus of technology and establishing the position of Scottish companies in the value chain
- Analyse the innovation system around the value chain and specific opportunities
- Facilitate an industry and stakeholder workshop with a focussed agenda on the specific opportunity, the challenges identified and development of an action plan

This innovation systems report describes the work carried out in the second of these stages. The other two stages are being addressed with separate reports.

1.2 Study Scope

This study focuses on the output of carbon dioxide (CO_2) in Scotland and its potential uses, as defined in our inception report. It adheres to the principle discussed at the earlier meeting that a core focus of the work is to develop activities that utilise CO_2 emissions in Scotland rather than demonstrate what can be done with CO_2 using commercially available gas.

The scale and distribution of CO_2 emissions in Scotland were summarised in our earlier value chain report.

1.3 Methodology

The study methodology was presented in the inception report. Key activities in assessing the CCU innovation system were:

- Preparation of an initial CCU innovation systems framework
- Stakeholder consultation to
    - Validate the innovation systems framework
    - Confirm the roles and activities of the organisations identified
    - Identify any additional relevant organisations that should be included
- Analysis of relevant innovation support mechanisms elsewhere

Those organisations that contributed to the analysis are listed in Appendix 2A. This includes a list of participants in the workshop held in June 2019, where the results of our analysis were presented and discussed.

1.4 Report Structure

This report presents the results of the analysis in four sections:

- An introduction to innovation systems and the analytical framework used
- Mapping of the innovation system for CCU in Scotland

  This section is based on desk research and company and stakeholder engagement
- Analysis of best practice in CCU sector innovation elsewhere
- Identification of key priorities for CCU innovation system development in Scotland

2 Innovation Systems and Relevant Analytical Frameworks

2.1 Innovation Systems

An innovation system is the network of stakeholders, infrastructure and funding programmes that support innovation[1]. We have developed an innovation system model, as follows, based on this definition. It has five main groups of actors:

- Companies in the Value / Supply Chain - the value chain and the profile of companies in the region. This is the focal point of the analysis.
  - Are there large dominant companies?
  - Is it mostly SMEs?
  - How competitive are they?
  - What is the flowrate of Techno Starters?

  This part of the analysis focuses on Scottish companies.
- Customers - those that use the end product with the most valuable customers being those that proactively specify / develop solutions etc.
  These customers may be local or global companies.
- The Knowledge Base - those that increase the knowledge within the sector by supplying people with the right skills, training people to have the right skills and the provision of technology through research.
  These knowledge-based organisations may be located in Scotland, elsewhere in the UK or overseas.
- The Public Sector – focusing on the initiatives and support mechanisms that the Public Sector has put in place and their relevance.
  These may be Scottish, rest of UK (e.g. InnovateUK), European (e.g. European Commission) or global support mechanisms.
- Intermediaries - those that aim to improve the effectiveness of access to technology customers, people, test facilities etc.
  Again, these may be Scottish, rest of UK, European or global organisations.

This can be shown schematically, as follows:

[1] For example, see
a) Technology and Economic Performance: Lessons from Japan, C Freeman, (1987), Pinter, London, 1987,
b) National Innovation Systems: Towards a Theory of Innovation and Interactive Learning, B-Å Lundvall (ed.), Pinter, London, 1992
c) National Innovation Systems, Organisation for Economic Co-Operation and Development, 1997

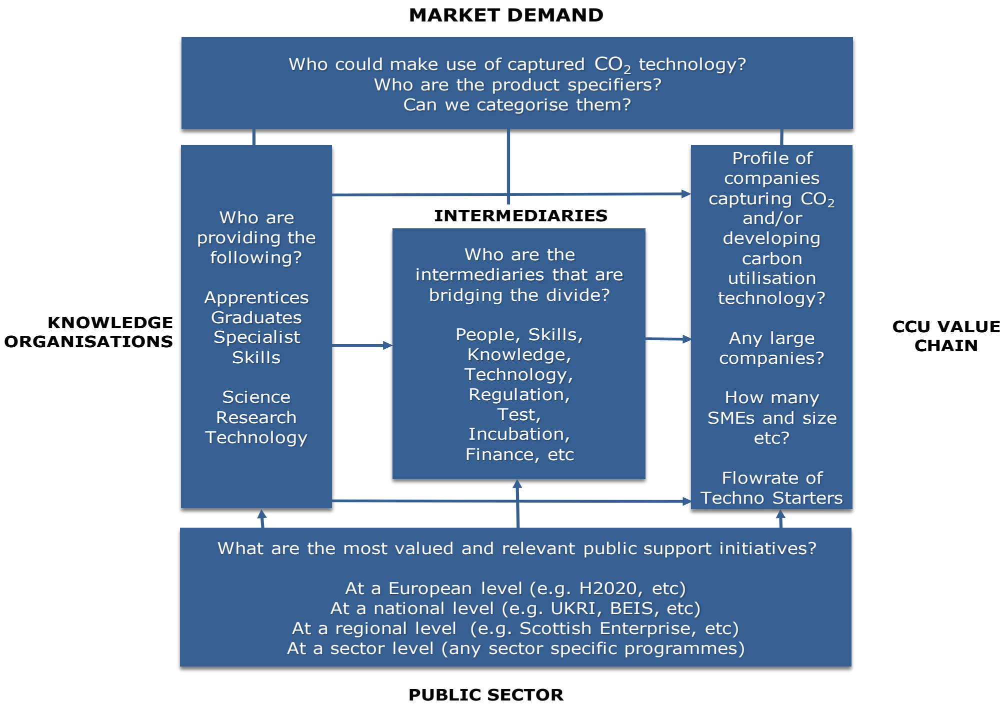


Figure 1: Innovation System Model

This innovation system model has been used as a basis of our analysis.

2.2 Analytical Frameworks

We developed the following analytical framework in previous sector innovation systems studies and have adapted it for the CCU value chain to provide a robust analytical framework so that the different support mechanisms, initiatives and stakeholders could be assessed in a systematic manner.

	TRL										Gas Handling/Mgt				Valorisation				Products				
Innovation Element	1	2	3	4	5	6	7	8	9	Source	Capture	Purification	Compression	Transport	Direct Use	Chemical Synthesis	IB Processes	Mineral Carbonation	Biofuels	Chemicals	Materials	Animal Feed	Enabling Technologies
Grants / Public Sector Funding																							
Industry Funding																							
Research / Innovation Infrastructure																							
Intermediaries																							

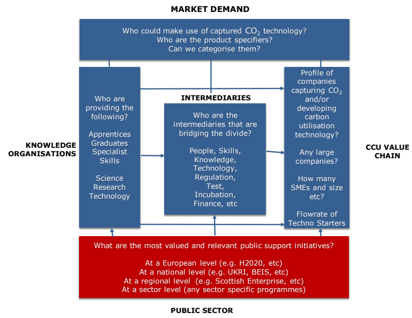
Figure 2: Analytical Framework

Using this framework innovation support activities were categorised, based on the technology readiness (TRL) levels and value chain actors that they support. In this way, areas where there are strong innovation support activities and those where there are gaps in support can be identified.

3 The Innovation Systems for CCU in Scotland

3.1 Public Sector

Public sector support for CCU innovation in Scotland is presented in Figure 3, below. This highlights that there are a wide range of Scottish, UK and European programmes to support CCU innovation and knowledge transfer activities.



	TRL										Gas Handling/Mgt				Valorisation				Products				
Innovation Element	1	2	3	4	5	6	7	8	9	Source	Capture	Purification	Compression	Transport	Direct Use	Chemical Synthesis	IB Processes	Mineral Carbonation	Biofuels	Chemicals	Materials	Animal Feed	Enabling Technologies
Grants / Public Sector Funding																							
European																							
Interreg Northern Connections Programme						■	■	■		●	●	●			●	●	●	●	●	●	●	●	●
H2020 Collaborative R&D				■	■	■	■			●	●	●	●	●	●	●	●	●	●	●	●	●	●
H2020 Dedicated SME Instrument						■	■	■			●		●	●	●	●		●	●	●	●	●	●
H2020 Fast Track to Innovation Pilot						■	■	■			●		●	●	●	●		●	●	●	●	●	●
ACT (Accelerating CCS Technologies) ERANET Cofund						■	■	■															
United Kingdom																							
Innovate UK Collaborative R&D			■	■	■	■					●	●	●	●	●	●	●	●	●	●	●	●	●
Innovate UK Feasibility Studies			■	■	■						●	●	●	●	●	●	●	●	●	●	●	●	●
UKRI ISCF - Wave 3 - Industrial Decarbonisation			■	■	■	■	■	■		●	●	●	●	●	●								
Innovate UK Smart			■	■	■	■	■				●	●	●	●	●	●	●	●	●	●	●	●	●
Innovate UK Innovation Vouchers						■	■	■			●	●	●	●	●	●	●	●	●	●	●	●	●
Innovate UK Small Business Research Initiative			■	■	■	■	■				●	●	●	●	●	●	●	●	●	●	●	●	●
Innovate UK - Innovation Loans					■	■	■				●	●	●	●	●	●	●	●	●	●	●	●	●
BEIS CCU Demonstrator Innovation Programme						■	■	■		●	●	●											
BEIS CCU Innovation				■	■	■	■	■		●	●	●	●	●	●								
Knowledge Transfer Partnerships			■	■	■	■	■	■	■		●	●	●	●	●	●	●	●	●	●	●	●	●
BBSRC Funding	■	■	■	■										●		●	●		●	●	●	●	●
EPSRC Funding	■	■	■	■							●	●	●	●	●	●	●	●	●	●	●	●	●
Scotland																							
Scottish Enterprise R&D Grants			■	■	■	■	■	■			●	●	●	●	●	●	●	●	●	●	●	●	●
Scottish Enterprise Seek and Solve					■	■	■	■			●	●	●	●	●	●	●	●	●	●	●	●	●
Scottish Enterprise SMART:Scotland			■	■	■	■					●	●	●	●	●	●	●	●	●	●	●	●	●
Scottish Enterprise Intensive Start-up Support								■	■		●	●	●	●	●	●	●	●	●	●	●	●	●
Scottish Enterprise High Growth Spin Out Support						■	■	■	■		●	●	●	●	●	●	●	●	●	●	●	●	●
Scottish Enterprise Aid for Envrionmental Protection								■	■	●													
SFC Standard Innovation Vouchers (Scotland)						■	■	■			●	●	●	●	●	●	●	●	●	●	●	●	●
SFC Advanced Innovation Vouchers (Scotland)						■	■	■			●	●	●	●	●	●	●	●	●	●	●	●	●
Interface Student Placement Innovation Vouchers					■	■	■	■			●	●	●	●	●	●	●	●	●	●	●	●	●
Interface Horizon 2020 SME Engagement Scheme				■	■	■	■				●	●	●	●	●	●	●	●	●	●	●	●	●
Zero Waste Scotland Circular Economy Investment Fund						■	■	■	■		●	●	●	●	●	●	●	●	●	●	●	●	●
IBioIC IB Accelerator Programme					■	■	■					●					●		●	●	●	●	●

Figure 3: Public Sector Support Mechanisms for CCU in Scotland

A number of these programmes are generic in nature, while others are focused on CCU. Further, it should be noted that some programmes have specific deadlines and will not always be available. Key points on selected specific funding streams are:

- In the EU H2020 programme there is a current call: Low carbon industrial production using CCUS (H2020-LC-SC3-2018-2019-2020) with a deadline of 27/08/2019 (see https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topicdetails/lc-sc3-nze-5-2019-2020;freeTextSearchKeyword=CCUS;typeCodes=0,1;statusCodes=31094501,31094502;programCode=null;programDivisionCode=null;focusAreaCode=null;crossCuttingPriorityCode=null;callCode=Default;sortQuery=openingDate;orderBy=asc;onlyTenders=false;topicListKey=topicSearchTablePageState)

- The next ACT (Accelerating CCS Technologies) ERANET Cofund call will be in 2020 (see http://www.act-ccs.eu/). It is understood that it will have a CCS rather than CCU focus.
- There are currently no relevant Innovate UK calls
- A £170 million call was announced in December 2018 for the UKRI Industry Strategy Challenge Fund (ISCF) - Wave 3 - Industrial Decarbonisation
- The BEIS CCU innovation and Demonstrator Innovation Programmes had calls valued at £24 million and £18 million respectively that closed in late 2018
- EPSRC is supporting the UKCCS Research centre (see https://ukccsrc.ac.uk/research/funding-opportunities/academic-members/ukccsrc-2018-funding-call)

There were no issues raised by those consulted during this study regarding a lack of innovation funding. A number of consultees are active recipients of grant funding and very familiar with the funding landscape, so were very able to discuss potential funding sources. The main challenge for such companies seeking to develop CCU technologies was identifying partners, whether companies emitting CO_2 or potential users of resultant products, that were willing to partner in projects. Some of the technology companies consulted could identify potential projects but could not persuade others to participate. This highlights the key challenge that was identified in the development of CCU activities – there are, currently, no drivers for companies to invest in mitigation options for CO_2 emissions. Specifically, there are

- No regulatory / legislative pressures on emitting companies
- Limited evidence of attractive market opportunities
- A lack of examples of those that have successfully delivered viable CCU activities. In fact, evidence suggests that most companies involved in CCU are, at best, breaking even from CCU activities

Further, investing in CCU is not core business for those emitting CO_2 and there is no part of the value chain that is taking ownership of the challenge of CCU.

The challenge, therefore, is to identify mechanisms that will catalyse CCU activities rather than optimising funding options to increase existing activity.

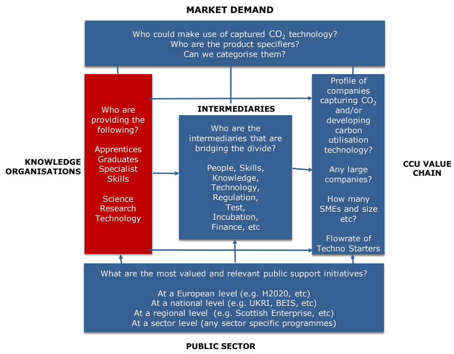
Climate change is a high profile, significant issue at the moment and there is recognition within industry that there is a need to change behaviour. Forward looking companies, especially those with a strong sustainability agenda, are keen to assess and pursue options for change. This is likely to catalyse action within some companies.

In addition, feedback from some parts of industry indicated that the funding landscape is complex and difficult to understand, which, in some cases, inhibits companies from seeking funding. This has been highlighted in similar previous studies (e.g. biorefining innovation system analysis) and will be addressed in the action plan prepared as an output from this study.

3.2 Knowledge Organisations

3.2.1 Scottish Organisations

There are a number of knowledge organisations (research and development infrastructure) in Scotland, mainly within universities. World class research is being carried out in these universities, across the value chain. The framework below summarises the academic capability that has been identified as being directly relevant to CCU. There is also a significant amount of more general chemical and industrial biotechnology research that is not listed below that could be relevant to CCU. The more general chemical and industrial biotechnology research expertise was collated in an earlier report for Scottish Enterprise[2].



Innovation Element		TRL 1	2	3	4	5	6	7	8	9	Source	Gas Handling/Mgt: Capture	Purification	Compression	Transport	Valorisation: Direct Use	Chemical Synthesis	IB Processes	Mineral Carbonation	Products: Biofuels	Chemicals	Materials	Animal Feed	Enabling Technologies
Research / Innovation Infrastructure																								
Heriot Watt University	Research Centre for Carbon Solutions										●			●	●				●			●		●
Edinburgh University	Carbon Capture Group										●	●	●											
	The Joseph Black Lab for CO2 Chemistry										●	●					●			●	●			
Aberdeen University	Aberdeen Institute of Energy										●	●												
	Chemical and Materials Engineering										●	●					●					●		
Strathclyde University	Centre for Energy Policy										●	●												

Figure 4: Leading CCU Research Groups in Academia

More details on these leading groups can be summarised as follows:

2 Actions required to develop a Roadmap towards a Carbon Dioxide Utilisation Strategy for Scotland, University of Sheffield, June 2017

University	Department/Group	Key Contact	Brief Description
University of Aberdeen	Chemical and Materials Engineering	Dr Mohammed Imbabi Dr Waheed Afzal Dr Claudia Fernandez Martin Dr Xiaodong Wang	Expertise in low energy buildings, energy efficiency, renewable energy, CCU and conversion of CO_2 to useful chemicals.
	Aberdeen Institute of Energy	Professor James Anderson Dr Euan Bain Professor Fred Glasser Dr Sola Kasim	CCU, CCS, transportation and economic analysis
Heriot Watt University	Research Centre for Carbon Solutions (RCCS) Centre for Innovation in Carbon Capture and Storage (CICCS)	Professor Mercedes Maroto-Valer	A range of capabilities and facilities covering carbon capture, CO_2 transport, CO_2 sequestration for mineral carbonation, utilisation for solar fuel production and assessment of environmental aspects of CO_2 release.
University of Edinburgh	School of Engineering: Carbon Capture Group	Professor Stefano Brandani Dr Enzo Mangano Dr Daniel Friedrich	Carbon capture and separation processes applied to a range of sources of CO_2 using adsorption and membrane processes.
	Joseph Black Laboratory for Carbon Dioxide Chemistry	Professor Lesley J Yellowlees Professor Colin Pulham Professor Eleanor Campbell	Chemical conversion of CO_2 and development of novel storage materials.
Strathclyde University	Centre for Energy Policy	Professor Karen Turner	Economic policy analysis and impact studies on the potential for CCU and CCS in Scotland.

Figure 5: Scottish University Groups with a Strong Focus on CCU

Input from key stakeholders indicates that Edinburgh and Heriot Watt Universities are also UK leaders in CCU research. Some of these groups are catalysing new ventures that are developing commercial CCU activities. Carbon Capture Machine, a spin out from the University of Aberdeen, is a leading example.

In addition, some private sector research capability is noted:

- TUV SUD, the UK National Measurement Institute for flow technologies. TUV SUD is actively investigating flow monitoring for CCU and CCS (see https://www.tuv-sud.co.uk/uk-en/about-tuev-sued/tuev-sued-in-the-uk/nel)
- Drochaid Research Services, a private sector contract research organisation with specific expertise in chemical technologies, particularly catalysis (see https://www.drochaidresearch.com/)

This academic and private expertise is a key asset for the development of CCU in Scotland.

3.2.2 Organisations in the Rest of the UK

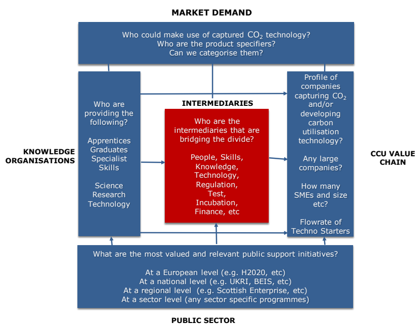
There are highly relevant knowledge organisations elsewhere in the UK that Scottish organisations have, or could, utilise in their product and process innovation activities. Some of the main (leading) facilities, which are active members of the EPSRC funded UK CCS Centre, are listed and EPSRC funded activities described in the following table[3]:

Name	Description
Sheffield University	Hosts the UK Centre for Carbon Dioxide Utilisation or CDUUK, which focuses on the utilisation of carbon dioxide as a feedstock for chemical synthesis, combining capability in seven academic departments Areas of expertise include catalysis, continuous flow processing, solid oxide electrolysis cells, organo-metallic chemistry and policy. Also hosts the pilot scale advanced capture technology (PACT) facility.
Cambridge University	A range of activities that includes carbon capture (CO_2 production from solid fuels, steam reforming of methane and process modelling), carbon storage (modelling of multi-phase flow and chemical reactions, geological storage and policy studies) and CO_2 use (power generation, manufacturing and carbonate mineralisation)
Nottingham University	Research at Nottingham spans carbon capture (including the use of high capacity absorbents), photochemical reduction of CO_2, analysis of the physical properties of CO_2 and coal and biomass utilisation.
Cardiff University	Research is focusing on valorisation of CO_2, including use of renewable energy for the conversion of CO_2 into fuels and chemicals and the development of novel catalysts for converting CO_2 into renewable fuels.
Cranfield University	Here research includes CO_2 transport and handling and mitigation of CO_2 in power generation.
Newcastle University	Leading a project to assess industrial CCS activities to collate data from a number of plants that will be used to develop software design tools for the development of new facilities.
Liverpool University	Development of membrane technologies for post combustion CO_2 capture
Swansea University	Development of metal organic frameworks for CO_2 capture

Figure 6: Other Relevant UK Innovation Infrastructure

3.3 Intermediates

These are organisations that support the CCU value chain in Scotland and facilitate engagement with the innovation infrastructure. These organisations are listed in the figure below.



3 https://epsrc.ukri.org/research/ourportfolio/researchareas/ccs/

	TRL										Gas Handling/Mgt				Valorisation				Products				
Innovation Element	1	2	3	4	5	6	7	8	9	Source	Capture	Purification	Compression	Transport	Direct Use	Chemical Synthesis	IB Processes	Mineral Carbonation	Biofuels	Chemicals	Materials	Animal Feed	Enabling Technologies
Intermediaries																							
Scottish Carbon Capture and Storage		■	■	■	■	■				●	●	●	●	●	●								
Energy Technology Partnership		■	■	■	■	■				●	●	●	●	●	●								
IBioIC		■	■	■	■	■											●		●	●		●	●
CO2 Chem - The CO2 Utilisation Network		■	■	■	■	■					●	●	●	●	●	●	●	●	●	●	●	●	●
The Carbon Capture and Storage Association				■	■	■	■	■	■		●	●	●	●	●								
Zero Waste Scotland				■	■	■	■	■	■	●	●	●	●	●	●	●	●	●	●	●	●	●	●
KTN - Biotechnology						■	■	■	■								●		●	●		●	●
KTN - Chemistry						■	■	■	■			●	●	●		●		●	●	●	●	●	●
KTN - Sustainability & Circular Economy						■	■	■	■	●													●

Figure 7: Intermediate CCU Organisations

3.4 Supply Chain

The innovation framework model uses supply chain terminology, but for the purposes of this study this can be considered as the value chain. The CCU value chain has already been described in detail in an earlier report. Value (supply) chain actors in the innovation system are essentially the private sector organisations that finance innovation, either internally, or on behalf of third parties. The scale of company funding of innovation is reflected in Business Enterprise Research and Development (BERD) data. In addition, investment banks (e.g. Scottish Investment Bank), investment syndicates and venture capital firms are potential sources of funding for innovation driven companies.

However, as part of this study we have not identified any significant private sector investment in CCU innovation in Scotland.

It must be stressed that the current level of activity within the value chain is very limited, as already reported in the earlier value chain report, underlining the immaturity of the sector.

3.5 Market Demand

Market demand defines the customers of the CCU value chain – these will be purchasers of chemicals, fuels or other products manufactured from captured CO_2. As indicated in the earlier value chain report this part of the innovation system could comprise a wide range of companies.

The market demand aspect of the innovation system model is not strongly linked to other aspects of the value chain, particularly in Scotland at the moment, due the immaturity of the value chain. It is important, however, to ensure that there is a mechanism to engage with this key value chain player.

4 Lessons from Elsewhere

This is considered in three parts – the development of CCU clusters, CCU research and development projects and fiscal support for CCUS investment. These are each discussed below.

4.1 CCU Clusters

The development of CCU clusters elsewhere in Europe and the associated innovation systems have been assessed.

The situation in Europe is driven by the European Union Strategic Energy Technology (SET) plan[4]. A core part of this plan is to accelerate the development and deployment of low carbon technologies. This ambition is defined by ***Action No. 9 – CCS and CCU implementation***, which includes two CCU-specific targets:

- 3 pilots on promising new technology
- 1 demonstration plant

Development of activities, however, does not seem to be progressing quickly.

The Fos-Berre/Marseille CCU Cluster, located in a large chemical cluster near Marseille, is a SET Plan flagship project. A feasibility study was completed in 2013 and there are plans to develop infrastructure to aggregate CO_2 from different sources, but there has been little progress.

Development of activity at the Port of Rotterdam was a second key initiative, however, a key project floundered due to the withdrawal of industrial partners. There are still ambitions to develop CCU[5] and some specific projects focusing on CCU for industrial greenhouses[6], but again progress has not been as expected.

A third key cluster was identified for Teesside. A full-scale CCUS 'Clean Gas Project' was announced last year as a strategic partnership between OGCI Climate Investments, industry and public sector. Work was expected to begin in 2020, however the status of this is unclear, with no further announcements. If this does go ahead as planned, then the plant is expected to be operational by 2025.

It should be noted that these three activities focus on infrastructure development, rather than innovation and industry cluster development.

Overall, these examples indicate the immaturity of CCU activities elsewhere in Europe and, as a result, do not offer high value transferable lessons for Scotland.

4.2 CCU Process Technologies

There has been significant investment in technology development for a number of years. For example:

4 https://ec.europa.eu/energy/en/topics/technology-and-innovation/strategic-energy-technology-plan
5 http://smart-port.nl/en/project/ccu-landscaping/
6 https://www.rotterdamccus.nl/en/ and https://www.the-linde-group.com/en/clean_technology/clean_technology_portfolio/co2_applications/greenhouse_supply/index.html

(footnote continued)

- A wide range of CO_2 process technologies developed to high TRL levels[7]. These are included in Appendix 2B for information.

  One specific example, linked to the Northern Connections Interreg project is Liquid Wind[8], a Swedish initiative to combine captured CO_2 with H_2 from electrolysis of H_2O (using surplus wind energy) to produce methanol. The company has secured 2.4M SEK from crowdfunding (~£200,620) and plans to develop five more plants in Scandinavia.

- The European Energy Research Alliance[9] has 17 joint programmes supporting the SET plan, one of which focuses on CCS with sub-programmes on capture, transport and storage, the first two of which are also relevant to CCU.
- Germany is considered a leader in CCU technology development. It commenced activities in 2009 and public sector funding programmes have included[10]:
  - "Technologies for Sustainability and Climate Protection - Chemical Processes and Use of CO_2", where €100 million of support was provided between 2010 and 2016
  - CO_2Plus, with €17.5 million support over 3.5 years from 2016 for collaborative programmes focusing on the manufacture of chemicals and the photocatalytic activation of CO_2
- There are a number of current international research projects developing CCUS technologies and numerous national/regional development plans

4.3 Fiscal Incentives

The most obvious examples of this are in the USA. It has offered financial incentives[11] for CCUS since 2008. It has recently enhanced these to encourage private sector investment in carbon capture. Tax credits of \$35 (for CCU) or \$50 (for CCS) per metric tonne of CO_2 captured will be available for 12 years of operation for CO_2 producing industries that commence construction of CCUS facilities by 2024. These recent enhancements have increased the tax credit per tonne and removed the earlier cap (75 million metric tonnes) on the amount of CO_2 produced that would qualify for tax credits.

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7 Industrial biotechnology research within circular carbon, Optimat report for Scottish Enterprise, May 2018
8 https://www.innovatum.se/wp-content/uploads/2017/05/final-final-liquid-wind-report-may-2017.pdf
9 https://www.eera-set.eu/
10 http://www.chemieundco2.de/en/co2plus/
11 Implementation of Recent Amendments to the 45Q Carbon Sequestration Tax Credit, The National Law Review, May 3rd 2019, https://www.natlawreview.com/article/implementation-recent-amendments-to-45q-carbon-sequestration-tax-credit

5 Developing the Innovation Systems for CCU in Scotland

5.1 Key Issues to Address

The existing innovation system, particularly to support low – mid TRL activities is considered to be relatively strong. The range of funding sources available, academic capability and the community of intermediary organisations support this assertion, as already highlighted.

Analysis of the situation for CCU in Scotland based on both the value chain and innovation system analyses carried out (including feedback from the numerous stakeholders consulted) highlights a number of issues that need to be addressed. These can be discussed as follows:

- Lack of existing value chain activity

  As a result, there are a lack of good case examples for interested companies to guide their ideas and to use as evidence of success.

- There are no regulatory or legislative drivers, despite the Scottish Government's policy target of net-zero greenhouse gas emissions by 2045[12]

  Existing activities and interest are driven by a strong commitment to sustainability or corporate and social responsibility within a cross section of industry.

- Apparent investment risk
- A lack of evidence of a viable business / financial case for CCU. Current interest in more forward looking companies is driven by the expectation of future changes that will require CO_2 mitigation.
- CCU is not core business for any emitters

  Evidence from this study indicates that this situation will continue, with a strong preference expressed for third parties to capture and process emissions on behalf of emitters. Similarly, technology developers typically wish others to implement their technologies. However, these third parties do not exist, highlighting a significant value chain gap.

  This leads to a lack of ownership of CCU development.

These five issues collectively lead to inertia. Addressing these issues is critical to the development of CCU activities.

- Limited funding mechanisms to support demonstration of utilisation technologies[13].

  A recent UK government announcement[14] to create the world's first 'net-zero' carbon cluster by 2040, with up to £170 million of funding, may offer support here but, to date, neither the technology / sectoral focus nor scale of funding have been defined.

- The complexity of the public support infrastructure

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12 Climate Change Action, Scottish Government, 02/05/2019, see https://www.gov.scot/news/climate-change-action-1/

13 For example, results of recent UK government funding competitions allocated the majority of funding to carbon capture or storage (see https://www.gov.uk/government/news/uks-largest-carbon-capture-project-to-prevent-equivalent-of-22000-cars-emissions-from-polluting-the-atmosphere-from-2021)

14 https://www.gov.uk/government/news/world-first-carbon-net-zero-hub-of-heavy-industry-to-help-uk-seize-global-economic-opportunities-of-clean-growth

These are business / commercial rather than innovation issues, as already highlighted, and they underline a reluctance / lack of commitment of those companies emitting CO_2 to act to mitigate emissions. This is an understandable position as there is no driver for action.

The challenge is to assess how innovation mechanisms can help address these issues.

Feedback from consultations in this study indicates that emitters do recognise the need to take a long-term view and consider options to make their processes more sustainable. They do not, however, wish to get involved in R&D but would be more amenable to implementing proven technology. They also have a strong motivation to manage and mitigate risk. So, there is a strong preference expressed for:

- Adaptation, demonstration and adoption of existing (high TRL) technology
  This should not imply that it is simply a case of fitting and operating existing technology. There is a requirement to:
  - Test and evaluate the potential of high TRL technologies in specific applications (i.e. composition, volumes and variability of emissions)
  - Assess the long-term viability of technologies (i.e. continuous process capability)
  - Assess the impact of capture technology on the host process
  - Evaluate the attractiveness of output products and the viability of the investment

  There is, therefore, a strong innovation focus within the adoption of high TRL technologies.
- Investment and operation of a CCU process plant by a third party
  Emitting companies are reluctant to operate CCU equipment. They would prefer a third-party company to build, own and operate plant on their behalf. Similarly, many of those companies that have developed CCU technologies are also looking for others to implement solutions. There is, therefore, a major gap in the value chain.
- Mitigation of the (technical and financial) risks associated with technology adoption
  Key issues raised by companies include:
  - What happens if the selected technology does not work? Who is responsible for removing the equipment?
  - Are there financial instruments that can underwrite the costs of unsuccessful projects?

An analysis of the types of interventions that may address this situation is presented below:

		Potential Interventions							Other Interventions		
		Living Lab	Feasibility studies	Demo-scale facility	Competition	Falkirk Growth Deal	Knowledge network	Technoeconomic analysis	Carbon R&D tax credits	Market incentives	Regulations
Issue	Demonstration at scale		●	●	●	●		●	●		
	No economic case	●	●	●			●	●		●	●
	No regulatory requirements										●
	No funding mechanisms		●	●	●	●			●		
	Technology push, not pull	●	●	●			●	●	●	●	●
	CSR	●	●				●	●	●		

Figure 8: Key Issues and Potential Interventions

This segments potential interventions into two groups

- ***Potential interventions*** that are within the remit of Scottish Enterprise to implement
- ***Other interventions*** that require government intervention / action

These are discussed further in the following section.

5.2 Proposed Innovation Interventions

The potential interventions shown in Figure 8 can be described as follows:

- "Living Lab"
  Scottish Enterprise and Falkirk Council, the Scottish partners in the Northern Connections project, are keen to identify an early stage or existing collaborative CCU feasibility or development project in Scotland that would benefit from identifying alternative/new technologies, services or processes to help better inform implementation or introduce improvements in the project. North Sea region businesses, linked to partners in the Northern Connections project, will be invited to pitch solutions to the challenges identified in the project.
- Feasibility studies
  These desk-based studies are important to
    - Assess and understand potential technologies for a given situation
    - Identify and select the optimum technology
    - Define the scope of the investment and potential partners
    - Prepare an initial techno-economic analysis
    - Assess, understand (and make) the business case for investment

  This activity would precede demonstration activities.
- Demonstration scale facility
  This is considered the core intervention to catalyse CCU activity. This facility will enable:
    - Evaluation of CCU technologies in a realistic pseudo-industrial emission environment.
    - Interested companies to increase their confidence in specific technologies by obtaining evidence of performance in industrially relevant situations
    - Completion of more detailed techno-economic analysis

  This facility would need to be sufficiently flexible to accommodate a range of different technology platforms, as specified by interested companies. It would also need to have the required monitoring and control equipment so that the performance of different systems could be accurately monitored.
- Innovation competition
  The establishment of a competition to develop attractive technologies that would convert CO_2 into viable products. Such a competition would offer the opportunity for the research and innovation community to propose ideas for CO_2 valorisation, with funding made available to those that are most attractive.
  This approach has been used successfully elsewhere (e.g. NRG COSIA Carbon XPRIZE – see https://carbon.xprize.org/prizes/carbon).
- Falkirk Growth Deal
  This could be used to fund infrastructure such as the innovation centre or demonstration scale facility for CCU technologies, as well as create a supportive and collaborative environment for

technology companies, emitters and others in the value chain (in particular third parties that might operate the CCU plant).

- Sectoral Innovation Network
  To bring together organisations interested in CCU, provide leadership, establish a forum for knowledge sharing and provide an industry voice that can raise issues regarding CCU and lobby government.
  The Scottish Enterprise "network integrator" initiative, already implemented in several developing industry sectors would be a suitable mechanism to support a knowledge network.

These issues, interventions and action areas were discussed at the stakeholder workshop, hosted by Falkirk Council on 19th June 2019. The workshop attendees (as listed in Appendix 2A) supported the action areas described above, provided insight and advice based on their individual perspectives and encouraged further development.

This is being addressed in the next and final stage of the project where an action plan for implementation of these activities will be developed.

5.3 Other Interventions

The analysis carried out in this study clearly highlights that the development of CCU in Scotland cannot be driven by innovation interventions alone. It is important that there are wider, political and policy interventions to catalyse change. Critical actions identified are:

- Clarity on the direction of travel
  It is important that the Scottish government sets a clear agenda and strategy for the mitigation of carbon emissions. This will provide a framework within which Scottish companies can operate.
  It is important, however, that the Scottish Government does not act in isolation in a way that affects the competitiveness of Scottish companies. It would be logical for a Europe wide approach to be developed, rather than individual nations acting in isolation.
- Development of market pull / market incentives
  A key catalyst for the development of CCU would be the introduction of market incentives for products utilising captured carbon. For example:
  - Public procurement of products utilising captured carbon
  - Tax relief on products using captured carbon, applying to both domestic and export markets – can a similar model to that implemented in the USA be considered?

  Such interventions would need to be compatible with existing frameworks and would be preferable to tariffs and regulations, which, as indicated above, would be detrimental to Scottish industry competitiveness.
- Parallel investment in necessary infrastructure
  Effective CCU requires, in most cases, access to cost effective (low cost) hydrogen and energy. If parallel investment in these resources is not made, then the potential of CCU will be significantly affected.

These other interventions will also be addressed in the action plan. It is further expected that the proposed sectoral innovation network will have a key role in raising these issues in the relevant forums.

Appendices

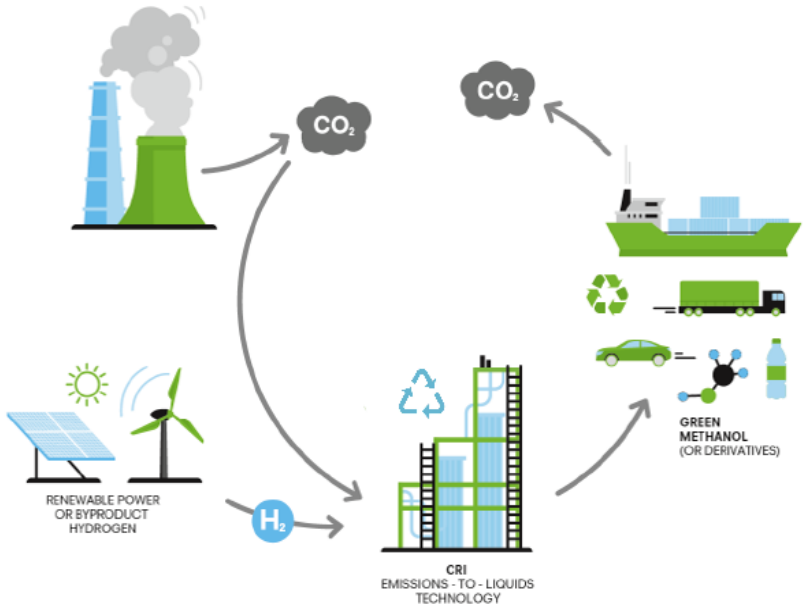
Appendix 2A: Stakeholders and Companies Participating in this Study

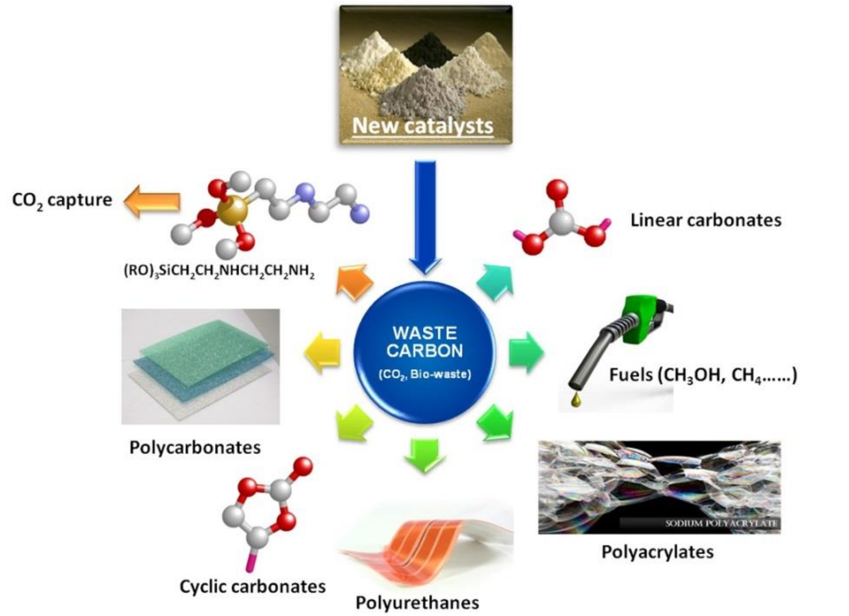
Company	Project Participation		
	Value Chain Consultation	Innovation System Consultation	Workshop
Argent Energy	●		
BEIS		●	
Birmingham University		●	
Brockwell Energy			1
Calachem		●	2
Carbon Capture Machine		●	
Chemical Sciences Scotland	●		1
Diageo		●	1
Doosan Babcock		●	1
Drochaid Research Service Ltd	●	●	1
DSM		●	1
Falkirk Council	●		1
Heriot Watt University	●	●	
IBioIC		●	
INEOS Olefins & Polymers UK Ltd		●	1
Ingenza Ltd	●	●	1
James Hutton Institute		●	
North British Distillery			2
Pale Blue Dot Energy	●	●	1
Petroineos Manufacturing (Scotland) Ltd		●	1
Scotch Whisky Research Institute	●		
Scottish Carbon Capture & Storage		●	
Scottish Enterprise	●●●●		6
Scottish Hydrogen and Fuel Cell Association	●	●	
TUV SUD National Engineering Laboratory		●	1
University of Strathclyde		●	1
Xanthella		●	
Zero Waste Scotland			1
	13	20	24

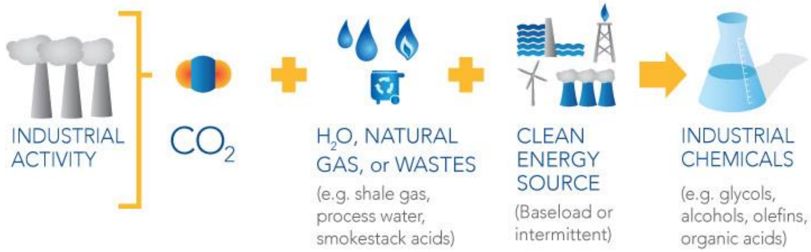
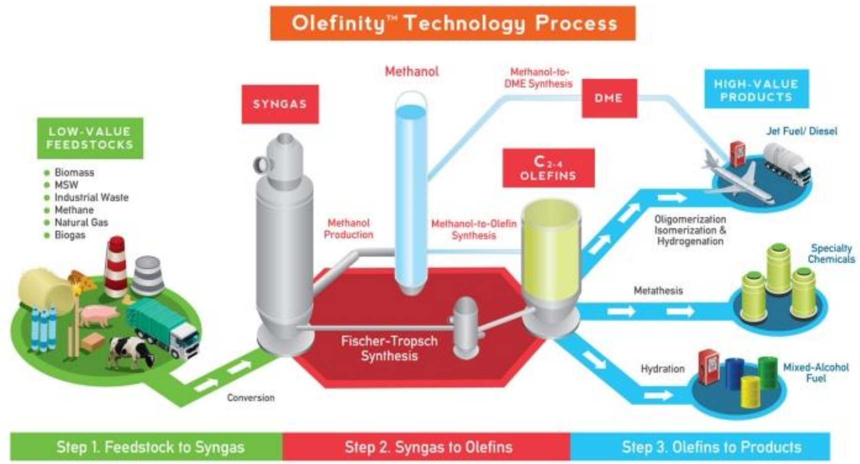
Appendix 2B: Examples of CCU Process Technologies Under Development

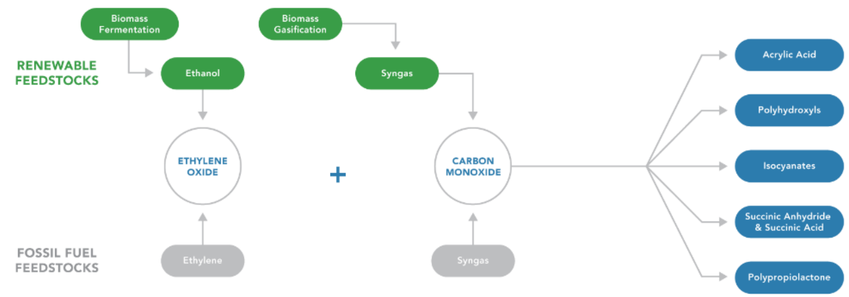
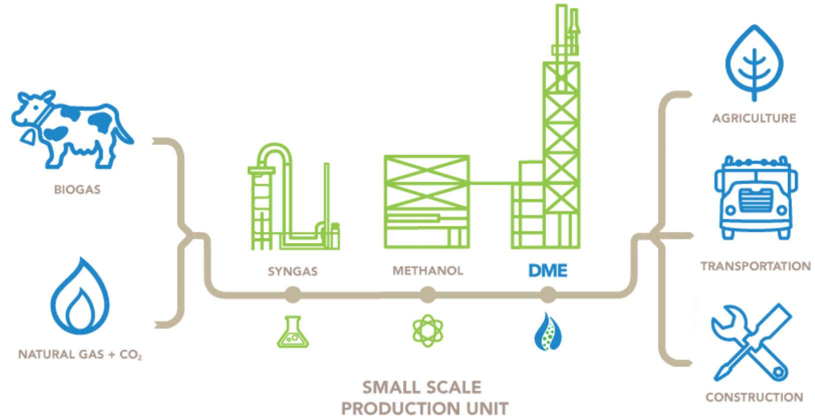
Chemical Processes

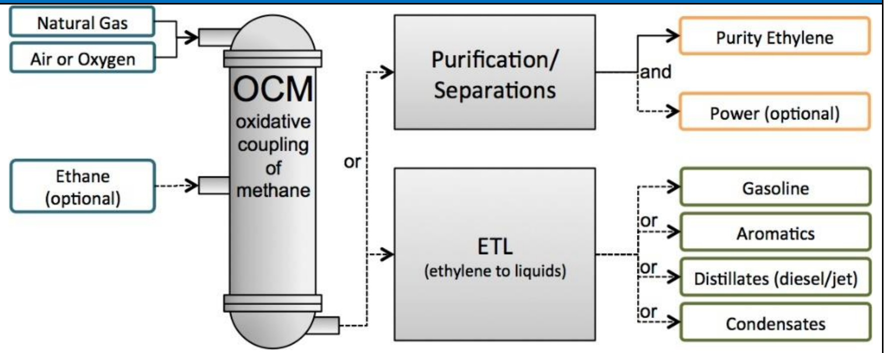
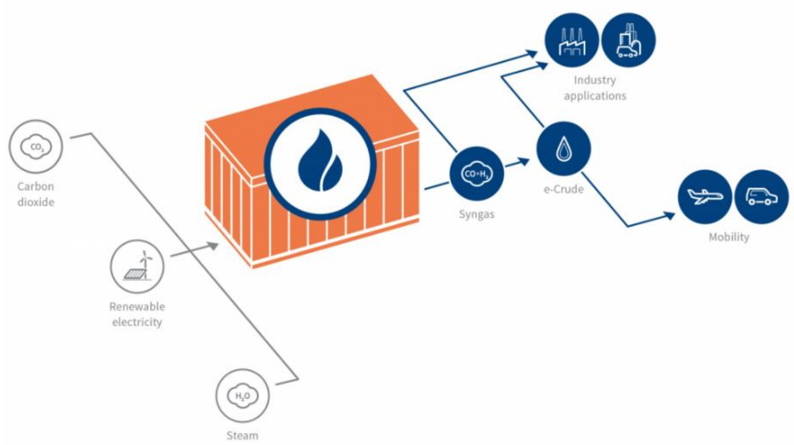
Company	Platform	Feedstock	Products	TRL	Overview
Carbon8	thermo/electro-chemical	CO_2	carbonate aggregates for construction	9	React calcium and magnesium salts from a variety of industrial sources (e.g. cement and steel manufacturers) with CO2 to produce inert aggregates that can be used in construction. Termed Accelerated Carbonation Technology (ACT). Have commercial scale manufacturing at 3 plants across England (first producing over 65,000 t aggregates p.a.).
Carbon Engineering	thermo/electro-chemical	CO_2, H_2	variety of fuels	7	Air to fuel technology – direct air capture of CO2 (DAC) combined with H2 from electrolyzed water (using renewable energy from PV) in a thermocatalytic process to convert into a variety of road and aviation fuels. Established a pilot plant in Squamish, Canada in 2015 and over 2018-19 intend to run a commercial validation project with the goal of building individual facilities with a capacity of 2,000 barrels per day. The company has raised about $16 million to date, two-thirds from private donors including Gates Foundation, and most of the rest from government grants.

Company	Platform	Feedstock	Products	TRL	Overview
Carbon Recycling International	thermo/electro-chemical	CO_2, H_20	methanol	9	 System comprises electrolytic cracking and catalytic synthesis, leading to a low pressure and low temperature electrochemical production process of 4,000 t methanol (tradename Vulcanol) p.a. @ George Olah plant (Iceland) plus pilot @ Steag Lünen coal-power plant in Germany. Can develop commercial scale plants for others
CCm Technologies	thermo/electro-chemical	CO_2	cellulosic waste materials bind CO2 and used in fertilisers, soil improvers and as filler for composites	7	Cellulosic materials (wood chip, compost, fibres, etc) are coated with amines/ammonia to bind CO2 efficiently. CO2 then converted into carbonate and material can then be pelletised and used as a fertiliser. Process produces only 15% of the carbon dioxide compared with conventional fertiliser production methods. In addition, have developed a fibre that can capture CO2 in the same way and be incorporated into plastic composites. Have a pilot plant co-located at Viridor in Ardley and various trials of the tech have taken place.

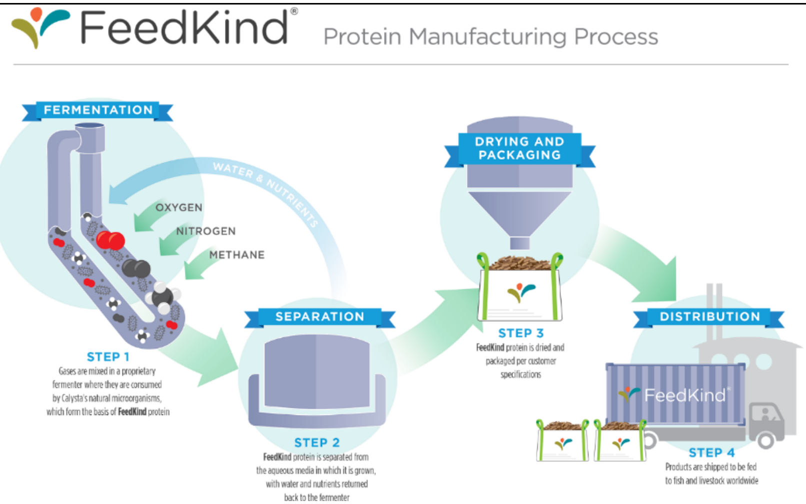
Company	Platform	Feedstock	Products	TRL	Overview
Covestro	thermo/electro-chemical	CO_2	polyols	9	Polyols are used in the manufacture of foams for mattresses and furniture. At present polyols contain about 20% captured CO2, but they are working to increase to 40%. Produce 5,000 tonnes p.a. plant at Dormagen (Cologne).
Econic	thermo/electro-chemical	CO_2	polyols	7	Proprietary catalytic system that reacts CO2 with epoxides to produce polyols. Polyols can then be used in the manufacture of polyurethanes. Can ‘tune’ the amount of CO2 incorporated to provide polyols with different properties. Company has built a demo plant at Runcorn (2018)
IC2Rsrl	thermo/electro-chemical	CO_2 (& biomass)	variety of commodity chemicals and fuels	<7	 Developing different catalysts (including enzymes) for the conversion of CO2 to different chemicals, which they license to others. Not manufacturing themselves.

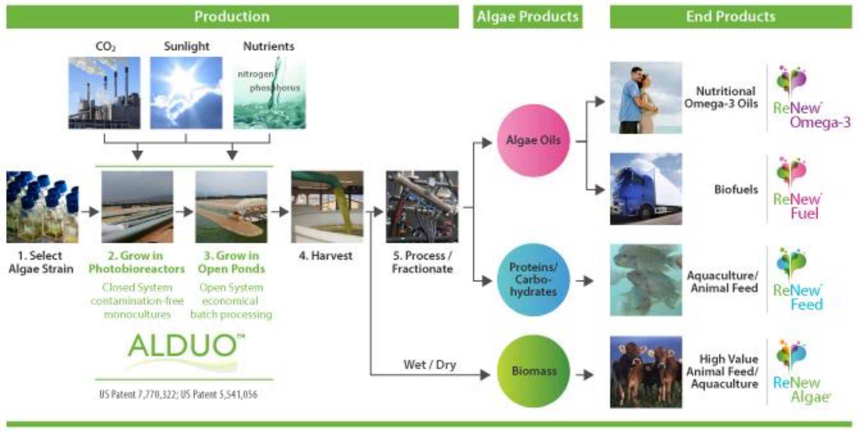
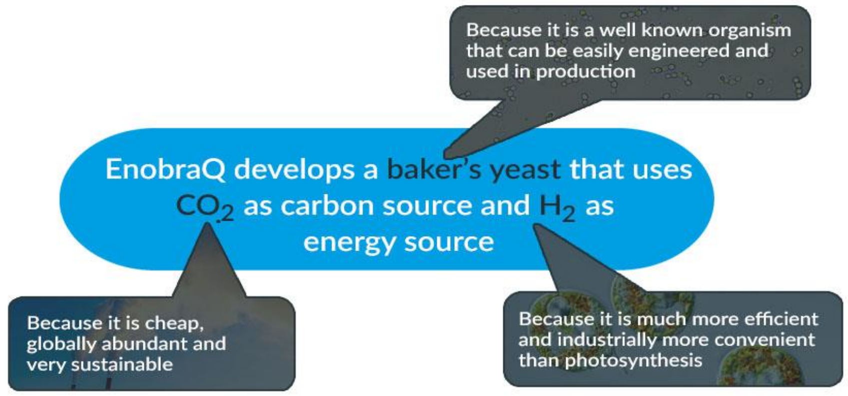
Company	Platform	Feedstock	Products	TRL	Overview
Liquid Light	thermo/electro-chemical	CO_2	ethylene glycol and others	<7	 Develops and licenses technologies for the low energy catalytic conversion of CO2 from industrial sources to a variety of chemicals.
Maverick Synfuels	thermo/electro-chemical	CH_4 (and others)	methanol and olefins	9	 Skid-mounted, small scale modular plants (Maverick Oasis™), with a 5,000 sq. ft footprint that can be shipped to customers. These can convert CH4 containing biogas, coal gas, landfill gases to methanol via Fischer-Tropsch synthesis (between 3,000 and 10,000 gallons per day).
Nordic Blue Crude	thermo/electro-chemical	CO_2, H_20	drop-in fuel substitutes and waxes from syngas	<9	Building a commercial plant in Norway, based on technology from Climeworks (DAC using amine-functionalized adsorbents), Sunfire (modular Solid Oxide Fuel Cell (SOFC) that can produce energy or chemicals) and an electrolysis plant powered by renewable energy to produce H2 from water.

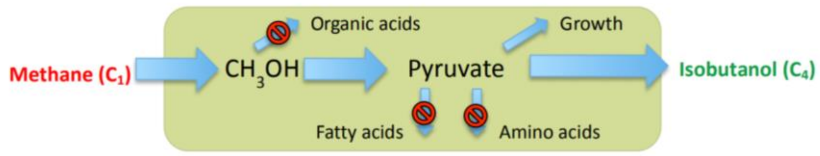
Company	Platform	Feedstock	Products	TRL	Overview
Novomer	thermo/electro-chemical	CO, ethylene oxide	acrylic acid, polypropiolactone, polyols	7	 CO biomass gasification or industrial sources and combined with ethylene oxide derived from ethanol via biomass fermentation. Demonstration unit operational, and automated pilot plant process validated. Commercial plants in development across the globe.
Oberon Fuels	thermo/electro-chemical	CH_4, CO_2	dimethyl ether (diesel substitute), methanol	9	 Skid-mounted, commercial scale plants capable of producing 10,000 gallons DME per day from a feedstock of 44 million litres of 72% CH4 / 28% CO2.
Orbix	thermo/electro-chemical	CO_2 (& steel slag)	carbonate aggregates for construction	7	Combine waste mineral materials from steel production and CO2 to produce carbonate aggregates for construction. These are being developed at Orbix' Carbstone Innovation centre which operates a pilot plant.

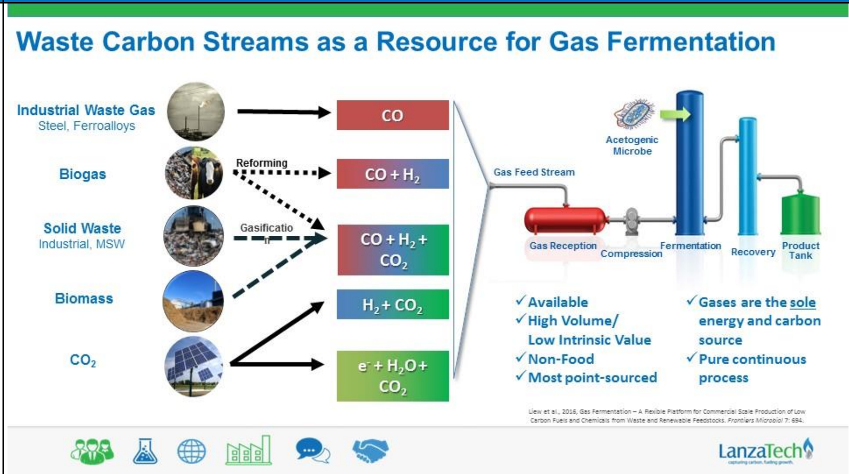
Company	Platform	Feedstock	Products	TRL	Overview
Siluria	thermo/electro-chemical	CH_4 (& C_2H_6)	Ethylene, fuel substitutes and chemicals	7	 Developed modular units that can be retrofitted to existing gas processing facilities to convert CH4 to ethylene and to other chemicals. Demo plant can produce 1 t of ethylene per day. Potential to be used at landfill sites, sewage works, and AD plants as has high tolerance to N2 and CO2.
Sunfire	thermo/electro-chemical	CH_4, CO_2, H_2O	syngas (H2, CO) via SOFC	<9	 Developed a modular solid oxide cell (Powercore) that is the basis of a fuel cell (to produce electrical energy or chemicals) and electrolyser to produce H2 from water. Partner with a number of others to produce chemicals and fuels, e.g. Nordic Blue.

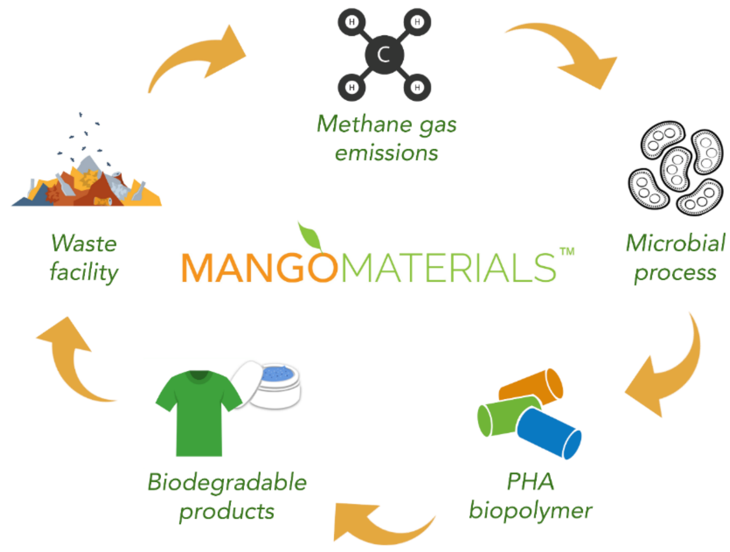
Industrial Biotechnology Processes

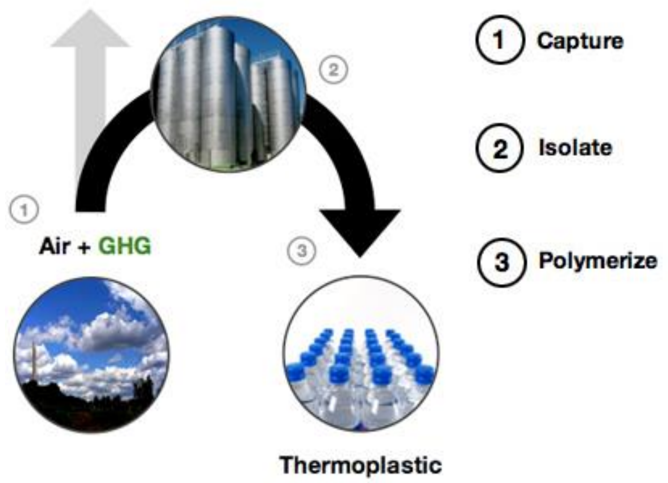
Company	Platform	Feedstock	Products	TRL	Overview
Algenol (US)	Cyanobacteria, microalgae	CO_2	ethanol, crude oils, protein and other biomass for health, nutrition and cosmetic purposes	9	Produce own products through cultivation (enclosed photobioreactors), harvesting and fractionation. Commercial plants in US. Access to a large library of different strains. Can undertake R&D and scale-up for clients.
Calysta (US)	Methanotrophic bacteria	CH_4	protein (fishfeed)	7	 Pilot scale plant in Teesside supplying samples to customers. Expect commercial plant to begin operation in 2019 in US (20,000 t)

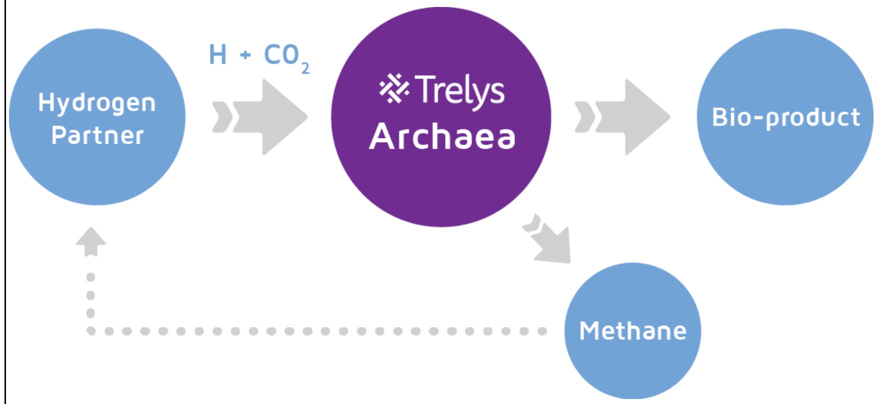
Company	Platform	Feedstock	Products	TRL	Overview
Cellana (US)	Microalgae	CO_2	omega 3 oils, animal feed and biofuels	7	 Patented production system, ALDUO™, which is unique in that its couples closed-culture photobioreactors with open ponds in a two-stage process. Pilot scale plant operational since 2009 producing >11 t to date. Aim is to open commercial plants across the globe.
EnobraQ (FR)	Yeast	CO_2, H_2	variety of commodity chemicals	<7	 Developing modified baker's yeast to produce a variety of chemicals – still very much development stage. At present looking to increase production efficiencies by 20%. Secured significant investment (€4.9M since 2015) and close partner of Toulouse White Biotechnology Centre of Excellence.

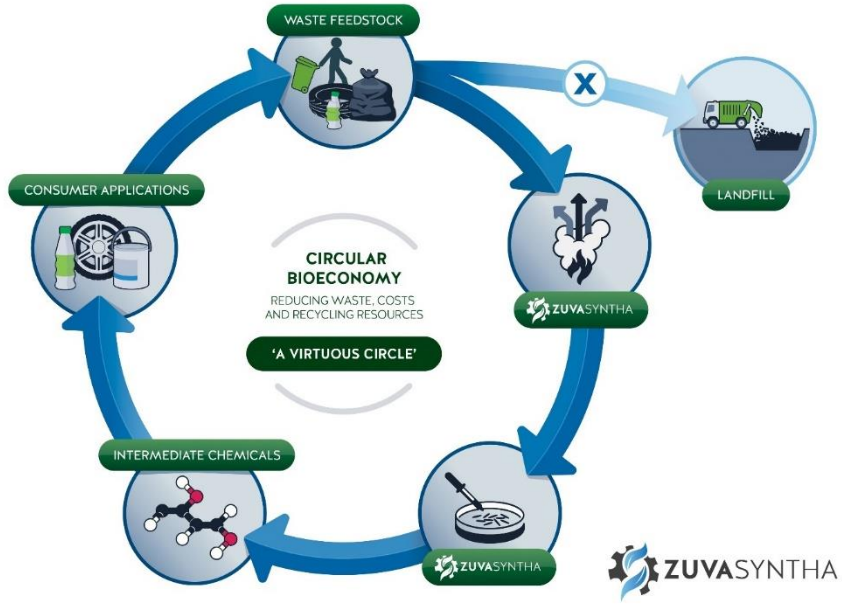
Company	Platform	Feedstock	Products	TRL	Overview
Global Bioenergies (FR)	Bacteria (Clostridium, Moorella, Desulfovibrio or others)	CO, CO_2 (& biomass)	light olefins (ethylene, propylene, isobutene)	<7	Technology came from SynGip which Global Bioenergies acquired. Use CO and CO2 from a wide range of low-cost and abundant streams, such as the industrial waste emissions of steel mills. First target product is isobutene. Advantage of their process is that the isobutene evaporates into the atmosphere that the microbes are cultured in, so easy to isolate and no toxicity.
Heliae (US)	Microalgae	CO_2 (others?)	mainly agricultural feed	9	Access to a number of algal strains. Operate lab and pilot scale facilities to develop new strains for particular products. Use a variety of culture facilities to commercial scale and operate downstream processing and fractionation. Products sold via re-sellers and formulators. Also undertake Joint Ventures.
Industrial Microbes (US)	Bacteria, (yeast?)	CH_4, CO_2	ethylene and others	<7	Early stage company, very much developing the platform.
Intrexon (US)	Methanotrophic bacteria	CH_4	isobutanol, farnesene	<7	 Demonstrated bioconversion of methane to isobutanol and farnesene, a key building block chemical for diesel fuel and specialty products, by engineered bacteria.
Invista (US)	Bacteria	CO	butadiene, nylon intermediates	<7	Partnering with LanzaTech, which provides the microbial platform, and developed further through metabolic engineering to convert butanediol to other higher value products, such as butadiene.
Kiverdi (US)	hydrogenotrophs	CO_2 and also CO, H_2	monoterpenes (C10), oils, protein for food	<7	Developed a system to fractionate different components from cultured bacteria. Awarded recent DoE grant to develop tools to engineer the microbes (thermophilic) for production of other hydrocarbons.

Company	Platform	Feedstock	Products	TRL	Overview
[LanzaTech](#) (US)	Clostridium	CO, CO_2	ethanol, isopropanol	9	 Operating a number of commercial plants that are manufacturing fuels from CO2 derived from number of sources, e.g. with ArcelorMittal in BE to use CO2 from steel foundries.

Company	Platform	Feedstock	Products	TRL	Overview
Mango Materials (US)	Methanotrophic bacteria	CH_4	PHA biopolyester	<7	 Developing technology further – incorporated 2010, received first funding 2011.

Company	Platform	Feedstock	Products	TRL	Overview
NewLight Technologies (US)	Methanotrophic bacteria	CH_4	'AirCarbon' - high performance, PHA-based polymer	9	 Several patents on the platform – modification of various methanotrophs and the processing technologies. Small scale commercial plant in California - now looking to launch across a number of product areas. Can use a variety of sources.
Photanol (NL)	Cyanobacteria	CO_2	organic acids, terpenes and others (17 products in total)	<7	Technology has been demonstrated at lab scale and currently plans for a modular pilot plant being finalised that can produce 10 t of acids. CO2 source does not need to be pure – successfully used exhaust gases.
Phytonix (US)	Cyanobacteria	CO_2	butanol, pentanol, octanol	<7	Process eliminates 1 t of CO2 for every 125 gallons of n-butanol produced. The company estimates the production cost of its n-butanol will be USD $1.95 per gallon. Initially targeting the $10 billion global n-butanol industrial chemical market, which is growing at ~7% CAGR, with demand exceeding supply in many areas including Asia.
Sapphire Energy (US)	Microalgae	CO_2	omega 3 oils and others		Appears to have gone bust – although attracted significant investment and produced oils and fuels at its Green Crude Farm.

Company	Platform	Feedstock	Products	TRL	Overview
TerraVerdae BioWorks (CA)	Multiple microbes	CH_4, CH_3OH	biopolymers for plastics, food additives and cosmetics	<9	Combine industrial biotechnology, microbial and metabolic engineering, and materials science to develop and manufacture high-value performance biomaterials and biocomposites from waste. Major commercial collaborations for high-yield production of challenging proteins, metabolites and fermentation scale up to 10,000L scale.
Trelys (US)	methanogenic archaea	CO_2, H_2	amino acid supplements	<7	 Technology is still being developed. Partnering with industrial H_2 producers (e.g. from steam reformation of CH_4). Initial focus is on amino acids, but platform has potential to develop a range of other intermediates including: propanediol, terpenoids, succinate.

Company	Platform	Feedstock	Products	TRL	Overview
ZuvaSyntha (UK)	Acetogenic bacteria	CO, CO_2, H_2 and CH_3OH	1,3-butadiene and others	<7	 Convert a variety of waste materials into C1 feedstocks can be used as feedstock. Still demonstrating technology.

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