Assessment of the CCUS Supply Chain in Scotland

Final Report
Scottish Enterprise
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Executive Summary

This report provides an in-depth analysis of the Carbon Capture, Utilisation, and Storage (CCUS) supply chain in Scotland. It explores the critical role of CCUS in supporting Scotland's transition to a net-zero economy by 2045, aligning with the UK's broader goal of achieving net-zero emissions by 2050. The analysis identifies key opportunities, challenges, and strategic recommendations to optimise Scotland's involvement in the emerging global CCUS market.

CCUS technology is recognised globally as essential for reducing emissions from hard-to-abate industries such as power generation, chemicals, and materials manufacturing. With substantial governmental investment earmarked for developing major CCUS clusters in the UK, Scotland is uniquely positioned to leverage its existing industrial base and expertise in oil and gas for the emerging CCUS sector. The establishment of clusters like the Scottish Cluster and Viking Carbon Capture and Storage (CCS) projects underlines Scotland's potential to capture significant industrial emissions, facilitating the development of a robust CCUS industry that could serve not only domestic needs but also foster an international market for CO_2 storage.

Scottish companies are actively exploring CCUS opportunities, with many already providing critical products and services across the CCUS supply chain, from capture and transportation to storage. Analysis reveals a strong level of innovation and engagement among local enterprises, driven by a combination of historical expertise in oil and gas and a forward-looking approach to new energy solutions. It also shows that Scotland has strong capabilities in key area of the CCUS supply chain, namely in control and instrumentation, pumps and valves, subsea engineering and operations and maintenance, as well as in professional services to support CCUS developments. However, the transition to a fully integrated CCUS supply chain is fraught with challenges, including skill shortages, regulatory uncertainties, and the need for substantial financial investment.

To capitalise on the opportunities and mitigate the challenges, the following strategic recommendations are proposed:

1. Advocate for more robust government policies that provide clear, consistent support for CCUS initiatives. This includes simplifying the regulatory framework for project approvals and enhancing financial incentives for companies investing in CCUS technologies.
2. Encourage the integration of CCUS projects with adjacent energy transition technologies like hydrogen production and offshore wind, leveraging synergies to enhance efficiency and cost-effectiveness.
3. Increase funding and support for CCUS-specific research and development initiatives to address technological gaps, particularly in the areas of capture and storage reliability and efficiency.
4. Encourage Scottish companies to identify opportunities to build on their current capabilities to engage in international CCUS projects and export their technologies and expertise. This not only opens new markets but will also help to position Scotland as a global leader in CCUS technology.
5. Develop platforms for knowledge sharing and collaboration among CCUS stakeholders to align efforts and share best practices. This could include setting up a series of opportunity specific regular industry roundtables, workshops, and joint ventures.

6. Develop targeted training and educational programs to build a skilled workforce that is well-prepared to meet the demands of the emerging CCUS market. This includes specialised training in CCUS technologies and regulatory compliance.

The CCUS sector offers a significant opportunity for Scotland to enhance its industrial base, create jobs, and reduce emissions. By leveraging existing capabilities and addressing current challenges, Scotland can establish itself as a key player in the global transition to a low-carbon economy. The strategic recommendations provided aim to support Scottish businesses to access and excel in the emerging CCUS market, fostering innovation and economic growth.

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1 Introduction

This report presents the results of a study, undertaken on behalf of Scottish Enterprise, on the Carbon Capture, Utilisation and Storage (CCUS) supply chain in Scotland. It summarises the expected demand for CCUS, collates and maps the value chain and Scottish company capability that could exploit emerging opportunities, assesses the appetite for participation in CCUS industry and infrastructure projects, discusses market access challenges and barriers for Scottish companies and offers recommendations to assist Scottish companies to access these emerging opportunities.

CCUS is identified as a critical technology in the global transition to net-zero emissions, enabling the capture of carbon dioxide (CO_2) from industrial processes before it is either reused (utilised) or permanently stored underground. As Scotland moves to net zero by 2045 and the UK towards its legally binding goal of achieving net-zero emissions by 2050, CCUS is expected to play a pivotal role in reducing emissions from hard-to-abate sectors such as chemicals, materials and power generation and in enabling the production of low carbon (blue) hydrogen

The UK's independent adviser on tackling climate change, the Committee on Climate Change, has consistently highlighted the importance of CCUS in meeting both Scotland's and the UK's climate targets. The UK is already recognised as one of the leading countries for CCUS readiness, with significant commitments being made to develop four major CCUS clusters. These clusters are:

- Track 1
    - HyNet in the North West of England and North Wales
    - East Coast Cluster across Teesside and the Humber

  £21.7 billion of government funding to support these two clusters was announced in October 2024.

- Track 2
    - The Scottish Cluster (Acorn Project) covering the East and North East of Scotland
    - Viking, based on the Humber

These clusters, strategically located in areas with concentrated industrial activity, aim to capture millions of tonnes of CO_2 each year, while supporting the development of low-carbon hydrogen production and other decarbonisation projects. The Scottish Cluster, in particular, is of major significance, as it is expected to address a significant proportion of Scotland's industrial emissions, position Scotland as a hub for CCUS activity in the UK and create a new international market for CO_2 transport and storage, all of which can offer significant opportunities for the local supply chain.

The analysis presented in this report is based on a combination of desk research, stakeholder engagement and industry consultation, carried out in late 2024 and early 2025.

2 The CCUS Market Opportunity

There is a healthy pipeline of projects for CCUS globally. Numerous national Governments have introduced policy that has catalysed and influenced the pace of development and adoption of CCUS and, as a result, the market continues to expand. Geographically specific market opportunities are detailed below that highlight the market potential and relevant active and proposed projects in each selected region.

It should be noted that the aggregation of CCUS can sometimes skew the specific supply chain opportunities towards either utilisation or storage. The scope of this research is predominantly focused on the CCS supply chains but will provide clear evidence of an active CCU supply chain that presents opportunities to businesses. To avoid doubt the specific details of the 'U' and 'S' are as follows:

- CCU Carbon used as a value-added asset – i.e. dry ice or as a raw material for chemicals or materials manufacture
- CCS Carbon permanently stored in geological sites – i.e. subsea oil and gas caverns

Whilst this research will generally refer to CCUS as a unified value chain, specific reference to CCU and CCS will be applied, where appropriate, to highlight key opportunities of engagement for Scottish companies.

2.1 Scottish Market

Market Insights

Scotland has the potential to become one of the leading CCUS markets and supply chain locations. The Scottish Government's Green Industrial Strategy highlighted CCUS as key area for investment to drive national growth and position Scotland as a global net zero leader. The Centre for Energy Policy (CEP) at the University of Strathclyde forecasted that the establishment of a CO_2 transport and storage (T&S) sector in Scotland could generate value of £300mn. This domestic potential could be bolstered by the development of an export market, increasing gross domestic product (GDP) contribution to £490mn per annum by 2042. These figures are representative of a T&S sector that is fully operational by 2030, backed by policy and support. Scotland is uniquely positioned as the primary storage location for UK CCUS projects with 75% of domestic storage capacity and 18% of Europe's potential storage capacity located within the Scotland's offshore sector. This enables the development of UK CCUS projects and facilitates the potential development of Scotland as an international import hub of captured carbon for permanent storage. Scotland is already demonstrating abilities at a local level, with several distilleries and a biogas plant currently capturing, or developing the capability to capture CO_2, initially for utilisation and offsetting CO_2 from fossil sources but with a potential for future storage. At a national level, larger, industrial sites including Grangemouth and Mossmorran form part of a Scottish Cluster. CCU will play a proportionate but significant role in the emerging green industrial economy in Scotland.

Key Projects

The Acorn Project is expected to be a critical factor in developing Scottish CCS capability. It will utilise a trunk network approach with a feeder pipeline (SCO_2T Connect) and offshore storage network that utilises geological storage sites under the seabed of the North Sea. Many of these storage sites are the remnants of depleted oil and gas fields. Acorn is projected to contribute £17.7bn to UK economic output (GVA), with £9bn attributed to Scottish economic output, and provide 10,800 development and construction jobs and 4,700 operational jobs. With a national net zero target for 2045, The Acorn Project will be critical to industrial decarbonisation efforts. It was expected that by 2030 the Scottish Cluster (Northeast Scottish industrial activity – detailed in the Scottish Net Zero Roadmap) would capture 5-10 Mtpa CO_2. This prediction is, however, now considered to be extremely optimistic, with key stakeholders suggesting that it will be at least 2030 before any significant process development or construction work is underway. This is a result of the project's position in the UK government's CCUS development plans. The project is currently a backup Track-1 project and is shortlisted for Track-2 funding and UK government decisions are awaited. The recent advancements of the UK market, as detailed below, offers some optimism for future funding.

2.2 UK Market

Market Insights

The UK Government has set a target to establish CCUS in 4 industrial clusters by 2030, and in doing so, expressed an appetite to develop the UK supply chain capabilities for export as the market grows. CCUS is a necessity rather than an option for the UK. If the UK is to meet the ambitious targets of 20-30 Mtpa of stored CO_2 per year by 2030 as a part of net zero 2050 targets, CCUS activity must accelerate. Despite some false starts, CCUS remains critical to net zero targets. Outlook can be buoyed by the recent progression, through final investment decisions, of the East Coast Cluster and Hynet Cluster, supported by £21.7bn of government funding. These present real opportunities for the supply chain to engage with active projects and develop the value chain for future projects. It is suggested that the supply chain opportunities for the CCUS sector could be worth around £100bn by 2050 and £20bn in the next decade. Businesses actively adapting technologies and engaging with projects will benefit most from the development of this sector. The UK already has significant assets with the largest CO_2 offshore storage potential in Europe (78 Gt), 6 industrial clusters engaged with CCUS for decarbonisation, and extensive oil and gas heritage (highly concentrated in Scotland) that can be transitioned to this developing industry.

Key Projects

Track 1 Clusters

East Coast Cluster – The Northern Endurance Partnership will develop the transport and storage for the East Coast Cluster, serving three initial capture projects: NZT Power, H2Teeside, and Teesside Hydrogen CO_2 capture. Majority shareholders and project coordinators include BP, Equinor and TotalEnergies. With construction due to commence mid-2025 and facilities in operation in 2028, the development of this project indicates a positive future for the market and tangible opportunities for early engagement. Whilst the procurement strategy is unclear, tenders have begun to be issued on the North Sea Transition Authority portal.

Hynet North West – ENI are lead partners in the consortium delivering the HyNet North West project. Storage potential in the second half of the current decade is expected to be 4.5 Mtpa CO_2 increasing to 10 Mtpa CO_2 after 2030. Associated economic value created in the UK is forecast to be £17bn until

2050. As a part of this project ENI are developing three spur pipelines to connect to future potential CCS sites in the North West of England and North Wales. This indicates the pipeline of projects that are expected to follow the pilot Track-1 funded projects which will act as trunk network enablers for the wider CCUS economy in the UK.

Track-2 Cluster Pipeline

Viking Cluster is a Humber based T&S initiative operated by Harbour Energy and BP. The aim is to repurpose the Lincolnshire Offshore Gas Gathering System (LOGGS) pipeline, transporting carbon offshore for permanent storage in the Viking gas field with a 300m tonnes storage capacity. Capture partners include HumberZero (a combined heat & power plant and refinery), West Burton Energy (natural gas plant), Associated British Ports (carbon distribution terminal), RWE (retrofitting capture technologies at Staythorpe power station), Cory (investigating carbon maritime transport potential) and Drax (bioenergy with carbon capture plant development). Whilst timelines on Track-2 projects remain unclear, the development after Final Investment Decision (FID) is likely to rapidly accelerate.

2.3 European Market

Market Insights

The European CCUS market is developing rapidly and leading the global adoption of permanent storage projects. The European CCS market was valued at USD 1.2bn in 2024 and is estimated to grow at a CAGR of 24% from 2025 to 2034, although figures are highly variable due to the uncertainties surrounding project progression timelines. The European market remains fragmented but is projected to become a hub for cross-border CCUS trade through a series of open-access projects that aim to stimulate the market. The EU has further committed to net zero by 2050 by introduction of the Net Zero Industry Act necessitating net zero manufacturing (including CCS technologies) to meet at least 40% of the EU's annual deployment needs by 2030, so adoption of technologies is certainly expected to accelerate. With the EU yet to establish a firm policy on cross-border distribution of captured CO_2, projects remain nationally focused. The Carbon Capture & Storage Association (CCSA) has highlighted that a cross-border model for CCUS is critical for reducing emissions efficiently and in time, reducing storage costs by 20%, and decreasing the risk associated with geographically isolated supply chains.

The London Protocol exists to protect the marine environment from pollution caused by waste dumping. A 2009 amendment allows the export of CO_2 for offshore geological storage, enabling international collaboration on CCS projects. This was adopted in 2019 to allow the progression of projects but it has yet to be fully ratified by the 52 signatories, which would allow bilateral agreements to progress at a faster pace and unlock Europe's potential market. The UK and EU have begun discussions on aligning their Emission Trading System (ETS) to enhance decarbonisation efforts. Currently, CO_2 stored within the EU and European Economic Area (EEA) is considered "not emitted" under the ETS, allowing industrial emitters to deduct captured emissions from compliance obligations. Storage outside these regions is permitted but offers no compliance benefits. The UK ETS, derived from the EU ETS post-Brexit, shares similar regulations but has recently seen a price divergence in price per tonne of carbon(£36/tCO_2e vs. £52/tCO_2e). A linked UK-EU ETS would increase market liquidity, stabilise carbon prices, and reduce capital risk for CCUS projects.

Norway has led CCUS developments with its experience from oil and gas heritage utilising enhanced oil recovery (EOR) techniques and operation of the Sleipner storage site since 1996. The UK Government's recent Green Industrial Partnership with Norway highlights the intent to develop cross-border CCUS opportunities and develop world-leading capabilities that can be exported. Denmark has established itself as strongly engaged with CCUS, allocating over DKK 27bn to a Green Transformation Scheme (GTS) fund, to support projects that capture a minimum of 0.9mn tons and 1.4mn tons in June 2024 and June 2025 respectively. The Netherlands has experienced multiple setbacks in CCUS adoption but has recently gained momentum and will play a significant role in Europe's early CCUS landscape. Active developments include the Aramis and Porthos projects . Additionally, the Netherlands is likely to develop as a CO_2 distribution hub with maritime network legacies should cross-border CCUS activities develop.

Despite a clear dominance of North Sea projects, strong emerging markets in Europe include Germany, France, Poland, Czechia, Italy, and Sweden. Europe has over 75 market-ready projects proposed, indicating the significant appetite to capitalise on these opportunities.

Whilst it is unlikely that Scottish/UK capabilities will be able to service the rapid increase in demand from these projects, it is important that capabilities are developed and utilised in the most applicable areas of the value chain.

Key Projects

Project Greensands, Denmark – This INEOS-led project will be a commercial scale carbon storage facility, designed to receive CO_2 transported by ship to an offshore platform to be permanently deposited in a geological reservoir. It is amongst the frontrunners of CCUS development in Europe. Progress is expected to support investments of more than USD 150mn across the Greensands CCS value chain to scale storage capacity. The project is expected to become operational in Q4 2025 with a number of contracts for offtake awarded. Collaboration with biogenic emission sources has ensured sufficient CO_2 feedstock for the project and offers the potential for further revenue from the voluntary carbon market. Undoubtedly, momentum has been supported by the Danish Government's active engagement with CCUS policy including the market-based, technology-neutral CCUS Fund.

Northern Lights, Norway – Norway has led CCUS development over the past decades. The Northern Lights Project exists to deliver CO_2 T&S as a service, the first phase of the Norwegian Government's full-scale CCS project, Longship. The project's open-source infrastructure was designated by the EU as a Project of Common Interest (PCI) and aims to contribute to establishing a commercial CCS market in Europe. Commercial contracts have been signed with multiple industrial emitters, including Yara Sluiskil (an ammonia and fertiliser plant in the Netherlands).

Ravenna CCS, Italy – This project will capture approximately 25,000 tonnes of CO_2 per year from ENI's natural gas treatment plant in Ravenna and transport it offshore through reconverted gas pipelines for injection into the depleted Porto Corsini Mare Ovest gas field. This project is expected to become Italy's hub for CCS deployment, supporting the continued competitiveness of Italy's industrial activities in the energy-intensive sectors of the Emilia-Romagna region. ENI's role in this project indicates the globally exportable potential that could be gained from engagement with UK based CCUS projects.

Porthos, Netherlands – Construction began last year of a full-length CCS system at the Port of Rotterdam, which, when commissioned will transport CO_2 20km offshore to store in depleted gas fields in the North Sea.

2.4 Global Market

Market Insights

The global CCS market was valued at USD 2.4bn in 2023 with a forecasted CAGR of 13.5% between 2024 and 2031, reaching a value of USD 16.5bn. Wood Mackenzie indicates that carbon capture capacity will reach 440Mtpa whilst storage capacity will reach 664Mtpa by 2034, requiring a total investment of USD 196bn. The findings suggest that nearly half the investment will be associated with capture, with the remainder split evenly between transport and storage. North America and Europe are set to receive much of the early value chain investment.

Globally, industrial carbon management is more targeted toward CCS initiatives as an abatement method rather than the incorporation of utilisation. This will likely change as Europe begins to dominate on utilisation technologies.

A network (or hub, cluster, trunk) approach to CCS is becoming the favoured method for infrastructure development globally. This supports sharing of costs and the risks that underpin the high capex and marginal finances of CCS projects. It is, therefore, expected that capture, transport, and storage value chains will be required to develop at a similar pace to ensure permitting and development timelines are met for the initial trunk networks. Staggered progress of these value chain segments could result in fracturing of the network approach, causing functional and economic inefficiency of projects.

Regionally concentrated markets are expected to emerge including China, India, North America and the Middle East, with the majority of investments likely to be in hard-to-abate sectors including cement, iron, steel, chemicals refining and energy (hydrogen).

Global policy and regulation for CCUS is evolving to support investment. Examples include:

- Canada will increase federal carbon price by CUD 15/tonne annually to stimulate industrial transitions
- Brazil became the first South American country to enact CCS-specific legislation to regulate and inspect activities
- China has launched The Implementation Plan for Green and Low-Carbon Technology Demonstration, providing financial support for decarbonised projects including six CCS projects
- Malaysia and Indonesia are seeking to develop a value chain that manages domestic emissions and store imported carbon for a fee
- Japan, Singapore and South Korea are attempting to develop transnational value chains for export to Malaysia, Indonesia and Australia
- Australia has developed national CCUS projects and amended legislation to allow the import of CO_2
- The United Arab Emirates (UAE), Kingdom of Saudia Arabia and Oman have launched long-term strategies and committed to CCUS for decarbonisation

- Kenya is developing a 1Mtpa Direct Air Capture (DAC) project

The IEA has identified 45 commercial facilities with CCUS in operation globally and a further 700 projects at various stages of development. Despite this, the global energy sector remains 'not on track' to achieve the IEA's Tracking Clearn Energy Progress (TCEP) Net Zero Emissions (NZE) by 2050 scenario.

Key Projects

The nature of CCUS projects varies globally with the majority of active projects completing carbon storage as a product of enhanced oil recovery (EOR). Examples of existing CCUS projects and future developments across a variety of project types include:

Shell Quest, Canada - Located in Alberta, the Quest facility captures CO_2 emissions from the Scotford Upgrader, which processes oil sands into synthetic crude oil. Operational since 2015, Quest was designed to capture about one million tonnes of CO_2 annually and has captured 7.7mn tonnes (as at the end of 2022).

The Alberta Carbon Trunk Line, Canada – The Alberta Trunkline consists of a 240 km pipeline which will gather, compress and store up to 14.6mn tonnes of CO_2 per year and inject this CO_2 into depleted oil reservoirs. The pipeline will run from the Alberta Industrial Heartland to a site near Clive and offers open access to emitters that can connect to the pipeline, ensuring offtake for proposed projects.

Gorgon Project, Australia – Part of the Gorgon gas development in Western Australia, this is one of the world's largest CCUS projects. It stores CO_2 extracted from natural gas reservoirs beneath Barrow Island, targeting an annual storage capacity of 3-4mn tonnes in new injection wells. Australia is beginning to assess the potential for CCUS hubs such as the Middle Arm Peninsula hub in the Northern Territory, serving domestic and Asian CCUS requirements.

Rio de Janeiro Hub, Brazil - Petrobras is piloting Brazil's first CCUS hub in Rio de Janeiro, storing 100,000 tonnes of CO_2 annually to test key technologies. It seeks regulatory support to enable industrial decarbonisation, with plans for a commercial hub, reusing pipelines and offshore storage with 20-million-tonne capacity, advancing Brazil's CCUS capabilities.

Ras Laffan, Quatar - This project, currently undergoing Front End Engineering & Design (FEED) and Engineering, Procurement & Construction (EPC) work led by Worley, will be a facility capable of capturing 4.3mn tonnes of CO_2 annually from liquefied natural gas (LNG) processing facilities in Ras Laffan Industrial City.

Taizhou Power Plant, China – China Energy's operational project represents the largest coal-fired power plant with carbon capture in Asia. Following the successful launch in 2023, further research is being undertaken in the facility in fields including production of ethanol utilising captured CO_2 and hydrogen, and refined chemical products.

3 The CCUS Supply Chain

3.1 CCUS Supply Chain

The following diagram provides a comprehensive overview of the products, services and infrastructure that comprise the CCUS supply chain. This visual representation categorises the entire CCUS process into three principal stages: Capture, Transport, and Storage, with an additional component dedicated to Carbon Utilisation (a larger version of diagram is provided as a separate digital file).

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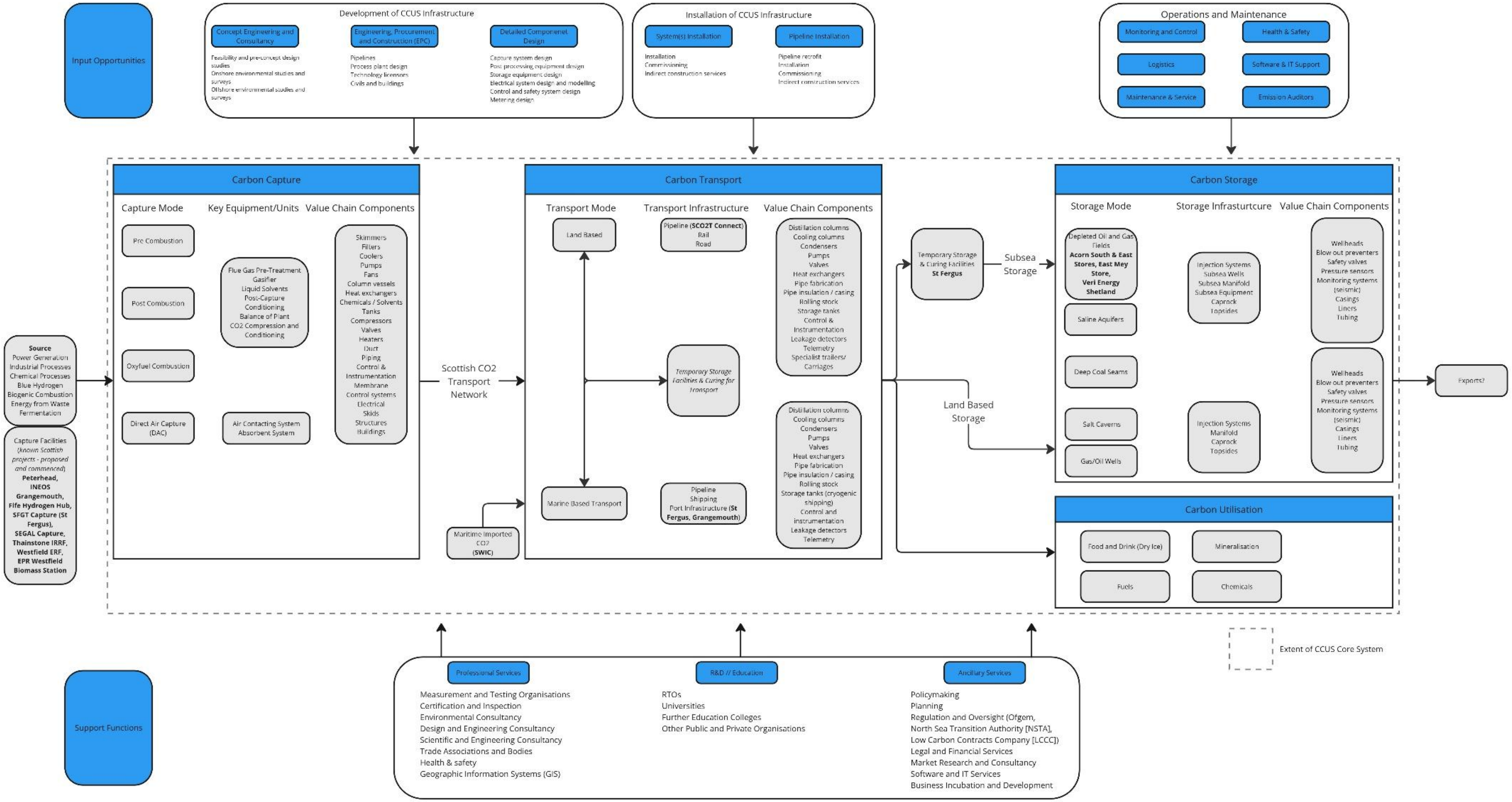


Figure 1 - CCUS Supply Chain

The core elements of the supply chain include:

- **Capture** – the capture segment outlines various technologies employed to extract CO_2 from industrial processes. These technologies are categorised based on the method of capture, including pre-combustion, post-combustion, direct air capture (DAC), and others, each using specific equipment like absorbers, washers, and compressors.
  This section also identifies potential source facilities like power generation plants and industrial processes where these technologies could be implemented.
- **Transport** – transportation mechanisms are detailed in the diagram, indicating how captured CO_2 is transferred from the capture sites to storage locations. This includes both land-based transport methods, such as pipelines and road transport, and marine-based solutions that utilise shipping. The diagram includes infrastructure elements like ports and temporary storage facilities that support the logistical requirements of CO_2 transport.
- **Storage** – the storage component of the diagram illustrates the final sequestration of CO_2, where it is securely stored to prevent its release into the atmosphere. Storage solutions include geological formations like depleted oil and gas fields, saline aquifers, and deep coal seams. The diagram also explores advanced concepts like subsea pipelines and the necessary equipment for ensuring safe and permanent storage, such as injection systems and monitoring equipment.
- **Utilisation** – beyond capture and storage, the utilisation of CO_2 as a resource for mineralisation and the synthesis of fuels and chemicals is acknowledged, highlighting the potential for creating value-added products from captured CO_2.
- **Support Functions and Ancillary Services** – Integral to the supply chain are the support functions and ancillary services that facilitate the operation of CCUS technologies. These include professional services like measurement, testing, certification, and environmental consultancy, as well as regulatory bodies and educational institutions that provide the necessary oversight and workforce training.

This CCUS supply chain diagram serves as a strategic tool for stakeholders to understand the complexities and interdependencies of integrating CCUS technologies into existing industrial frameworks. It not only helps in identifying key areas for investment and development but also helps in visualising the potential for scalable solutions that can significantly impact carbon management practices globally.

It presents CCUS as a fundamentally connected value chain comprised of independent supply chains that can be engaged by SE to promote opportunities. It is not exhaustive but aims to capture the fundamental components whilst also indicating the macro-level operations. The value chain has developed with the Acorn Project in mind but could be translated to any CCUS network development, focusing on each part of the supply chain. It has been broken down to the level of components to provide clarity on the equipment and infrastructure required. Details of specific capture technologies including Amine-based, membrane gas separation, bioenergy with carbon capture and storage (BECCS), chemical looping, cryogenic and potential nanotechnologies are not included in this value chain. These technologies include information that is proprietary to the businesses active in the respective area. Many of the components identified as relevant to CCUS supply and value chains already exist in adjacent sectors such as oil and gas and liquified gas transport as well as sectors such as food and drink, albeit adhering to the specific regulatory requirements of these sectors.

CCUS is a new market opportunity, but it does not require a new supply chain. The market opportunity is accessible to both existing companies supplying other end use sectors (e.g. oil and gas, chemicals, process industries, construction, etc., etc.) and new businesses.

CCUS is, therefore, a new market or diversification opportunity for existing businesses rather than a new supply chain requiring new businesses.

3.2 Transferrable Products and Services

The development of a CCUS supply chain offers significant opportunities to leverage existing products and services from other industries. By adapting (where required) and transferring these established solutions into the CCUS domain, it is possible to accelerate deployment, enhance technological advancements, and reduce overall costs.

Examples of some key areas where transferable products and services can play a crucial role in the CCUS supply chain would include:

Engineering and Construction Services

Engineering and construction services used in oil and gas, power generation, and large-scale infrastructure projects are highly transferable to the CCUS supply chain. This includes modular construction techniques, project management expertise, and specialised engineering services for designing complex installations. For example, the skills and technologies used in constructing offshore oil platforms can be adapted for building offshore CO_2 storage facilities, including subsea injection systems and pipeline networks.

Pipeline Transportation Technology

The oil and gas industry's extensive experience in pipeline design, construction, and operation can be directly applied to the CCUS supply chain. This includes the use of advanced materials for high-pressure environments, corrosion protection systems, and leak detection technologies. These capabilities are essential for developing reliable transportation networks for CO_2, whether over land or underwater.

Monitoring and Control Systems

Advanced monitoring and control systems developed for the chemical processing industry and power generation can be adapted for use in CCUS operations. These systems include sensors and software for real-time monitoring of emissions, process control technology for managing capture and storage operations, and safety systems designed to prevent leaks and ensure the integrity of storage sites.

Industrial Gases Expertise

Companies that specialise in the handling and manipulation of industrial gases already possess technologies and knowledge that are critical for managing CO_2. This includes gas liquefaction and regasification, compression systems, and storage solutions. The transfer of these technologies can facilitate efficient handling and processing of CO_2 at various stages of the CCUS supply chain.

Environmental Consulting and Legal Services

Environmental impact assessments, regulatory compliance, and legal services developed for the mining and environmental sectors are highly applicable to the CCUS industry. These services help CCUS project developers to navigate the complex regulatory landscape, ensure compliance with environmental standards, and assist in obtaining necessary permits and approvals.

Digital Technologies and Data Analytics

Digital transformation initiatives across various industries provide tools that can be utilised within the CCUS supply chain. This includes the use of big data analytics for optimising operations, blockchain for ensuring data integrity in emission tracking, and artificial intelligence for predictive maintenance and process optimisation.

Research and Development Collaborations

R&D collaborations that have been successful in pharmaceuticals, biotechnology, and materials science can be directed towards innovations in CCS technologies. This includes the development of new absorbents and catalysts, improvements in process efficiency, and breakthrough technologies for direct air capture.

By identifying and integrating these transferable products and services, the CCUS supply chain can leverage existing competencies and resources to scale up rapidly and efficiently. Such cross-industry synergies not only reduce the learning curve and associated costs but also foster innovation through the application of proven technologies in new contexts, driving forward the global agenda on carbon management and climate change mitigation. There are, of course, some technologies that will require more extensive repurposing. The temperature of liquified or compressed CO_2 is significantly lower than that of extracted gas or oil. Therefore, some well-based and subsea components will require more rigorous testing and development to ensure that they can be applied to such low temperature applications.

It is important to highlight that the development within this sector does not necessitate the creation of a new supply chain. Rather, it leverages and integrates the vast array of existing systems and components that have already been utilised extensively in other industries. For example:

- Pipeline transportation technology has been used widely in the oil and gas industry, these technologies are readily adaptable for CO_2 transport in CCUS applications
- Monitoring and control systems, used in various industries, are crucial for ensuring the operational integrity and efficiency of CCUS processes
- Heat Exchangers and compressors are commonly used in various manufacturing processes, these components are essential for the operation of CCUS technologies, especially in the capture and compression stages.

3.3 The Scottish Supply Chain

A database of approximately 1,000 companies that have operational bases in Scotland and offer products and services that have the potential to be diversified into, or adapted for, the CCUS supply chain has been developed. It is not an exhaustive database of potential supply chain companies, rather, an indication of the type of companies and types of products and services that are applicable for CCUS.

The companies were categorised, according to main supply chains segments (as presented in Figure 1). This was based on information on company websites and, in many cases, a company's products or services were applicable to many segments of the supply chain – for example, pumps and valves can be applicable to the capture, transport and storage segments.

Key observations include:

- In terms of carbon capture components, control and instrumentation was the most often listed offering on company websites, followed by chemicals, filters, seals and valves. A segmentation of companies by capture components is shown in the figure below:

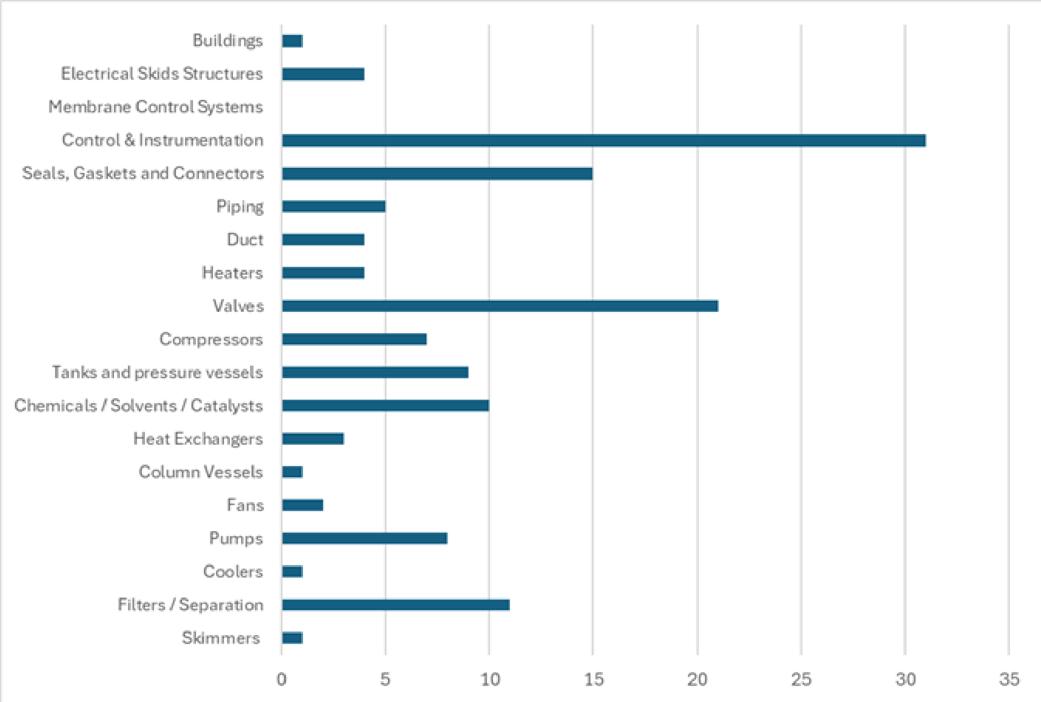


Figure 2: A Distribution of Companies by Capture Components Categories

- Relatively few companies supply transport equipment and components. The most often listed system/components were valves, pipe fabrication, control and instrumentation and pumps.

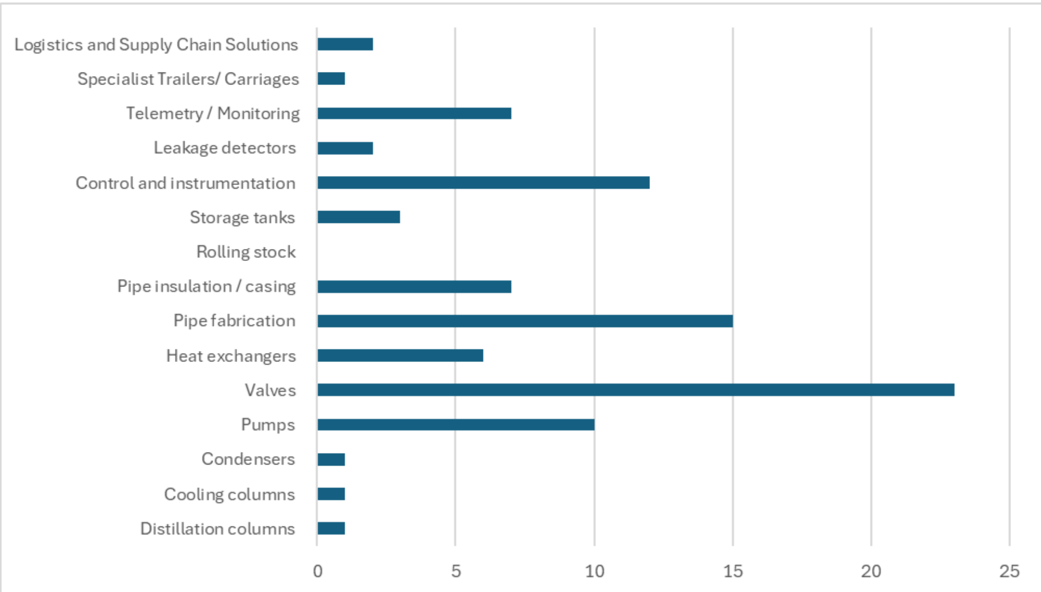


Figure 3: A Distribution of Companies by Transport Components Categories

- In terms of storage infrastructure and components, is no surprise that subsea engineering was the most populous category. This includes products and services ranging from remotely operated vehicles (ROVs) to cabling and subsea umbilical products, and diving services and equipment. Control and instrumentation was, again, a key category as was subsea well management.

  A distribution of companies by storage infrastructure and components is shown in the figure below.

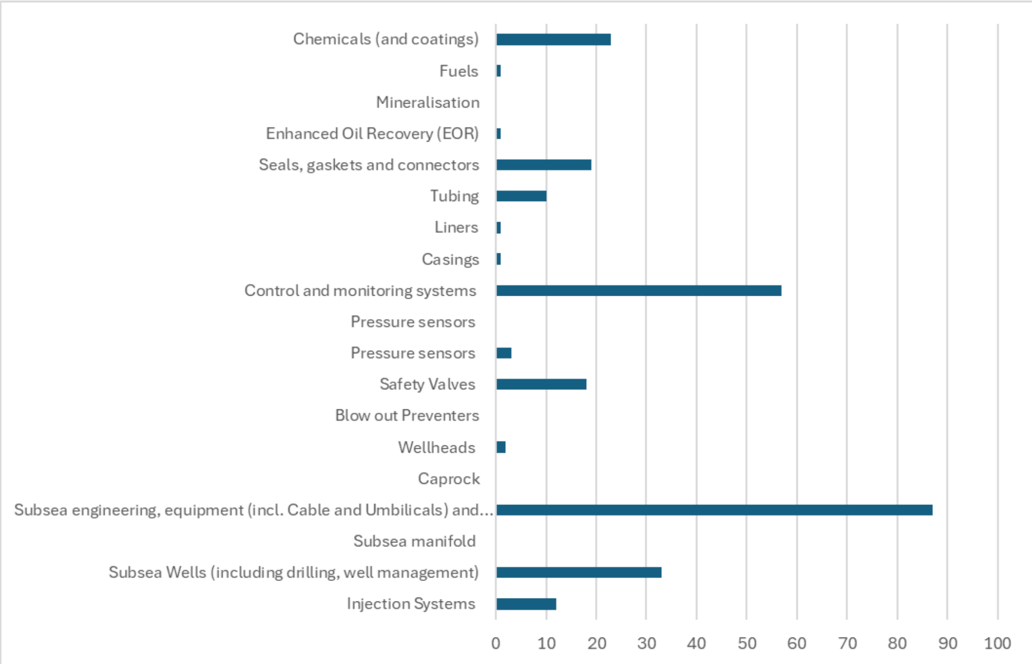


Figure 4: A Distribution of Companies by Storage Components Categories

- Most companies on the database offer support functions, which include professional services; logistics, warehousing and supply chain management; general, precision and custom fabrication (inc. material supply); drilling (and servicing of drilling tools); and others. For further clarification:
  - Professional services included companies providing specialist testing, specialist consultancy services (such as environmental consultancy), recruitment and legal services.
  - Those categorised as 'other' including a range of companies, from data specialists and IT services to companies treating waste and providers of rental equipment.

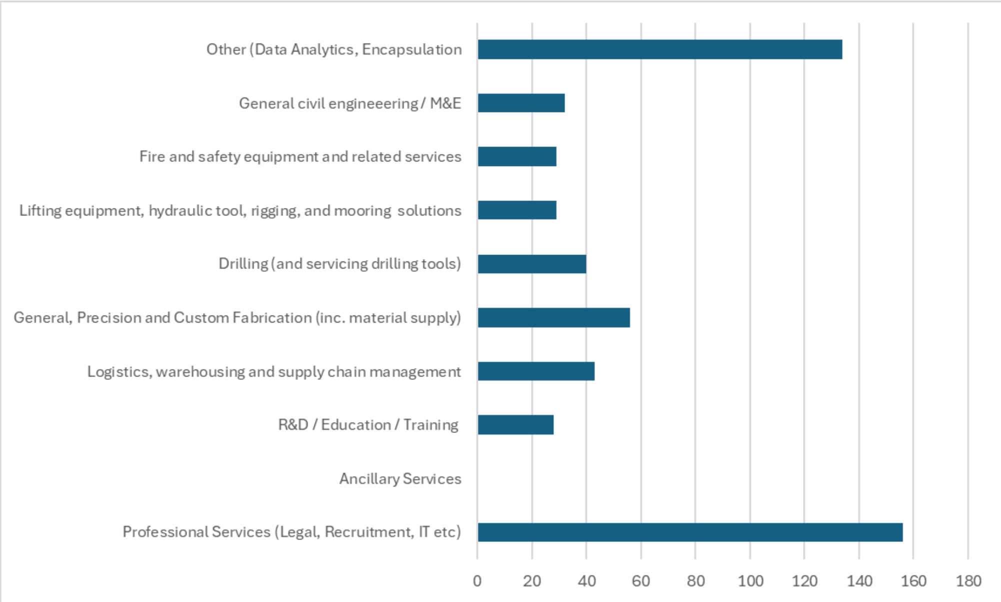


Figure 5: A Distribution of Companies by Support Function Categories

- The category labelled 'input opportunities' was the next most populous category, it includes:
  - Companies offering operations and maintenance services (including asset management)
  - Large, international companies offering engineering, procurement and construction (EPC) services
  - Companies providing design and engineering consultancy services

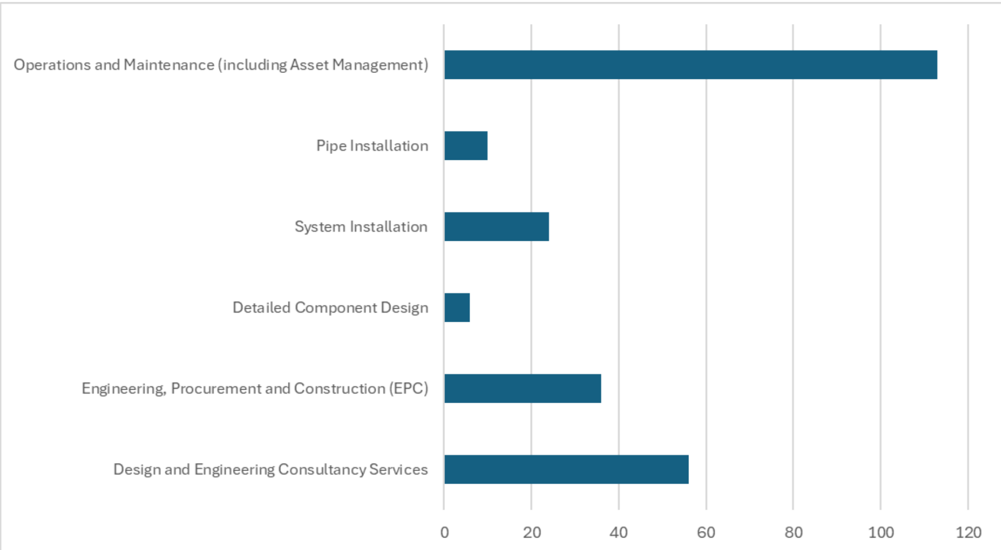


Figure 6: A Distribution of Companies by Input Opportunities

The analysis of companies shows a prevalence of companies with capabilities spanning multiple segments of the CCUS supply chain. For instance, many engineering firms possess the skills and technologies applicable to both the Capture and Transport segments. This cross-functional capability not only demonstrates the versatility of Scottish companies but also their potential for seamless integration into the CCUS sector.

"The CCS supply chain is 80-90% the same as the upstream oil and gas supply chain…where Aberdeen is a world centre…so currently very strong capability in the North East of Scotland."

To summarise Scottish capability, we would highlight areas such as control and instrumentation, pumps and valves, subsea engineering and operations and maintenance as core areas of strength.

A database of categorised Scottish companies, as potential suppliers into CCUS, is provided as a separate document.

4 Industry's Understanding of CCUS and Potential Opportunities

A programme of industry consultation was conducted as part of this study. The primary objective was to engage with a diverse cross-section of potential suppliers to gather insightful data, understand market readiness, and identify key areas of opportunity and challenge within the CCUS sector.

The consultation consisted of two parts:

- Online Survey – we designed and disseminated an online survey targeting potential suppliers from various sectors relevant to the CCUS supply chain. The survey aimed to capture detailed information on company profiles, current involvement in CCUS, interest in future engagement, and perceived barriers to entry or expansion in the CCUS market.
  The survey link was distributed through multiple channels to ensure wide participation. We collaborated with sector associations, such as CeeD, ETZ Ltd., Hydrogen Scotland, NECCUS, NMIS, Offshore Energies UK and Scottish Carbon Capture and Storage, to reach a broad audience of potential suppliers, leveraging their networks to enhance survey participation. SE also played a role in distributing the survey link.
  65 complete surveys were received.
- Detailed Interviews – to complement the survey data, we conducted a series of detailed interviews with selected companies. These interviews were conducted via telephone and online meetings, allowing for deeper insights and discussions about the specific needs, challenges, and opportunities companies face regarding the emerging CCUS sector and its supply chains.
  The selection of companies for interviews was based on their potential impact on the CCUS supply chain, their innovative approaches, or their strategic importance to the sector.
  16 detailed interviews were carried out.

The subsequent subsections will present a detailed quantitative analysis of the online survey responses augmented with insights from the one-to-one interviews

4.1 Overview of Respondents

This section provides an overview of the companies that participated in the online survey. The 66 responses were received from a diverse range of industries, company sizes, and geographic locations, reflecting the broad interest in CCUS technologies across Scotland.

In terms of industry sectors, we had responses from companies across a wide spectrum of sectors, including:

- Oil and Gas
- Engineering
- Renewable Energy
- Manufacturing
- Consultancy Services
- Transport and Logistics
- Others including sectors such as Health and Safety, Legal Services, and Software Development

The distribution, by sector is shown opposite (it should be noted that many companies listed more than one sector).

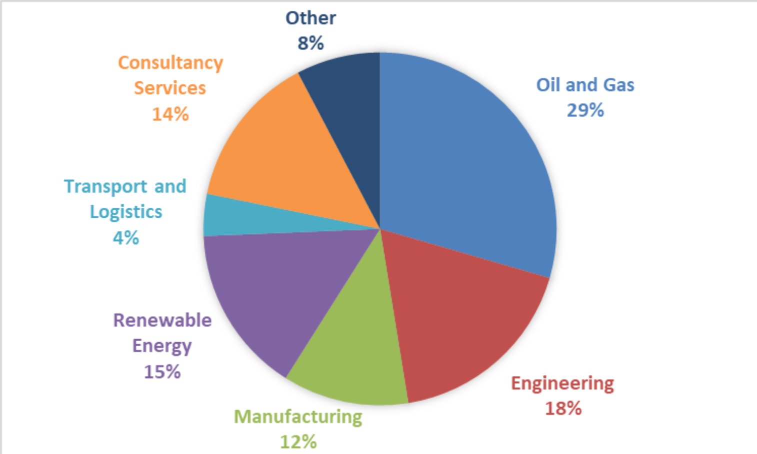


Figure 7: Distribution of Companies by Industry Sector

This reinforces the widely held view (amongst CCUS commentators and industry associations) that to successfully implement CCUS projects, a multifaceted approach is required, encompassing everything from technical and engineering solutions to strategic and regulatory consulting.

In terms of company size, businesses of different scales, from fewer than 10 employees to more than 500 employees, responded to the survey. This diversity in company size suggests broad potential for engagement, from small, specialised firms to large corporations

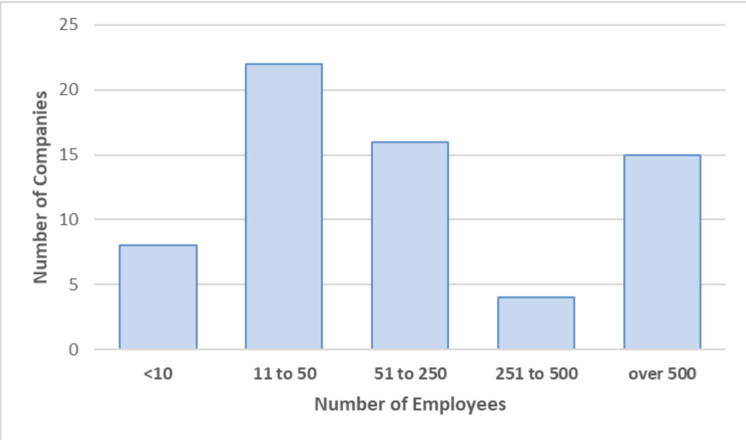


Figure 8: Company Size Distribution

A distribution of companies by turnover is provided in the figure opposite – which indicates that many of the respondents are well-established companies with significant financial turnover.

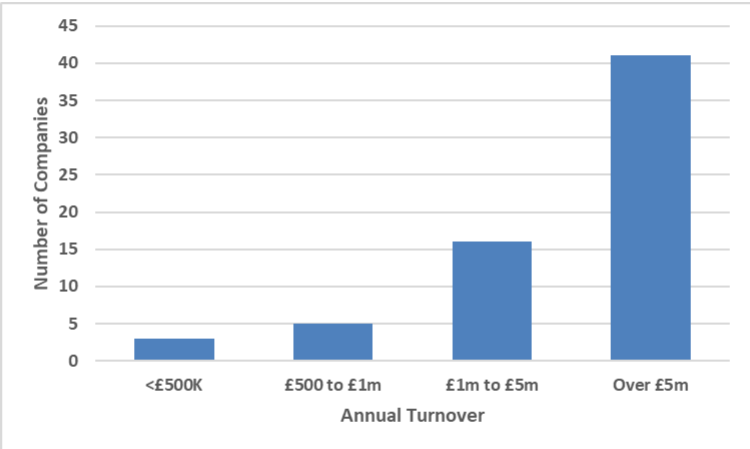


Figure 9: Annual Turnover Distribution

4.2 General Awareness of and Engagement in CCUS

This section examines the current level of awareness of and active engagement in CCUS among the surveyed companies in Scotland. Understanding these factors is critical to developing targeted educational and partnership opportunities to enhance company involvement in the emerging CCUS opportunity.

The survey data indicate varying levels of awareness of CCUS among respondents, which can be categorised as follows:

- Very Aware – companies that are well-informed about CCUS technologies and their role in industrial decarbonisation. These companies are typically already considering or actively pursuing CCUS-related projects.
- Somewhat Aware – companies that have some knowledge of CCUS but may lack detailed understanding or have not yet engaged in any CCUS activities.
- Not Aware – companies that are unfamiliar with CCUS technologies and their benefits. This group represents a key target for outreach and educational initiatives.

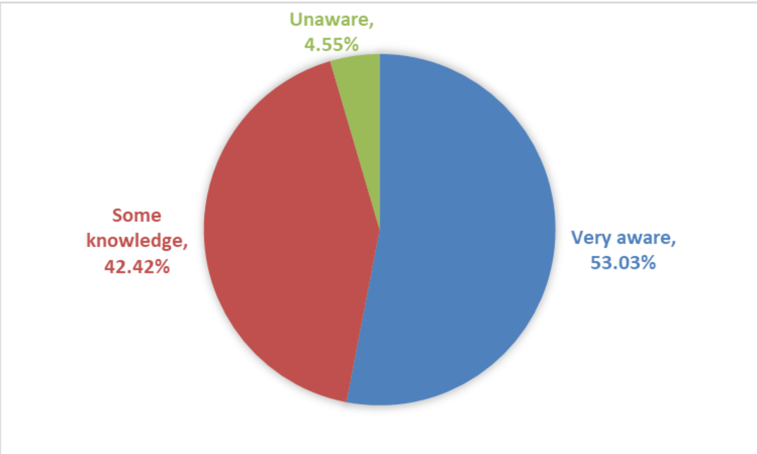


Figure 10: CCUS Awareness Levels

As shown in Figure 10, there is a high percentage of companies that are very aware or somewhat aware, suggesting a foundational understanding of CCUS within industry. Only a small proportion of companies indicated that they are unaware of CCUS opportunities.

This high level of awareness is very positive, but it could be argued that the majority of those companies that responded to the survey were a self-selecting group that is already engaged with CCUS and are not fully representative of all companies that could access CCUS opportunities.

Engagement levels can further clarify the practical steps companies are taking toward integrating or supporting CCUS solutions. Of the 66 respondents, 73% (48 companies) stated that they have already taken steps to explore CCUS opportunities. We have segmented engagement as follows:

- Actively Engaged - companies that are currently involved in CCUS projects or have taken concrete steps toward such involvement. This includes those exploring partnerships, participating in pilot projects, or investing in CCUS-related research and development.
- Planning to Engage - companies that recognise the potential of CCUS and are in the planning stages prior to commencing activities. These firms are likely evaluating their capabilities and seeking opportunities within the CCUS supply chain.
- Not Engaged - companies that have not yet taken steps toward CCUS engagement. This group may require additional information and support to understand how CCUS could benefit their operations and the broader environment.

This engagement data will help in identifying specific segments of the emerging CCUS supply chain that are already attractive to Scottish companies and gaps in provision that could be filled through facilitated engagement.

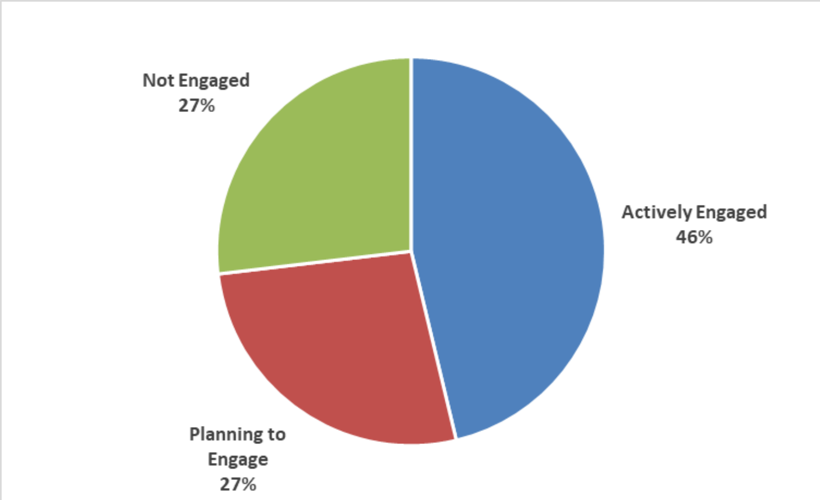


Figure 11: CCUS Engagement Levels

4.3 Type of Current Participation

The survey feedback from companies that have begun to engage in the CCUS domain reveals a proactive stance towards exploring possible current and future opportunities. These companies, representing a spectrum of industries, have taken significant, albeit varied, steps towards understanding, developing and implementing solutions for CCUS applications, underscoring the sector's potential for growth and innovation.

We can group these responses (on current engagement activities) into the following types of participation:

- Research and Development (R&D) – many companies are actively involved in R&D, focusing on developing products suited for CCUS applications such as OCTG (Oil Country Tubular Goods) casing, tubing, and line pipe products. This investment in R&D is pivotal as it drives innovation tailored to the unique demands of CCUS, enhancing the technological readiness of solutions required for effective carbon capture and storage.
- Service Provision to Major Projects – companies have supplied crucial services to flagship CCUS projects like the Acorn CCS Project. Activities include inspection services for critical infrastructure such as the Goldeneye pipeline. This engagement not only provides these companies with direct exposure to CCUS operations but also aligns them with ongoing major developments in the sector.
- Participation in Front End Engineering Design (FEED) Studies and Consultations – engaging in FEED studies for projects like Hynet illustrates a deepening involvement and readiness to tackle the complex engineering challenges posed by CCUS. These activities are critical for laying the groundwork for successful project execution.
- Marine Warranty Services and Infrastructure Studies – some companies have expanded their service offerings to include Marine Warranty Services for the construction of subsea CCUS

infrastructure and studies assessing the logistics of transporting liquid CO_2. These services are essential for ensuring that the CCUS facilities are built to the appropriate standards and operate safely.

- Bidding on CCUS Projects – actively bidding on various CCUS projects indicates a strong desire to be at the forefront of this emerging market. This involvement spans multiple regions, highlighting the global interest and potential for Scottish and UK-based companies in the international CCUS landscape.
- Regulatory and Industry Body Engagement – companies are not only engaging technically but also navigating the regulatory landscapes by liaising with regulators and industry bodies. This is crucial for aligning technological deployments with current laws and standards, ensuring compliance, and advocating for supportive CCUS policies.

Further analysis on the specific products and services provided by these companies is summarised in the following section.

4.4 Products and Services Already Supplied

This part of the report explores the types of products and services that surveyed companies have already supplied to the CCUS sector. Understanding this can help to identify established supply chains, gaps in the market, and potential areas for development or improvement.

The types of products and services provided to the CCUS sector by respondents are diverse, reflecting the interdisciplinary and complex nature of CCUS projects. These contributions can be categorised as follows:

- Process Equipment – this includes pumps, valves, heat exchangers, and compressors that are essential for the operation of CCUS technologies, especially in the capture and compression stages.
- Monitoring and Control Systems - equipment and systems such as sensors, control units, and telemetry systems that are crucial for monitoring the integrity and efficiency of CCUS processes.
- Consultancy and Engineering Services – expertise in project management, CCUS technology implementation, regulatory compliance, and environmental impact assessment provided by consultancy firms.
- Research and Development Services – activities focused on improving CCUS technologies, reducing costs, and enhancing system efficiency, often provided by academic institutions and specialised research firms.
- Safety and Maintenance Services – including safety systems, emergency response services, and regular maintenance schedules to ensure the safe operation of CCUS facilities.
- Logistics and Transportation – services related to the transport of CO_2 from capture sites to storage locations, which may include specialised pipeline systems, shipping solutions, and storage infrastructure.

The service category plays a crucial role in bridging technological innovation with practical implementation. An indication of the key services categories, based on survey responses, includes:

- Engineering Consultancy – engineering consultancy services in the CCUS domain are pivotal for the design, optimisation, and execution of projects. These services encompass a range of activities from preliminary engineering design studies to detailed design and full-scale project management. This segment also includes feasibility studies and conceptual field screening which are crucial during the initial phases of CCUS projects.

- Safety Services – safety services are integral to ensuring that CCUS operations adhere to the highest standards of industry safety and compliance. This includes everything from the development and implementation of safety management systems to emergency response planning and safety training for personnel. The supply of equipment such as safety valves, liner hanger systems, and casing running systems, which ensure the integrity and safety of wells and other storage sites, is also a critical component of this segment. Survey responses include companies that specialise in assessing legacy wells for suitability in CCS projects, focusing on the integrity and safety of these structures to adapt them for CO_2 storage.
- Environmental Consulting – environmental consulting services in CCUS are focused on assessing and mitigating the environmental impacts of projects. This includes conducting detailed environmental impact assessments, providing regulatory compliance advice, and developing environmental management systems. Environmental consultants play a key role in navigating the complex CCUS regulatory landscape, helping project owners obtain necessary permits and approvals, while ensuring that all operations are environmentally sound. These services are essential for building and maintaining public trust and meeting the stringent environmental standards set by governments and international bodies.
- Integration of Services – the integration of these specialised services for delivery into the CCUS sector provides a comprehensive approach to project development and execution. Engineering consultants often work in tandem with safety and environmental professionals to ensure that all aspects of project design, implementation, and operation are conducted safely, efficiently, and within the regulatory framework. For instance, a project may begin with environmental consultants assessing site suitability, followed by engineering consultants designing the infrastructure, and safety specialists developing risk management strategies.

This analysis highlights that Scottish companies are already offering consultancy and engineering services, which underscores the demand for expertise in navigating the complexities of CCUS projects.

4.5 Areas of Future Interest

This section explores the specific areas of CCUS that companies have expressed interest in exploring further. Understanding these areas of interest helps identify where businesses see potential for growth, innovation, and investment, which can guide future development strategies and policy formulations.

These interests are broadly categorised into the following themes:

- Technology Development – many companies are interested in developing or improving CCUS technologies, particularly for capture and storage. This includes interest in advancing membrane technologies, solvent systems, and direct air capture solutions.
- Infrastructure and Engineering – there is interest in the engineering aspects of CCUS, such as the design and construction of storage sites, transport logistics, and pipeline infrastructures. This also covers retrofitting existing facilities with CCUS capabilities.
- Regulatory and Compliance Services – as CCUS is expected to be a heavily regulated field, there is a significant interest in understanding and navigating the regulatory landscape. Companies are looking to provide or improve services in compliance consulting, legal advice, and environmental impact assessments.

- Renewable Integration – some companies are interested in how CCUS can be integrated with renewable energy sources. This includes using captured CO_2 for renewable fuel production or enhancing renewable energy storage.
- Educational and Training Services – with the growing importance of CCUS, there is a noticeable interest in offering educational programs and training workshops to upskill the workforce in CCUS-related technologies and practices.
- Safety and Environmental Monitoring – interest in developing services and technologies that ensure the safety of CCUS operations and monitor the environmental impact, including leakage detection and long-term containment monitoring.

4.6 Company Export Activity

This section explores the export activities of companies that responded to the online CCUS survey. 68.18% of companies are currently exporting their products or services, which would suggest strong international activity across the potential Scottish CCUS supply chain. However, a large majority of these companies generate less than 25% of the turnover from exports, which indicates that, while many companies are exporting, for most this still represents a smaller proportion of their total business. Only a small proportion of companies reported that they were generating more than 75% of turnover from exports, which shows that some companies heavily rely on exports, possibly due to the specialised nature of their offerings. An overwhelming 87.69% of respondents expressed interest in overseas CCUS opportunities, underscoring the global nature of the sector and that companies are proactively searching for international projects.

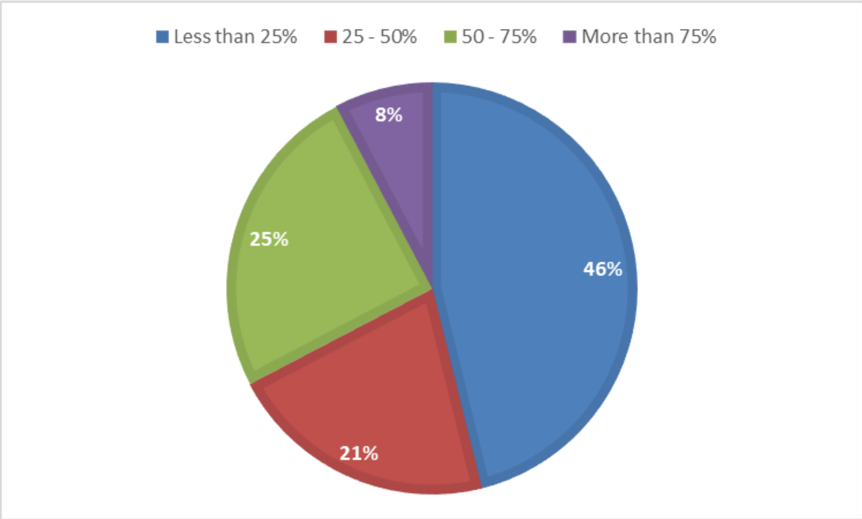


Figure 12: Percentage of Turnover Generated from Exports

4.7 Barriers and Challenges

Understanding the barriers and challenges faced by companies interested in the CCUS sector is essential for identifying what might impede the development and implementation of CCUS technologies and services. This analysis helps stakeholders prioritise efforts to overcome these obstacles, enhancing the sector's growth potential.

From the survey responses and one-to-one interviews, several key barriers to entry, or expansion within, the CCUS market have been identified. These barriers are broadly categorised into the following groups:

- Technical Challenges – the technical complexity involved in capturing, transporting, and storing CO_2 can be daunting, especially for smaller firms or those new to the sector. For many potential entrants, the perceived risk of investing in technologies that are not yet commercially proven is a significant deterrent.
- Economic and Funding Challenges – the capital-intensive nature of CCUS projects, especially for capture and storage infrastructure, is a major hurdle. The long-term profitability of CCUS projects, given current economic models, dependence on government support and market conditions, remains uncertain. Also, respondents consider access to public or private funding for CCUS projects to be difficult due to stringent criteria and competition for limited resources.
- Uncertain Market Demand – the first generation of CCUS project have been considerably delayed but are now showing some progress. Many of the potential supply chain companies see CCUS as a very uncertain and speculative market and, until the situation is more predictable, are continuing to focus on current markets.
- Regulatory and Policy Barriers – the evolving regulatory landscape can create uncertainties, complicating planning and investment decisions. There is a view that the lack of robust governmental incentives and support programs is discouraging investment in CCUS.
- Information and Awareness Issues – a lack of accessible, detailed information about CCUS technologies, processes, and market opportunities is hindering companies' ability to engage effectively with the emerging market. In particular, companies are unaware of emerging projects and, specifically, how to access project supply chains. Also, there is a perception (from interviews) that there is still a significant number of companies that could potentially supply into the CCUS market that are not fully aware of the environmental and business opportunities and benefits.

  “If you want the supply chain to be ready, as much as anything this is what we need—we need that engagement. We need the problem statements and timelines."

- Cultural and Operational Challenges – in industries accustomed to traditional processes (such as steel and cement fabrication), there can be cultural resistance to adopting new technologies like carbon capture.

Technical and economic challenges are the most frequently cited barriers, pointing to the need for enhanced R&D investment, subsidy schemes, and more aggressive government-led initiatives to reduce financial risk.

4.8 Market Entry Support Needs

Understanding the types of support that companies require to effectively engage with, and expand within, the CCUS sector is critical for tailoring strategies that facilitate growth and overcome existing barriers. This section of the report details the support needs expressed by companies, which can guide stakeholders in developing targeted assistance programs and policies.

The survey responses have highlighted several key areas where companies seek support to overcome the challenges associated with CCUS projects. These needs are categorised as follows:

- Financial Incentives – many companies are looking for direct financial support to help mitigate the high upfront costs associated with CCUS projects. Grants, subsidies, and other fiscal incentives can lower the entry barriers for smaller players. Further, implementing tax incentives such as tax credits or reduced rates for CCUS-related activities could encourage more companies to invest in this domain. Also, programmes that provide price guarantees or other forms of financial security can help companies navigate the economic uncertainties of CCUS projects.
- Information and Knowledge Sharing – companies are seeking detailed technical information and guidance on best practices for CCUS implementation. Also, access to current and projected market data, including regulatory changes, potential demand, and emerging technologies, is needed for strategic planning. Establishing training programs and workshops to upskill employees in CCUS technologies and operations can also help companies bridge the knowledge gap.
- Partnership and Networking Opportunities – facilitating platforms where businesses can form partnerships can enhance resource sharing and innovation. Encouraging more direct collaboration between the private sector and government agencies can help align regulatory and business goals. Further, linking companies with academic institutions can promote research and development in advanced CCUS technologies.
- Regulatory Assistance – companies need help understanding and complying with the complex regulatory environments that govern CCUS. Support with advocacy efforts to shape policies that are conducive to CCUS development is highly valued.

The diversity in support needs indicates a multifaceted approach will likely be required, addressing financial, informational, and relational aspects to effectively scale CCUS technologies. The call for enhanced partnership opportunities reflects the collaborative nature of CCUS projects and the need for shared expertise and resources.

4.9 Skills Support Needs

In this section will explore potential skills needs. Of the responses, the majority of companies (66%) reported to not experiencing difficulties in recruiting or retaining staff. However, companies did identify significant gaps in the availability of skilled professionals, which could potentially hinder the growth and efficiency of CCUS initiatives.

- Specialised Engineering Roles
  - Naval Architects and Specialist Process Engineers – critical for designing systems that are efficient and compliant with stringent regulatory standards.
  - Mechanical Engineers and Industrial Automation Engineers – essential for the development and maintenance of sophisticated machinery used in CCUS processes.
  - High Voltage Engineers and Electrical Engineers – particularly in demand due to the high-voltage requirements of many CCUS applications, especially when coupled to onshore/offshore wind projects.
- Technical and Trades Skills
  - Skilled Tradespeople – including welders, pipefitters, and electricians. These roles are crucial for the construction and maintenance of CCUS infrastructure.

  - Technicians, Chemical Engineers, and Scientists – specialising in catalysis and process development, these professionals are vital for optimising the chemical processes involved in carbon capture.
- Project Management and Quality Control
  - Project Managers and Quality Engineers - needed to oversee CCUS projects, ensuring they are delivered on time, within budget, and to the required quality standards.
  - Senior QHSE (Quality, Health, Safety, and Environment) Advisors and Trainers – important for ensuring compliance with health, safety, and environmental regulations, and for delivering training to new and existing staff.

In many cases the identified skills shortages are common to many other emerging low carbon domains, such as hydrogen.

4.10 Summary of the Market Potential and Industry Activity

The emerging CCUS industry in Scotland represents a diversification opportunity for existing suppliers within other, more established industrial sectors.

It is important to note that potential suppliers do not see CCUS as a new supply chain, but rather as a new market for existing supply chain capabilities.

The CCUS supply chain is, therefore, not starting from scratch but is being built upon the deep-rooted capabilities of industries like oil and gas, chemical manufacturing, and heavy engineering. These sectors already possess the advanced technical know-how, infrastructure, and logistical networks that are largely transferable to CCUS. For instance, the skills involved in managing high-pressure systems, complex fluid dynamics, and large-scale engineering projects in oil and gas are directly applicable to the deployment and operation of CCUS technologies.

"The development of CCUS activity offers an additional end use application for existing capability such as existing suppliers of process plant and equipment, pipeline systems and offshore engineering."

While the potential for CCUS could be substantial, it is important to recognise the nascent state of this market, which introduces a degree of uncertainty for potential suppliers. The CCUS projects currently underway or in planning stages, such as the Acorn Project, signify pioneering efforts. However, these projects are subject to long developmental timelines and a fluctuating policy landscape that can affect investment and commitment. For Scottish suppliers, this translates to a need for a cautious approach, balancing current stable market activities with potential future opportunities in CCUS.

The uncertain pace of CCUS project rollouts, compounded by the yet-to-be-fully defined regulatory and financial support frameworks, makes it difficult for suppliers to commit fully to transitioning or scaling up their capabilities for CCUS. This uncertainty is particularly challenging for smaller companies that may lack the financial resilience to invest in new technologies without assured returns.

The scale of opportunity for Scottish suppliers in the CCUS market is another aspect that has still to be fully defined. While Scotland has the potential to lead in this sector due to its existing industrial base and innovation capabilities, the actual size of the opportunity will depend, heavily, on national and international market developments. The integration of CCUS with other green technologies, such as hydrogen production and offshore wind, offers additional pathways for growth, but this is still in early developmental phases.

5 SWOT Analysis

This SWOT analysis is based on insights gathered from the industry consultation, together with the intelligence gathered during the desk-based research activities, to assess the current state of the CCUS sector in Scotland. It highlights the need for strategic interventions to address weaknesses and threats while capitalising on the strengths and emerging opportunities in the CCUS market

Strengths

Strong Industrial Base – the existing oil and gas infrastructure and expertise in Scotland provide a solid foundation for the development of the CCUS supply chain. This industrial base facilitates easy integration and repurposing for CCS activities, leveraging long-established skills and resources

Innovative Technologies and Capabilities – several Scottish companies possess advanced technologies, notably in monitoring subsea infrastructure. These capabilities are adaptable for CCS applications, providing cost-effective, long-term solutions for areas such as CO_2 leak monitoring. In addition, companies are developing innovative technologies specific to CCUS applications, such as alloy-based seals for carbon storage wells.

Collaborative Environment – the culture of collaboration among Scottish companies helps drive technological advancements and project execution. This collaborative spirit is crucial for the scale-up and commercialisation of CCUS technologies.

Government and Policy Engagement – companies express a proactive stance towards engaging with government policies and frameworks, which is crucial for navigating the CCUS sector's regulatory landscape. For instance, Wood Group's involvement in shaping policies underscores the strategic alignment with governmental goals.

Weaknesses

Lack of Available Time and Resources – many companies that have the potential to exploit CCUS opportunities are already fully occupied addressing needs in their current markets. As such, investment in an emerging, unproven market, where there is no clarity about the market development timescales or the scale of the opportunity, is not seen as a priority.

Support for Innovation – there is a recognised lack of support for innovative technology development within the CCUS sector. This deficiency hampers product development and limits the sector's growth potential. Companies like Isol8 have pointed out that, while there are guidelines on how to abandon wells, there is little guidance on constructing new ones for CO_2 injection, demonstrating that there is a gap in knowledge and support.

Well Integrity and Design Issues – the integrity of wells for CO_2 storage, particularly older wells not designed for CO_2 reinjection, poses a significant challenge. This includes handling extremely low temperatures that most current designs are not built to withstand. Innovations like advanced alloy seals are being developed to address these weaknesses, but progress is limited by current industry standards and practices.

Lack of Large-Scale Fabrication – there was consistent feedback from companies concerning the lack of large-scale fabrication capabilities in the Scotland and the UK. CCUS will require large pressure tanks and storage vessels, but the capability to fabricate at such large scale has been lost. This work will most likely be done elsewhere in Europe of further afield.

Funding and Financial Challenges – companies express significant concerns about funding, especially for novel CCUS technologies that do not yet have a proven market. The financial risk associated with scaling new technologies without clear, demonstrated revenue streams or government support is a substantial barrier

Regulatory and Market Barriers – there is considerable frustration with the slow pace of regulatory developments and policy support. This sluggishness creates uncertainty for companies looking to invest in, and deploy, CCUS technologies. The lack of clear timelines and guidelines for technology deployment and well construction and maintenance further exacerbate this issue.

Educational and Training Gaps – there is a need for more targeted education and training programs to prepare the workforce for the specific demands of the CCUS sector. Norway's significant investment in educational programs for CCUS contrasts sharply with the UK's approach, which has not been as systematic or supportive in developing a skilled workforce for this emerging industry.

Dependency on Existing Relationships – the reliance on established supplier lists and previous business relationships limits the involvement of new entrants and innovative technologies.

Opportunities

Development of Infrastructure – the expansion of CCUS in Scotland necessitates the development of dedicated infrastructure such as large CO_2 storage tanks and enhanced transport facilities. This build-out represents a significant investment opportunity and could stimulate local economic growth and job creation

Expansion of Export Markets – there is significant potential for Scotland to export CO_2 storage to regions beyond its borders, such as wider UK and Europe. This opportunity arises due to the anticipated surplus of CO_2 storage capacity compared to local needs, providing a chance to establish Scotland as a key player in the international CCUS markets.

Integration with Other Energy Sectors – CCUS development is closely linked with other energy transition initiatives such as offshore wind and green and blue hydrogen production. Scotland's strategic approach allows for the development of these technologies and maximising the utilisation of available resources.

Collaboration and Networking – there is a recognised need for enhanced collaboration and networking among stakeholders in the CCUS sector. Organising roundtable discussions and other collaborative forums, such as peer-to-peer networking, could help align efforts and drive the sector forward by connecting supply with demand more effectively.

Government and Policy Incentives – the establishment of investment zones and tax incentives by the UK and Scottish Governments could spur significant growth in the CCUS sector. These zones can provide favourable conditions for companies to invest in and develop green technologies, including green hydrogen production facilities, which could complement the CCUS infrastructure.

Training and Skill Development – as the infrastructure expands, there will be substantial opportunities for training and the creation of green jobs. Developing a skilled workforce is crucial for sustaining the growth of the CCUS sector and ensuring its operational success.

Threats

Regulatory Uncertainty and Complexity – the regulatory framework in the UK is often cited as a significant barrier to the growth of the CCUS sector. The complexity and uncertainty regarding permitting and regulation can deter investment and slow down project development, as seen with companies having difficulties in acquiring storage capacity due to restrictive policies.

Engagement in Early Project Phases – new and smaller companies in the CCUS sector face challenges in participating in early phases of flagship projects like Acorn, where entry barriers are high due to the dominance of established players and complex procurement strategies.

Dependence on International Suppliers – the Scottish CCUS sector's reliance on overseas suppliers for critical components and technology limits the development of a local supply chain and increases operational costs. This dependence could threaten the sustainability and competitiveness of the sector in the global market.

6 Case Studies

In the sections below we present three case studies as examples of current CCUS activity by Scottish companies. These case studies were developed with the assistance of the companies involved.

6.1 Sentinel Subsea

Company Overview

Sentinel Subsea (Sentinel), established in 2018, has developed unique technologies for the real-time passive monitoring of subsea infrastructure and equipment, including for offshore CCS projects. The company has an office and workshop facility in Aberdeen and currently employs 8 personnel. Sentinel's core business and ongoing innovation, uses a passive, trigger technology (a technology that responds to external stimuli, user inputs, or events), enabling continuous subsea monitoring without the need for active power or data communication. This unique approach ensures an easy to deploy monitoring system that is made for long-term operation in challenging underwater environments, while significantly reducing the carbon footprint associated with traditional monitoring methods. Developed and tested entirely in the UK, Sentinel's systems represent the culmination of a programme of innovation and collaboration. With early support from the Net Zero Technology Centre (NZTC), Scottish Enterprise and a partnership with Heriot-Watt University, Sentinel's innovative monitoring technologies have gained traction globally and have been deployed to support subsea oil and gas operations in Brazil, Australia, and the USA.

CCUS Involvement

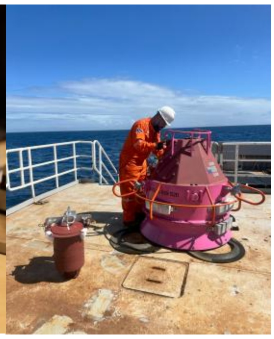
Beyond monitoring the integrity of subsea oil and gas infrastructure, passive systems are now being adapted to support CCS initiatives, providing long-term, continuous monitoring of offshore CO_2 storage sites for the early detection of potential leaks. Sentinel are involved in several high-profile CCS projects, globally, with their monitoring technologies being used to support robust measurement, monitoring, and verification (MMV) plans. Unlike other systems, which often involve higher costs and intermittent intervention, the technology provides cost-effective, continuous monitoring. By leveraging existing expertise, Sentinel have expanded their technology to meet the specific needs of CCS initiatives. Systems are uniquely designed to support long-term and scalable solutions, providing operators with the confidence to manage carbon storage sites effectively while meeting regulatory requirements

Key Challenges and Solutions

Timeline Ambiguity	Regulatory Framework	Established Testing Protocol	Company Reach
One of the primary challenges Sentinel faced when entering the CCS market was the ambiguity surrounding project timelines, with stakeholders often unable to provide concrete dates for key milestones. This uncertainty made it difficult to plan development, testing, and deployment effectively.	The regulatory landscape for CCS is still evolving, with many jurisdictions developing frameworks for measurement, monitoring, and verification (MMV). Sentinel proactively engaged with regulatory bodies and project operators to align its technology with emerging standards.	The lack of established testing standards for CCS monitoring systems presented a significant hurdle. Sentinel addressed this by drawing on its extensive experience in rigorous field trials for oil and gas applications.	As a relatively small company, Sentinel faced the challenge of competing with larger, more established players in the monitoring technology space.

Impact and Results

- **Business Growth** - Expanding from monitoring subsea oil and gas infrastructure to supporting CCS projects has opened new opportunities for Sentinel. By adapting its passive monitoring systems for CCS, Sentinel has solidified its position as a leader in subsea monitoring technologies.
- **Enhanced Monitoring Reliability** - Sentinel's passive systems ensure continuous and long-term monitoring of offshore CO_2 storage sites, providing early detection of potential leaks. This capability is critical for maintaining the integrity of CCS projects and supporting operators' MMV plans.
- **Cost-Effective Solutions** - By offering continuous monitoring without requiring active power or frequent intervention, Sentinel has significantly reduced operational costs for CCS projects, addressing a major challenge in the sector.
- **Supportive Innovation Ecosystem** - Sentinel's collaboration with the Net Zero Technology Centre (NZTC), Scottish Enterprise, and Heriot-Watt University highlights the importance of partnerships in fostering innovation and advancing Scotland's CCS capabilities.
- **Competitive Edge for Scotland** - Sentinel's success in exporting its technology globally underscores Scotland's potential to lead in the development and deployment of cutting-edge CCUS technologies, boosting its international reputation.



Summary

Sentinel's proactive approach to overcoming challenges—such as regulatory ambiguity and the absence of established testing standards—positions the company as proactively engaged in innovation and adaptation for the growing CCS market.

6.2 The Carbon Removers

Company Overview

The Carbon Removers capture, remove and sequester biogenic CO_2. Founded by brothers Ed and Richard Nimmons, the team combines practical, real-world experience from sectors such as distilling, biomethane, CO_2 capture, transport, utilisation, storage and engineered carbon removals. Diverse expertise underpins their innovative and agile approach to simplifying the complexities of the CCUS sector by offering end-to-end solutions, covering installation, capture, transport, storage and carbon removal credit generation. CO_2 capture is focused on biogenic sources such as distilleries and biogas sites fed with farm waste. Captured biogenic CO_2 is either utilised (e.g. as dry ice or liquid CO_2 for the food and drink industry or as feedstock for future e-fuels projects), or sequestered permanently (e.g. through carbonation processes or storage in depleted oil and gas fields), which generates high-quality, permanent carbon removal credits. Primarily working with CO_2 sources that already use the underlying biomass for a primary product, and previously vented the CO_2 as a waste product, ensures no additional environmental pressure or competition with food production.

CCUS Involvement

The Carbon Removers has developed its proprietary Nimmons900 module, a compact, efficient, and mobile CO_2 capture technology designed for fermentation sources. The system is suitable for smaller plants with limited space, integrates seamlessly with existing processes, and minimises environmental disruption. Cryogenic ISO-tanks are used for non-pipeline CO_2 transport, emphasising safety, economic viability, and low environmental impact based on lifecycle analysis.

CO2 Utilisation: Dry Ice

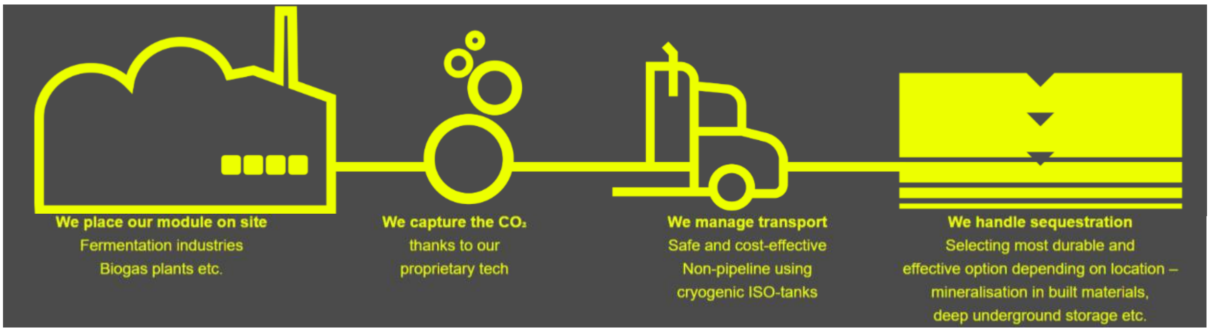
Captures biogenic CO2 from a Scottish biomethane facility and a whisky distillery, and converts it into dry ice for the pharmaceutical industry and other industrial users in Scotland and the North of England, through the wholesale partner Nippon Gases. This project has been successfully operating since 2021, leveraging the founders' extensive experience from their previous global dry ice blasting joint venture with Air Liquide. This expertise has enabled the team to develop deep technical understanding of CO2 capture and liquefaction, ISO-tank transport, and value chain economics. Operating without subsidies (beyond initial grant funding), this project is sustained by the merchant price of dry ice, catering to a small but reliable niche market.

Permanent CO2 Removal in UK through Carbonated Building Material

Captures biogenic CO2 from a Scottish whisky distillery and English biomethane facilities, and permanently stores it in a carbonated building material – a green aggregate used in for example, road building. While not recognised as "sequestration" by the EU or UK CCS regulations, this form of permanent storage of biogenic CO2 is recognised by leading voluntary carbon standards, allowing the issue of high quality carbon removal credits. This project, which has been operational since July 2024, also operates without subsidies and relies on merchant customers for carbon credits. Its current customer list includes Autotrader, British Airways, NatWest Group and multiple European corporations.

Permanent CO2 Removal in Denmark through Geological Sequestration

The Carbon Removers are currently preparing two projects in Denmark, both creating permanent carbon removal based on capture of biogenic CO2 and geological sequestration in a depleted gas field operated by INEOS (Project Greensand).
One initial project will capture ca. 5,000 tons of biogenic CO2 from a Danish biomethane facility and sequester the CO2 in Project Greensand. This is supported by a full-value-chain subsidy from the Danish Energy Agency's "Negative Emissions from CCS fund", which The Carbon Removers were awarded in a competitive, EU-wide tender in 2024. Its negative emission effects will be used by Denmark to achieve their national net zero and net negative roadmap.
A second project will capture ca. 50,000 tons of biogenic CO2 from a mix of Danish biomethane facilities and other biogenic CO2 sources from adjacent countries. This project will rely on the sale of unsubsidised carbon removal credits to European corporates.
Both these projects are scheduled to begin operations in Q2 2026 and are currently preparing the required modular capture units and permitting processes.



Key Challenges and Solutions

UK-Based Supply Chain for Components

The CO_2 capture sector lacks a UK supply chain for key components like compressors, refrigeration units, and electrical control panels, which are typically sourced from Europe. Assembly is handled by European or US OEMs, despite relevant skills existing in the UK's oil and gas sector. While The Carbon Removers leverage their existing capabilities, a coordinated approach is needed to strengthen domestic supply chains.

Engagement with CCUS Utilisation

CCUS can focus on large-scale CCS, leaving utilisation underdeveloped and under-represented. The Carbon Removers' early involvement provided a competitive edge but has also made visibility and supply chain development challenging. Policy, shaped by O&G players, can overlook expertise in shipping, import terminals, and non-pipeline transport, gained from supplying the UK with CCU CO2. While CCU has established standards for liquid CO_2 (acceptant pollutant levels, measurement processes, standard pressure ranges, etc.), CCS projects are developing new project-by-project standards.

Lack of Policy Clarity

Frequent policy shifts hinder long-term planning and investment. Legislation favours large-scale CCS, restricting smaller merchant projects from sequestration access or inhibiting merchant projects from straddling the boundaries between CCS and CCU (e.g. sharing assets between CCS project and e-fuels projects). Clear, consistent policies and regulatory changes are needed to attract investment and support sector growth.

Permitting Challenges

Unclear classification of CO_2, as waste or a value-added product, is a grey area caused by inconsistencies between the European Waste Directive and European CCS Directive. Transporting CO_2 must also align with CCU industry standards such as those for liquefied CO2, food grade CO2, and dry ice. Clarifying permit requirements across waste and CCS directives (already done by countries such as Denmark) would help accelerate project development.

Impacts and Results

- Developed multiple CCU projects in UK, monetising biogenic CO_2 which would otherwise have been wasted and re-deploying skills and staff from the oil and gas industry, the farming industry, and the industrial gas engineering industry.
- Partnered with emerging CCS projects such as Greensand, advancing full-scale CO_2 storage in Europe.
- Pioneered multiple utilisation streams for captured CO_2, including its conversion into building materials and food industry applications.
- Established a groundbreaking multi-year agreement with British Airways to supply carbon credits, showcasing the scalability and commercial potential of CCUS technologies.
- Leveraged over a decade of experience in reusing CO_2 through dry ice production and other food solutions, reinforcing their reputation as a leader in sustainable practices.

Summary

Early engagement across the CCUS value chain is key to securing a foothold in this emerging industry. Developing small, modular projects for niche markets enables early revenue generation, attracts private investment sooner, and provides opportunities to test the full supply chain. These initial supply chains create valuable insights, helping the market align synergies and leverage regional strengths—such as Scotland's industrial capabilities—to support the sector's long-term growth at scale.

6.3 Well-Safe Solutions

Company Overview

Well-Safe Solutions, with its headquarters in Aberdeen, Scotland, is a leading provider of comprehensive well decommissioning services, specialised in assessing legacy wells for suitability in CCS projects. With a focus on the energy transition sector, Well-Safe Solutions leverages its multidisciplinary expertise encompassing geophysical, petrophysical, geological, reservoir, and geomechanics specialisations.

CCUS Involvement

The Viking CCS project, that aims to establish a CO_2 transport and storage network across the Humber in Northern England, required a detailed evaluation of the integrity and suitability of abandoned wells in the Southern North Sea for CO_2 storage. Given that most wells in the license area were previously abandoned, with only a few remaining operational, a thorough reassessment was crucial.

Well-Safe Solutions conducted a desktop study to evaluate these legacy wells, adhering to their Well Decommissioning Delivery Process (WDDP). This process integrates multiple disciplines and is backed by the company's well engineering resources. The assessment focused on understanding the geological characteristics and history of each well, particularly analysing the barriers within the annuli and the internal bore to ensure their adequacy for CO_2 containment.

Key facts:

- Legacy wells examined and assessed
- Southern North Sea project
- Desktop study carried out in line with industry best practice
- Part of large-scale energy transition project
- Project utilised Well-Safe Solutions' well evaluation specialism and WDDP

Supporting your energy transition projects

Project Challenges and Solutions

Scope Definition and Subsurface Analysis

The project began with defining the scope through detailed analysis of subsurface elements, particularly the Rotliegendes Leman sandstone, the intended CO2 storage formation. Key zones of flow potential (ZOFP), cap rock, and minimum safe abandonment depths (MSAD) were identified.

Data Mining and Barrier Research

The second stage involved extensive data mining to assess the well elements critical to ensuring CO2 containment, focusing on cap rock integrity and the placement of rock-to-rock barriers.

Detailed Well Assessment

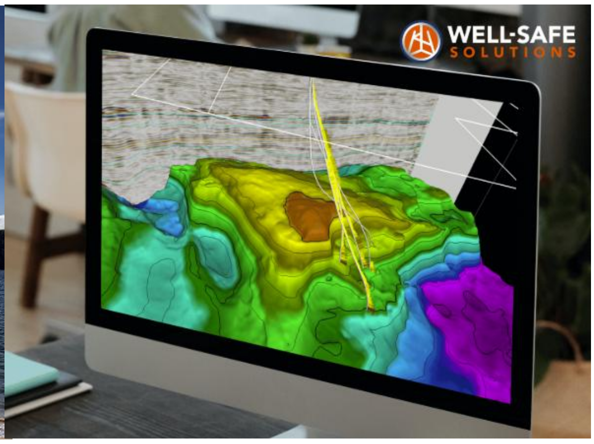
Each well underwent a meticulous review, focusing on internal and annular wellbore elements. Factors such as the base of the cement barrier, the volume of cement injected, its verification, and the analysis of annular isolation using abandonment data and cement bond logs were scrutinised.

Quantitative Scoring and Analysis

The final stage quantified the gathered data, assigning scores to internal cement quality, cap rock integrity, and annular cement conditions to derive a conservative overall well integrity score.

Impacts and Results

- **Assessment**: Well-Safe Solutions applied a rigorous and holistic approach to deliver a reliable and detailed evaluation of legacy wells for Harbour Energy, ensuring a comprehensive understanding of their condition.
- **Business Growth**: The project's success reinforced Well-Safe Solutions' reputation and capability in managing large-scale energy transition projects, demonstrating their expertise in well decommissioning and repurposing.
- **Regulatory Alignment**: The work was conducted in full compliance with Offshore Energies UK guidelines for Well Decommissioning and CO_2 Storage, ensuring adherence to industry best practices and legal requirements.
- **Risk Mitigation**: Through detailed engineering assessments, Well-Safe Solutions effectively identified and mitigated potential risks associated with reusing old wells for CCS, enhancing project feasibility.
- **Environmental Compliance**: By prioritising environmental safety and regulatory adherence, the project ensured that repurposed wells met stringent environmental protection standards, supporting the long-term sustainability of CCS initiatives.



Summary

Well-Safe Solutions' expertise and systematic approach to legacy well assessment provide a crucial service in the CCS industry, helping to ensure that old wells can be safely repurposed for CO_2 storage. This project highlights the company's role in facilitating the energy transition by enhancing the integrity and viability of CCS infrastructure.

7 Conclusions and Recommendations

Scotland's rich heritage in oil and gas and the process industries provides a solid foundation for development of the emerging CCUS industry. The existing infrastructure and technical expertise can be repurposed to support growth in the CCUS supply chain. There are several Scottish companies at the forefront of developing cutting-edge technologies and processes that enhance the efficiency and viability of CCUS operations. This is supported by a robust tradition of engineering excellence.

Our analysis shows that Scotland has strong capabilities in key areas of the CCUS supply chain, namely in control and instrumentation, pumps and valves, subsea engineering and operations and maintenance, as well as in professional services to support CCUS developments.

While Scotland has strong capabilities, it faces stiff competition from countries with more advanced CCUS research and development initiatives and better integration of academic, industrial, and governmental efforts. Also, current policies and regulations lack the clarity required for companies to commit fully to CCUS, leading to hesitation and potential delays in project deployment.

To capitalise on the opportunities and mitigate the challenges within the CCUS sector, the following strategic recommendations are proposed:

1. Advocate for more robust government policies that provide clear, consistent support for CCUS initiatives. This includes simplifying the regulatory framework for project approvals and enhancing financial incentives for companies investing in CCUS technologies.
2. Encourage the integration of CCUS projects with adjacent energy transition technologies like hydrogen production and offshore wind, leveraging synergies to enhance efficiency and cost-effectiveness.
3. Increase funding and support for CCUS-specific research and development initiatives to address technological gaps, particularly in the areas of capture and storage reliability and efficiency.
4. Encourage Scottish companies to identify opportunities to build on their current capabilities to engage in international CCUS projects and export their technologies and expertise. This not only opens new markets but also positions Scotland as a global leader in CCUS technology.
5. Develop platforms for knowledge sharing and collaboration among CCUS stakeholders to align efforts and share best practices. This could include setting up a series of regular, opportunity specific industry roundtables, workshops, and joint ventures.
6. Develop targeted training and educational programs to build a skilled workforce that is well-prepared to meet the demands of the emerging CCUS market. This includes specialised training in CCUS technologies and regulatory compliance.

By implementing these recommendations, Scotland can enhance its competitiveness in the CCUS sector, contribute to global carbon reduction efforts, and foster economic growth through green technology advancements.

Appendices

Appendix A – Stakeholder Consultation

Altrad Babcock

Carbon Circle

Carbon Removers

Clean Carbon

Glacier Energy

Howco

Howden

IMRANDD

Ineos

Isol8

Peterhead Ports

Sentinel Subsea

Storegga

TUV

Well Safe Solutions

Wood Group

Appendix B – Online Survey Responses

AEL CCS	NOV ReedHycalog
AFS Technologies Ltd	OSI Renewables
Apollo Engineering Consultants	Oxford Flow
AquaTerra Group Ltd	Pepperl Fuchs
Astrimar	Peterhead Port Authority
ATV Spa	Premier Technical Ltd
Blue Gentoo	Project Pipeline Supply Limited
CalaChem Ltd	QHSE Aberdeen Limited
CCU International	Redwing UK
Chiyoda Corporation	Resolute Energy Solutions
CMS Cameron	Roemex Ltd
Dales Engineering Services	Ross-Shire Engineering
Dales Marine Services	RSL NDT
Draeger Safety	SeaFlo Consultancy
Drochaid Research Services	Sentinel Subsea
Emerson Process Management	SFF Services Ltd
Exceed Torridon	StoreCO2
Fennex	Subsea Commercial Services Ltd
Freudenberg Flow Technologies	Sweco UK
Fraserburgh Harbour Commissioners	Sybear Consultants
FTV Proclad International	Tenaris Global Services
Fugro	Thistle Occupational Health
Gilchrist Steels	Turner and Townsend
Global Maritime	TUV SUD
Howco Group	Vysus Group
IKM Testing UK Ltd	Wizzair Group
Infinity	Weatherford
Interocean Marine Services	Whittaker Engineering
J&S Subsea Limited	Wincanton
John Bell Pipeline Equipment Company Ltd	Wood PLC
LFH Fluid Control Limited	Woollard and Henry
Metron Group	ZLX Ltd
NOV Process Systems	

Business Growth

Economic Development

Technology Commercialisation

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