This report was commissioned by the Industrial Decarbonisation Challenge

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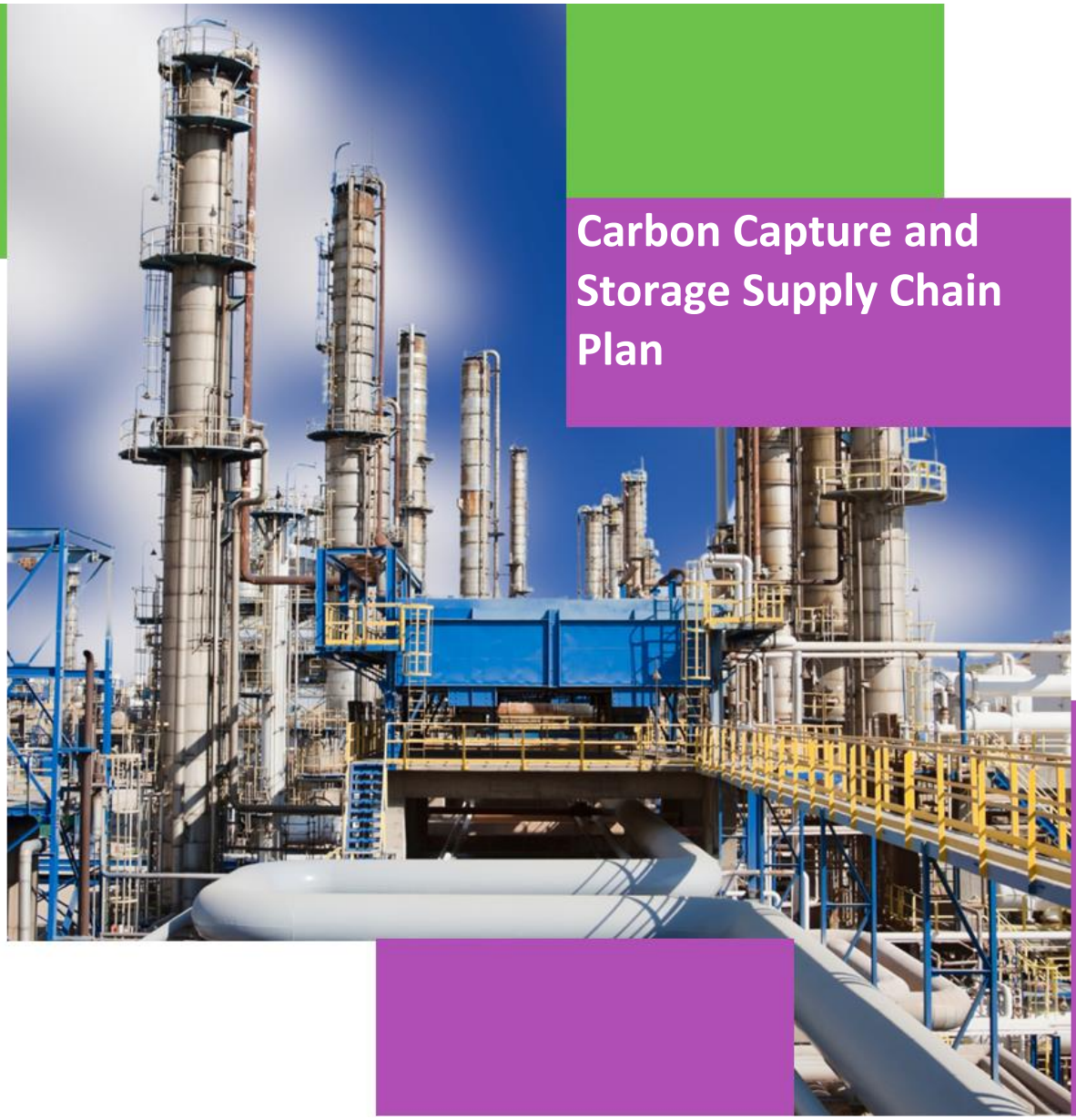
Industrial Decarbonisation



Carbon Capture and Storage Supply Chain Plan

Published: September 2024

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1 Executive Summary

This report has been commissioned as part of the UK's Industrial Decarbonisation Challenge (IDC), a government-supported initiative to accelerate the decarbonisation of industrial clusters nationwide. The IDC is a crucial element of the UK's broader strategy to achieve Net Zero emissions by 2050. Carbon Capture and Storage (CCS) is a critical technology to mitigate industrial carbon emissions.

1.1 Purpose of the Report

The primary aim of this report is to evaluate the current readiness of the UK's CCS supply chain from the Developer's perspective. It also identified challenges that the developers perceived and offered strategic recommendations to enhance the capacity and capabilities of the supply chain, which the developers would welcome being implemented. This evaluation is crucial for ensuring the UK can meet its ambitious CCS deployment targets, as outlined in the government's Net Zero Strategy, while also maximising the country's economic and social benefits. The findings and recommendations presented in this report are based on a comprehensive analysis of existing literature, stakeholder engagements, and industry workshops.

1.2 Key Findings

Supply Chain Readiness: The UK's CCS supply chain shows significant potential, yet it faces considerable challenges, particularly in manufacturing capacity, workforce availability, and infrastructure development. The UK already has considerable capacity in sectors such as construction and engineering, which can be leveraged to meet the growing demands of CCS projects. However, targeted investment is needed to scale up in areas like large-scale component manufacturing. Strategic coordination and investment are essential to bridge these gaps.

Strategic Gaps: There is a pressing need to bolster domestic capabilities in critical areas, such as the production of large-scale pressure vessels and proprietary amines. The UK's reliance on international suppliers for these critical components introduces cost, project timeline, and supply chain security risks.

Workforce Challenges: The CCS sector is projected to generate many jobs, particularly during project construction and operational phases. However, specialised roles have substantial skills gap, including welders, engineers, and technicians. Addressing this gap is imperative for the UK to meet its CCS deployment targets and to ensure that the sector can sustain its growth over the long term.

1.3 Strategic Recommendations:

a) Ensure CCS remains a core component of any new National Industrial Strategy and enabling the 2030 Clean Power Mission:

- **Objective:** Embed CCS as a central pillar of a comprehensive National Industrial Strategy, aligned with the UK's 2030 Clean Power Mission (and beyond). This will give the supply chain the confidence to invest and expand, enabling mobilisation to meet CCS project timelines.
- **Detail:** CCS should be embedded in the UK's overarching industrial strategy, ensuring alignment with other key clean energy sectors such as offshore wind and hydrogen. By positioning CCS in support of the 2030 Clean Power Mission, the government can provide clear signals to the supply chain, strengthening investment flows and supply chain capabilities. A funding body akin to the Offshore Wind Growth Partnership could be pivotal in mobilising CCS supply chain investment, ensuring readiness for large-scale deployment.

b) Enhance Investment in Supply Chain Capabilities:

- **Objective:** Reduce reliance on international suppliers by bolstering domestic production of critical CCS components, and ensuring the supply chain is as low-carbon as possible.
- **Detail:** The government should incentivise the establishment of new manufacturing facilities for large-scale CCS components, such as pressure vessels, and the expansion of existing chemical production capacities, particularly for proprietary amines. Early investment in supply chain firms is essential to prepare them for future contracts, particularly in sustainable and low-carbon manufacturing and construction. This approach will enhance the UK's supply chain resilience and position the country as a leader in the global CCS market.

c) Address Workforce Development Needs:

- **Objective:** Bridge the skills gap within the CCS sector to ensure a sustainable workforce supporting the industry's growth.
- **Detail:** A targeted approach is required to develop the necessary skills within the workforce, including specialised training programs and partnerships with educational institutions. These programs should focus on critical roles such as engineering, welding, and plant operations and promote careers in the CCS sector to attract people who are seeking roles which have an impact on climate change. Promoting UK-based employment should also be central to the workforce development strategy, ensuring job creation aligns with national goals.

d) Position the UK as a Global Leader in CCS Technology and Services:

- **Objective:** Develop exportable capabilities in CCS technologies and services to strengthen the UK's global market position and support decarbonisation on a global scale.
- **Detail:** By leveraging its offshore expertise and advancing capabilities in design, instrumentation and monitoring, the UK can become a global hub for CCS technology. This will support domestic supply chain growth and create opportunities for exporting UK expertise to international markets.

e) Further Develop Industrial Clusters:

- **Objective:** Develop the industrial clusters into wider regional clusters concentrating on CCS activities and supporting local supply chain development and expertise.
- **Detail:** These Clusters could serve as focal points for CCS development, bringing together research institutions, industry players, and government agencies. They would facilitate knowledge sharing, provide infrastructure, and enable economies of scale, making it easier to implement CCS projects. Industrial Clusters could support the local supply chains by leveraging local expertise and infrastructure, so they are better positioned to support the CCS Developers.

1.4 Implementation Summary:

The successful implementation of these recommendations will require a phased approach. Immediate actions should include policy adjustments and development, funding allocations, and workforce development initiatives. In the medium to long term, efforts should be directed towards:

- building infrastructure regionally to support supply chain firms to operate,
- enhancing supply chain capabilities by investing in supply chain firms so they are better capable of supporting CCS, and
- strengthening international collaboration so that supply chain firms benefit from international support, e.g. designs, and so they can also sell to international markets.

Continuous coordination among government agencies, industry stakeholders, and academic institutions will be crucial to achieving the ambitious CCS deployment targets and ensuring the sector's sustainable growth and the Developers' ability to deliver CCS in the most value-for-money way.

Successfully implementing the recommendations outlined in this report requires a structured and phased approach, ensuring that both short-term and long term goals are met efficiently and effectively. All changes and initiatives must be conducted in a controlled manner with sufficient engagement with the Developers. The following phases are proposed:

1.4.1 Immediate Actions (0-12 months)

- **Policy Adjustments and Funding Allocations:** To support Developers, the government should prioritise policy adjustments that streamline regulatory processes and allocate targeted funding to key areas such as infrastructure development and workforce training. Immediate funding should focus on de-risking early-stage projects and supporting SMEs within the CCS supply chain to ensure they are ready for upcoming contract opportunities.

  Stakeholder Engagement and Coordination: Establish a strategic Industry Leadership Forum comprising government, industry, and academia representatives to engage with government bodies to shape and influence relevant policy areas, begin development of a UK CCS supply chain strategy and plan for its implementation. This group should facilitate ongoing stakeholder engagement to ensure alignment and collaboration across sectors. This alignment will aid supply chain firms as it removes uncertainty when developing their products. It also gives them a larger future market, making product development more cost-effective.

1.4.2 Medium-Term Actions (1-5 years)

- **Infrastructure Development:** Invest in critical infrastructure, including transport networks, storage facilities, and manufacturing supply chains, to support the scaling of CCS projects. This phase could also see the development of regional centres of excellence that focus on specific aspects of the CCS supply chain, such as materials production or technology innovation. This will aid contractors and developers in delivering CCS more efficiently in the future.
- **Workforce Development:** Launch specialised training programs in partnership with educational institutions to address the skills gap in the CCS sector. These programs should target roles critical to the construction and operation of CCS projects, ensuring a steady pipeline of qualified workers for the Developers to employ.
- **Promotion of UK Content:** Implement measures to maximise UK content in CCS projects, including incentives for companies that source materials and services domestically, particularly where a positive impact on carbon reduction can be demonstrated. This will help build a resilient local supply chain and create job opportunities nationwide. It will also allow developers to achieve their voluntary 50% UK Content targets.

1.4.3 Long-Term Actions (5-10 years)

- **Expansion of Domestic Capabilities:** Focus on expanding domestic manufacturing capabilities for key CCS components, such as pressure vessels and chemical absorbers, to reduce reliance on imports and enhance supply chain security. This will allow developers to purchase from UK suppliers in the future.

- **Global Competitiveness and Export Strategy:** Develop and implement a strategy to position the UK as a global CCS technology and services leader. This should include the promotion of UK-designed CCS solutions in international markets and the establishment of export-oriented partnerships.
- **Continuous Monitoring and Adaptation:** Establish a robust monitoring and evaluation framework to track the progress of implementing the CCS Supply Chain plan. This framework should include key performance indicators (KPIs) that measure the effectiveness of investments, the growth of the domestic supply chain, and the success of workforce development initiatives. This needs to be implemented in collaboration with Developers to obtain the data efficiently.

These phased actions are designed to ensure that the UK's CCS supply chain evolves in tandem with the growing demands of the sector, thereby supporting the country's broader decarbonisation goals. This will also help the UK's CCS sector compete for investment, talent, and components in an increasingly competitive global market.

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2 Introduction

2.1 Purpose and Scope of the Report

The United Kingdom has committed to achieving Net Zero greenhouse gas emissions by 2050, a goal that requires a transformation across all sectors of the economy, particularly in heavy industry. As part of this national effort, the Industrial Decarbonisation Challenge (IDC) was launched to accelerate the decarbonisation of the UK's most carbon-intensive industrial clusters. This report, commissioned under the IDC, focuses specifically on the Developers' view of the supply chain for Carbon Capture and Storage (CCS) ability to support them in delivering CCS quickly and efficiently so that this critical technology for mitigating industrial emissions can be delivered as soon as possible to help the UK reach Net Zero.

The primary purpose of this report is to assess the current state of the UK's CCS supply chain, identifying its strengths, weaknesses, opportunities, and threats. By evaluating the supply chain's readiness, this report aims to provide strategic recommendations that will enhance its capacity and capabilities so that Developers are supported as effectively as possible in delivering their CCS projects. These recommendations are designed to ensure that the UK is prepared to meet its CCS deployment targets and positioned to become a global leader in CCS technology and services. The scope of this report encompasses the entire CCS value chain, from the manufacturing of capture equipment to the storage of CO_2. It considers the roles of both public and private stakeholders in achieving the necessary scale and efficiency.

2.2 Importance of CCS for the UK's Net Zero Goals

CCS is a pivotal technology in the UK's strategy to reduce carbon emissions from energy-intensive sectors, such as cement, steel, and chemicals. These industries contribute significantly to the UK's overall greenhouse gas emissions. While improvements in energy efficiency and the adoption of renewable energy sources are crucial, they are insufficient to achieve the deep emissions cuts required. CCS provides a solution by capturing CO_2 emissions at source, transporting them via pipelines or ships, and securely storing them underground in geological formations, such as depleted oil and gas fields or saline aquifers.

The integration of CCS into the UK's industrial clusters offers multiple benefits. Firstly, it enables the continued operation of industries vital to the economy but difficult to decarbonise through other means. Secondly, it provides a pathway for negative emissions when combined with bioenergy (BECCS), further supporting the UK's Net Zero ambitions. Finally, CCS can help safeguard existing industries' jobs while creating new employment opportunities in the emerging green economy. However, realising these benefits requires overcoming significant challenges, particularly in developing a robust and resilient supply chain.

2.3 Overview of the UK CCS Landscape and Supply Chain Challenges

The CCS landscape in the UK is characterised by a strong commitment from both the government and industry. The government has set ambitious targets to capture and store 20-30 million tonnes of CO_2 per year by 2030, with significant investment already allocated to support the development of CCS infrastructure. Several CCS projects are currently in various stages of development, particularly within the industrial clusters of Teesside, Humberside, Scotland, South Wales and the North West, which have been identified as key areas for early deployment.

Despite this momentum, the UK's CCS supply chain faces several challenges that must be addressed to meet these targets. One of the most pressing issues is the gap in manufacturing and infrastructure capabilities. The scale-up required for CCS deployment necessitates the production of large, specialised components such as pressure vessels, compressors, and storage tanks and the construction of extensive CO_2 transport networks. Currently, the UK lacks sufficient domestic capacity to meet this demand, relying heavily on imports for critical components, which introduces risks related to supply chain security, cost, and project timelines.

In addition to manufacturing challenges, there is a significant shortage of skilled workers in the CCS sector. Key roles, including engineers, welders, and technicians, are in high demand but short supply, and the existing workforce is not adequately equipped to handle the specific requirements of CCS projects. This skills gap poses a substantial barrier to the timely and efficient deployment of CCS technologies.

Financial and investment barriers also present a challenge. The high upfront costs associated with CCS and uncertainties around long-term revenue streams and policy support make it difficult to attract necessary investments. While government funding has been available, private investment is crucial for growth. However, investors are often hesitant due to the perceived risks of new technologies, regulatory uncertainties, and the long payback periods typical of large-scale CCS projects. This investor hesitance precludes new supply chain firms from being able to enter the CCS sector, even if they have similar experience in nearby sectors. This reduces the number of suppliers that Developers can engage.

2.4 Methodology and Approach

The findings and recommendations presented in this report result from a comprehensive and multi-faceted research methodology. This approach combines qualitative and quantitative research to provide a holistic view of the UK's CCS supply chain.

An extensive literature review was conducted, analysing existing research, government publications, and industry reports. This review provided a foundational understanding of the current state of the CCS supply chain, identified existing gaps, and highlighted areas where further investigation is needed.

Secondly, the report draws on insights gathered through stakeholder engagement. This involved consultations with various stakeholders, including industry, government representatives, academics, and supply chain experts. These engagements were crucial for validating the findings of the literature review, understanding the practical challenges faced by industry players, and exploring potential solutions. Due to the significant engagement with Developers in the Clusters,

there is a strong emphasis on their perspective. This has been supplemented with additional feedback from Tier 1 Engineering, Procurement and Construction (EPC) Contractors, other supply chain organisations and stakeholders.

Workshops and focus groups were also held as part of the research process. These sessions brought together stakeholders to discuss specific issues related to the CCS supply chain, such as workforce development, manufacturing capacity, and investment strategies. The collaborative nature of these workshops allowed for generating innovative ideas and identifying best practices that could be applied across the sector.

Finally, data analysis played a key role in the research methodology. Both qualitative and quantitative data were collected and analysed to assess the capacity and capabilities of the UK's CCS supply chain. This analysis included a detailed examination of the supply chain's strengths, weaknesses, opportunities, and threats, providing a robust basis for the strategic recommendations presented in this report.

3 Current State of the UK CCS Supply Chain

3.1 Overview of CCS Deployment Projects

The United Kingdom has made significant strides in advancing CCS projects, particularly in industrial clusters, which have been identified as critical areas for early deployment due to their high concentration of industrial carbon emissions and proximity to suitable offshore geological storage sites. The government has set ambitious targets to capture and store between 20 and 30 million tonnes of carbon dioxide emissions annually by 2030.

Key CCS Projects include:

- **The Acorn Project (Scotland):** Acorn is focused on repurposing existing gas pipelines to transport CO_2 from industrial emitters in Scotland and Northern England to offshore storage sites. The project is strategically located at the St Fergus Gas Terminal, which has the potential to become a hub for CCS in the UK.
- **Net Zero Teesside:** This project aims to develop the world's first fully integrated gas-fired power station with CCS technology. It is part of the broader Teesside industrial cluster, which hosts a range of industries from chemicals to energy. The project plans to capture up to 10 million tonnes of CO_2 annually by the late 2020s.
- **Hynet North West:** Aiming to decarbonise heavy industry across the North West of England and North Wales, Hynet combines CCS with hydrogen production. The project intends to capture and store around 10 million tonnes of CO_2 annually by 2030, significantly contributing to the UK's decarbonisation targets.
- **Humber Zero:** Located in the Humber, this carbon capture project focusses on carbon capture from a CHP plant and a refinery and the project aims to store up to 10 million tonnes of CO_2 per year by 2030. Storage will be in the Viking depleted gas field.
- The IDC programme supported two further projects that are not yet part of the Track process, Zero Carbon Humber (which, together with Teesside, forms the East Coast Cluster) and South Wales Industrial Cluster. The South Wales Industrial Cluster is different from the other industrial clusters in that it does not have a carbon storage facility, so the captured carbon will need to be moved by ship to one of the other clusters for sequestration.

These six projects are central to the UK's CCS strategy, demonstrating the country's commitment to deploying CCS at scale. However, they also highlight the significant demand that will be placed on the domestic supply chain in terms of infrastructure, technology, and skilled labour.

3.2 Analysis of Current Supply Chain Readiness

While the UK's CCS ambitions are well-defined, the current state of the supply chain presents both opportunities and challenges. The ability to scale up CCS deployment will depend heavily on the readiness and resilience of the supply chain, which must be capable of delivering the necessary components, skills, and services at the right time and scale. The planned UK capture

projects are significant, with the transport and storage elements also very substantial. These first-of-a-kind projects are very complex, so although there is a lot of opportunity for UK-based supply chains, it is difficult for them to win contracts unless they have a strong CCS track record in the area where their product operates.

3.2.1 Physical Content: Components, Devices, and Services

Due to the scale of CCS projects and their first-of-a-kind nature, the requirements of the CCS supply chain are highly complex, encompassing a wide range of components, devices, and services required for capturing, transporting, and storing CO_2. Key components include capture equipment such as absorbers and compressors, transportation infrastructure like pipelines and ships, and storage solutions including injection wells and monitoring systems.

Currently, the UK has a strong foundation in certain areas of the CCS supply chain, particularly in engineering services, project management, and the design of offshore infrastructure, drawing on its expertise from the oil and gas sector. However, there are significant gaps in the domestic manufacturing of large-scale components. For instance, the production of pressure vessels, large compressors, and specific chemical absorbers is limited, leading to a reliance on imports. This dependency increases costs and introduces supply chain risks, particularly in the context of global supply chain disruptions.

Integrating these components into functioning CCS systems requires specialised knowledge and skills, which are currently in short supply within the UK. The lack of a fully integrated domestic supply chain for CCS means that projects must rely on international suppliers, which can delay project timelines and increase vulnerability to geopolitical risks.

There is an intrinsic risk that the world-renowned UK offshore engineering supply chain may no longer be available to CCS Developers to contract with due to the reduction in oil and gas exploration before CCS requires the capability. This reduces the options and choices Developers will have in the future.

3.2.2 Workforce Availability and Skills Gaps

The CCS sector is poised to create numerous jobs, particularly in engineering, construction, and operations. However, the industry is already facing a significant skills shortage, which could hinder the timely deployment of projects. The existing workforce in the energy sector, while experienced, is not fully equipped with the specific skills required for CCS technologies. For instance, expertise in areas such as CO_2 compression, pipeline installation, and subsurface storage is currently limited.

The successful deployment of CCS technologies relies on the availability of physical components and a skilled workforce capable of designing, building, and operating these systems. The UK's current workforce in the CCS sector is relatively small, with expertise concentrated in a few specialised areas. This concentration is partly due to the nascent stage of CCS deployment in the UK and the high level of technical expertise required.

A significant skills gap exists in key areas such as engineering, welding, and plant operations. Many of these roles require specific training and experience, often gained in related industries such as oil and gas or chemical processing. However, transitioning workers from these sectors to CCS is not straightforward, as CCS operations involve different technical challenges and safety considerations.

To address these gaps, the UK needs to invest in workforce development initiatives that provide targeted training and upskilling opportunities so that there is a competent workforce for the construction contractors and the Developers during operations. This includes creating new educational programs at universities and technical colleges and offering retraining programs for workers transitioning from other industries. Additionally, there is a need to attract new talent to the CCS sector by promoting the opportunities available in this growing field, particularly among younger workers and those from underrepresented groups.

3.2.3 Infrastructure and Logistics

The successful deployment of CCS projects also hinges on the availability of adequate infrastructure and logistics to support the transport and storage of CO_2. The UK's existing infrastructure, particularly in regions with a history of oil and gas production, provides a solid foundation for CCS. However, significant upgrades and expansions are necessary to meet the scale required for large-scale CCS deployment.

One of the critical infrastructure components is the CO_2 transport network, which includes pipelines and shipping routes. Developing an integrated network connecting multiple capture sites with storage facilities is essential for the success of cluster-based CCS strategies. The UK is in the early stages of planning and constructing such networks, initially focusing on the major industrial clusters. However, these efforts need to be accelerated to ensure that transport capacity keeps pace with the growth in capture capabilities.

In addition to transport networks, storage infrastructure needs to be developed and expanded. The UK has significant potential for CO_2 storage, particularly in depleted oil and gas fields in the North Sea. However, realising this potential requires investment in the necessary infrastructure, such as injection wells, monitoring systems, and long-term storage management facilities. The logistics of managing large volumes of CO_2, including its compression, dehydration, and safe injection into geological formations, present additional challenges that must be addressed to ensure the reliability and safety of storage operations.

3.3 Track 1 and Track 2 CCS Projects

The UK government (Department for Business, Energy and Industrial Strategy, now the Department for Energy Security and Net Zero) has promoted the development of a pipeline of CCS projects by announcing the provision of competitively tendered financial support. This looked to identify two CCUS clusters that were best placed to begin deployment in the mid-2020s. The two identified clusters, HyNet and East Coast Cluster, were sequenced as Track-1 in October 2021. In 2023, DESNZ identified two subsequent clusters, Acorn and Viking, to form Track-2. The aim was to conclude negotiations with the projects in Track-2 in time to enable them to be operational by 2030.

Track 1 Projects: The Track 1 projects represent the forefront of the UK's CCS deployment, having been identified as the most advanced in development and readiness for implementation. These projects are expected to be operational by the mid-2020s and are located within key industrial clusters with significant carbon emissions. A Track 1 expansion process has been announced to further develop these regions.

- **HyNet North West:** This project is focused on decarbonising the North West of England and North Wales. It combines CCS with hydrogen production, leveraging the region's infrastructure, including the extensive pipeline network and access to offshore storage sites in the East Irish Sea. HyNet aims to capture up to 10 million tonnes of CO_2 annually by 2030.
- **East Coast Cluster (Teesside and Humber):** The East Coast Cluster is crucial for decarbonising two of the UK's largest industrial regions. This project is supported by Net Zero Teesside and Zero Carbon Humber, both of which aim to capture and store CO_2 from a wide range of industrial sources. The East Coast Cluster has the potential to capture and store over 20 million tonnes of CO_2 per year by the late 2020s, making it one of the most significant CCS initiatives globally.

Track 2 Projects: Track 2 projects are expected to follow closely behind the Track 1 projects. These projects are vital for scaling up the UK's CCS capacity and will build on the lessons learned by the Track 1 initiatives.

- **Scottish Cluster (Acorn):** Acorn is based at the St Fergus Gas Terminal in Scotland and focuses on repurposing existing North Sea infrastructure to transport and store CO_2. The project is strategically important as it lays the groundwork for future CCS expansion in the North Sea, with the potential to store significant volumes of CO_2 from both Scottish and international sources.
- **Humber Zero:** Located in the Humber, Viking is leading this carbon capture, transport and storage project. Looking to store 10 million tonnes of CO_2 per year by 2030, this critical solution is looking to decarbonise the Immingham industrial area and the VPI Combined heat and power plant as well as the Phillips 66 refinery. Storage will be in the Viking depleted gas field.

These projects are well-positioned to move into construction, with much of the necessary infrastructure and supply chain elements already prepared for rapid deployment. The learning from Track 1 projects must support improvements to Track 2 and future CCS projects.

3.4 The Role of Industrial Clusters in CCS Deployment

Industrial clusters play a pivotal role in the UK's CCS strategy. These clusters are geographic concentrations of interconnected businesses, suppliers, and associated institutions in a particular field, which, in the case of CCS, are typically centred around heavy industries such as steel, cement, chemicals, and refining. The concentration of CO_2 emissions within these clusters makes them ideal candidates for CCS deployment, as they can achieve economies of scale and develop shared infrastructure, reducing overall costs and increasing the feasibility of CCS projects.

Key Benefits of Industrial Clusters:

- **Shared Infrastructure:** By clustering CCS projects within certain regions, multiple industrial emitters can share the same infrastructure, such as pipelines and storage facilities. This shared approach reduces the capital expenditure required for individual projects and enhances the overall efficiency of CO_2 capture and storage operations.
- **Economies of Scale:** Industrial clusters allow for aggregating CO_2 volumes from multiple sources, making it more economically viable to develop large-scale CCS infrastructure. This scale is crucial for attracting investment and ensuring that projects can operate at a level that delivers significant emissions reductions.
- **Regional Economic Development:** The development of CCS infrastructure within industrial clusters can also spur regional economic growth by creating jobs, attracting investment, and supporting the transition of traditional industries towards low-carbon futures. These clusters are often located in regions with a strong industrial heritage, which can be leveraged to build new green economies based around CCS and other decarbonisation technologies.
- **Innovation Hubs:** Clusters provide fertile ground for innovation, as the proximity of different industries and research institutions encourages collaboration and exchanging ideas. This can lead to developing new technologies and processes that improve the efficiency and effectiveness of CCS operations.

The success of the UK's CCS strategy is heavily dependent on the ability to leverage these industrial clusters for their economic efficiencies and potential to serve as models for CCS deployment in other regions. By focusing on these clusters, the UK can maximise the impact of its CCS initiatives and ensure that it meets its emissions reduction targets while driving economic growth.

3.5 Geographic Trends in Design Activity

The geographic distribution of design activities within the CCS sector has evolved. Historically, much of the high-level design and engineering work was concentrated in the UK, leveraging the country's strong industrial base and expertise in related fields like Oil & Gas. However, recent trends indicate a shift towards relocating detailed design work—and, increasingly, high-end design work—to international locations due to cost considerations and the weakening of offshore capabilities due to the decline in new Oil & Gas projects.

Whilst there are some examples of UK-based contractors, the majority being considered are ultimately foreign-owned, e.g. US-based Babcock and Wilcox and Australian head-quartered Worley. Figure1 illustrates these shifts, showing the past, current, and anticipated future locations of design activities related to CCS projects, as communicated by the Developers and EPC Contractors who are part of the first two Track processes. The diagram underscores a critical challenge for the UK CCS supply chain: maintaining and enhancing its role as a hub for CCS design work in the face of increasing global competition and offshoring.

The changes depicted in Figure 1 have several implications:

- **Loss of Domestic Capability**: As detailed design work moves abroad, there is a risk of eroding the UK's capabilities and expertise in high-value CCS design activities, which could impact the country's competitiveness in the global CCS market.
- **Need for Strategic Intervention**: To counteract these trends, strategic interventions are necessary, including targeted investment in digital design capabilities, training programs to enhance local skills, and policies that incentivise companies to retain design activities within the UK.
- **Opportunities for Re-localisation**: By focusing on sectors where the UK has competitive advantages, such as high-value, bespoke engineering solutions and complex project management, there is an opportunity to attract and retain more CCS design activity domestically.

By understanding these shifts and their drivers, stakeholders can better position the UK CCS supply chain to respond proactively, ensuring that the UK remains a leading hub for CCS design and engineering.

This concept is not a new one. If we take Aberdeen as a case study of the UK's oil and gas industry, it has been shown that once a leading hub has been established, an area and its supply chain companies will benefit in the long term. Aberdeen, often called the "Oil Capital of Europe," became a leading oil and gas industry hub, attracting substantial foreign investment. Its strategic location near the North Sea and advanced infrastructure supports extensive exploration and production activities. This vibrant sector creates numerous expert opportunities, drawing skilled professionals worldwide.

The University of Aberdeen and Robert Gordon University offer specialised programs, fostering a highly educated workforce. The Oil & Gas Technology Centre (OGTC) drives innovation, addressing industry challenges and enhancing technological advancements. Aberdeen's annual Offshore Europe conference further solidifies its status as a global knowledge hub. The city's collaborative environment and strong industry-academia partnerships attract continuous foreign investment and export opportunities. Additionally, Aberdeen can switch this capability towards pioneering renewable energy solutions, ensuring its relevance in the evolving energy landscape. This dynamic ecosystem sustains the local economy and positions Aberdeen as a World leader in energy excellence, helping to improve and develop the sector Globally.

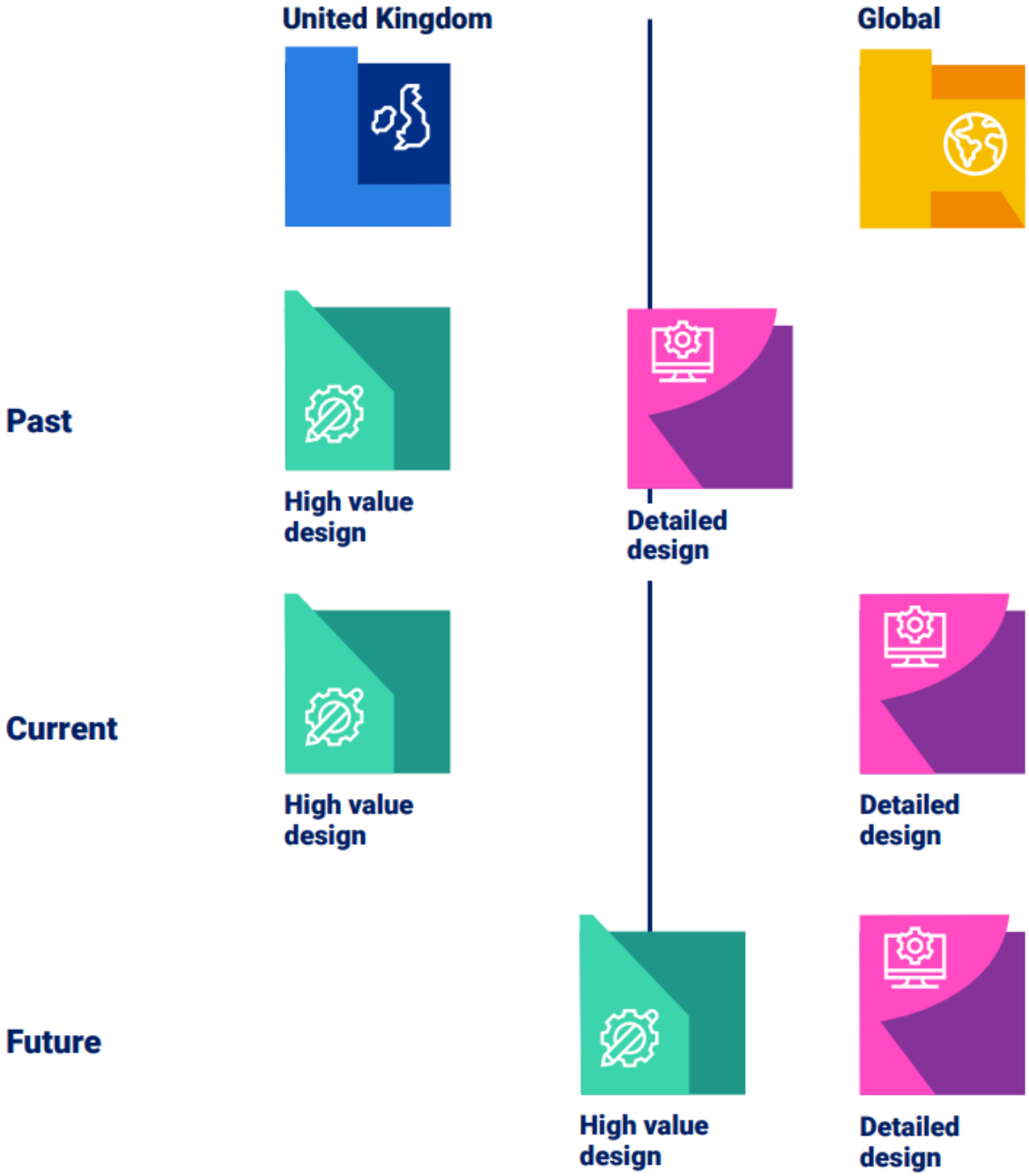


Figure 1 - Diagram showing the Past, Current and Future location of the Design Activity

3.6 Key Barriers and Challenges Identified

To establish a robust Carbon Capture and Storage (CCS) supply chain within the United Kingdom, several significant barriers and challenges must be addressed. These challenges span various aspects of the supply chain, from manufacturing and infrastructure to workforce development and regulatory frameworks. Understanding these barriers is essential for developing strategies to overcome them and ensuring the successful deployment of CCS technology at the scale required to meet the UK's Net Zero targets.

3.6.1 Manufacturing and Infrastructure Constraints

One of the most pressing challenges facing the UK's CCS supply chain is the constraint on manufacturing and infrastructure capabilities. The scale-up required for CCS deployment demands a substantial increase in the production of key components such as CO_2 compressors, pipelines, and storage tanks. However, the UK lacks sufficient domestic capacity to meet these demands, particularly for large-scale projects.

Manufacturing Challenges:

- **Limited Domestic Production:** The UK's manufacturing sector has seen a decline in heavy industrial production over recent decades, reducing capacity to produce the large-scale components necessary for CCS projects. For instance, manufacturing large pressure vessels and pipelines is currently insufficient to meet the anticipated demand, necessitating reliance on imports. This dependence on international suppliers introduces risks related to supply chain security, fluctuating costs, and potential delays. These delays could occur as a result of manufacturers favouring larger, more regular and more lucrative contracts for the same or similar components from CCS and wider energy-related projects in other countries.
- **Supply Chain Fragmentation:** The CCS supply chain is highly fragmented, with various components sourced from different domestic and international suppliers. This fragmentation can lead to coordination challenges, increased lead times, and higher costs. The complexity of integrating these components into a cohesive CCS system adds further strain to the supply chain.

Infrastructure Challenges:

- **Logistical Barriers:** The construction and expansion of infrastructure are also hindered by logistical barriers, including land acquisition, regulatory approvals, and environmental considerations. This also includes moving larger components, whether by road, rail or sea; these factors can lead to delays and increased costs, further complicating the deployment of CCS technology.
- **Inadequate Supply Chain Infrastructure:** Many supply chain firms lack the infrastructure to compete in a World market. Manufacturers lack the production lines needed due to insufficient tooling, and the land or buildings are unsuitable for the vast size of CCS components. Similarly, fabricators lack yard space and lay-down areas near

the site needed to assemble these huge modules. Manufacturing, fabrication and construction all lack the skilled people to construct or operate in the supply chain. This reduces choice and competition open to the Developers, driving up price and uncertainty.

3.6.2 Workforce and Skills Shortages

The deployment of CCS technology across the UK presents a unique set of challenges for the workforce, particularly regarding the availability of skilled labour and the adequacy of current training programs. While the earlier analysis highlighted the current state of workforce readiness, this section delves deeper into the barriers that could impede the growth and effectiveness of the UK's CCS workforce.

Critical Skills Gaps:

- **Specialised Technical Expertise:** As previously noted, there is a significant shortage of workers with the specific technical skills required for CCS projects. However, the impact of this shortage on the overall deployment of CCS technology cannot be understated. The lack of expertise in critical areas such as CO_2 compression, pipeline installation, and subsurface storage creates bottlenecks in project timelines and increases the risk of operational inefficiencies.
- **Delayed Project Timelines:** The shortage of skilled workers is not just a theoretical concern but a practical barrier that has already impacted project timelines. Without sufficient trained professionals, CCS projects face delays in both the construction and operational phases, which can result in missed milestones and increased costs. One Developer reported that they now schedule their construction activity around when their trusted sub-contractors and labour is available, rather than normal drivers to their construction schedule.

Challenges in Training and Education:

- **Inadequate Training Programs:** Although existing training programs are aimed at developing skills for the energy sector, they often do not focus specifically on the unique demands of CCS. Developing comprehensive training programs that address these specific needs is a critical barrier that must be overcome. Moreover, the lag time between establishing new programs and workers becoming fully skilled and competent poses a significant challenge for meeting immediate project demands.
- **Alignment with Industry Needs:** The misalignment between educational institutions and industry needs is another barrier. CCS projects, being new, do not have a well-accepted career path; instead, they use a more generic academic and vocational syllabus taken from other industrial processes and oil and gas. There is a pressing need for closer collaboration between industry and academia to ensure that training programs are designed to meet the specific requirements of CCS projects. This includes technical skills, project management, and regulatory compliance, which are critical for the successful deployment of CCS technology.

Retention and Recruitment Challenges:

- **Attracting Talent:** The CCS sector must compete with other emerging industries, such as renewable energy and digital technologies, to attract top talent. Given that these sectors are often seen as offering more appealing career prospects, particularly by younger workers, the CCS industry needs to put more emphasis on how it communicates both the environmental benefits of these projects and wider range of roles (technical, digital, environmental, safety, management etc) being supported within each project.
- **Retention of Skilled Workers:** Retaining skilled workers within the CCS sector is equally challenging, particularly in the face of ageing demographics.

3.6.3 Financial and Investment Barriers

Financing CCS projects presents a significant challenge, given the high upfront costs, long payback periods, and uncertainties around future revenue streams. While government support has been instrumental in advancing CCS projects, private-sector investment is crucial for scaling up deployment.

High Capital Costs:

- **Upfront Investment:** The supply chain requires significant speculative investment to prepare for the contracts associated with delivering CCS. Many of these investments must be made before any contracts are signed, so they represent very real risks. This pre-emptive investment is needed as there is insufficient time to implement the investment, whether obtaining land, buildings, equipment, designs or skilling up people between contract award and expected delivery. International suppliers already have this capability and a shorter lead time that fits the project schedule driven by the Track process. This lack of upfront investment and preparation effectively makes many UK suppliers unable to tender for the contracts.

- **Investors Risk Management:** Investors see CCS as a first-of-a-kind initiative and, therefore, perceive a high level of risk. To mitigate this risk, developers and EPC contractors must use suppliers with as much track record in their area of CCS operation as possible. This essentially precludes many UK supply chain firms from being contracted with as they have no track record in CCS. If EPC contractors try to use novel suppliers, they are often directed to use a lower-risk supplier. This has led to UK-based EPC contractors communicating during the engagement that a higher UK Content expectation would assist them in forcing investors to accept more UK supply chain suppliers.

Market and Policy Uncertainties:

- **Regulatory Risks:** The evolving regulatory landscape for CCS presents challenges for investors, who may be concerned about the stability and predictability of government policies. Uncertainty around carbon pricing, incentives, and long-term support for CCS can deter investment as investors seek assurance that their investments will remain viable over time.

- **Revenue Streams:** The future revenue streams for CCS projects are closely tied to carbon pricing and government incentives. However, fluctuations in carbon prices and policy changes can create uncertainty about the profitability of CCS investments. This uncertainty makes it difficult for project developers to secure financing, as potential investors may be wary of committing to projects with uncertain financial outcomes.

3.6.4 Regulatory and Policy Barriers

The regulatory environment for CCS in the UK is still evolving, and while progress has been made, several barriers remain that could impede the deployment of CCS technology.

Complex Regulatory Framework:

- **Permitting and Approvals:** The process for obtaining the necessary permits and approvals for CCS projects can be complex and time-consuming. This complexity is often exacerbated by the need to navigate multiple regulatory bodies, both nationally and locally, each with its own requirements and timelines. Delays in the permitting process can lead to significant setbacks for CCS projects, increasing costs and creating uncertainty for Developers.
- **Environmental Regulations:** While environmental regulations are essential for ensuring that CCS projects do not harm the environment, they can also pose challenges for project developers. Strict environmental assessments, coupled with public opposition in some cases, can delay or even halt CCS projects. Balancing environmental protection with the need for rapid deployment of CCS technology is a key challenge for policymakers.

Policy Support:

- **Inconsistent Policy Signals:** The success of CCS deployment depends heavily on strong and consistent policy support. However, inconsistencies in government policy, such as fluctuations in funding commitments or changes in carbon pricing, could create uncertainty for project developers and investors. Clear and stable policy signals are essential for building confidence in the CCS market and attracting the necessary investment.
- **Global Competition:** The UK is not the only country pursuing CCS technology, and global competition for investment and talent is fierce. If the UK's policy environment is perceived as less favourable compared to other countries, it could struggle to attract the investment needed to scale up its CCS industry. This global competition underscores the need for the UK to maintain a competitive and attractive policy framework to ensure its leadership in CCS.

4 Strategic Analysis

The deployment of CCS technology in the United Kingdom is a complex and multifaceted challenge that requires careful strategic planning. This section delves into the lessons learned from other sectors, explores cross-sector opportunities and synergies, compares international practices, and assesses the risks associated with the UK's CCS supply chain. The aim is to provide a thorough analysis that will guide the development of a robust and resilient supply chain capable of meeting the UK's ambitious CCS targets.

4.1 Lessons Learned from Other Sectors

The experiences of other sectors that have undergone significant technological and infrastructural transformations offer valuable lessons for the CCS supply chain. The offshore wind and nuclear energy sectors are particularly relevant, as they share similar challenges in scaling up technology, managing complex supply chains, and navigating regulatory landscapes.

Offshore Wind Sector: The offshore wind sector in the UK has seen rapid growth over the past decade, transforming from a nascent industry into a global leader in renewable energy. One of the key factors behind this success has been the strategic development of the supply chain. Early investment in manufacturing capabilities, such as turbine production and installation vessels, was crucial in building the necessary infrastructure to support large-scale projects. The creation of supply chain clusters associated with regional project portfolios, such as those close to the Humber and the North East, provide concentrated areas of expertise and resources, supporting innovation and logistical efficiencies. These developed clusters might serve as models for the CCS sector, where similar centres of excellence could accelerate the deployment of CCS technology by bringing together key players in the supply chain.

Government support played an instrumental role in this transformation. The offshore wind sector benefited from stable and long-term policy frameworks, including subsidies, feed-in tariffs, and contracts for difference (CfDs), which reduced financial risks and encouraged private investment. The CCS sector can draw from this experience by advocating for similar policy stability and financial mechanisms that lower the barriers to entry for investors. Additionally, the offshore wind industry's emphasis on collaboration between stakeholders - from manufacturers to local governments - facilitated the standardisation of components and processes. This standardisation not only reduced costs but also streamlined the supply chain, making it easier to scale up operations.

A similar approach could be applied to CCS, particularly in the standardisation of pipeline and storage infrastructure, where practical. Developers were keen on the standardisation of components as they believed that this would reduce costs and increase the availability of components and modules; however, they were very mindful that most of the current pipeline of projects needed to be bespoke due to the variation between carbon sources. They believed that the specification of captured carbon needed to be standardised to allow as many emitters as possible to use the available transport and storage infrastructure. Developers also found the possibility of having options for storage and thus competition in the system appealing to drive

down costs in the future. Standardisation is a prerequisite for this as it is also necessary for transport across borders.

4.2 Cross-Sector Opportunities and Synergies

Integrating CCS technology with other sectors involved in the energy transition presents significant opportunities for creating synergies that can reduce costs, enhance efficiencies, and open up new avenues for innovation. Two key areas where these synergies are most evident are the hydrogen production sector and the broader renewable energy landscape.

Integration with Hydrogen Production: Hydrogen production, particularly blue hydrogen, which involves the separation of natural gas into hydrogen and CO_2, with the CO_2 being captured and stored (CCS), is a crucial component of the UK's decarbonisation strategy. The process makes use of the CCS pipeline and storage infrastructure, offering an opportunity for some cost sharing, streamlining logistics, improving efficiency, and reducing the carbon footprint of both processes. This integration makes economic sense and supports the creation of a more resilient and versatile energy system.

Moreover, the economic viability of blue hydrogen is closely tied to the success of CCS. By aligning hydrogen and CCS strategies, the UK creates a mutually reinforcing relationship where advancements in one sector drive progress. For instance, the development of CCS infrastructure can lower the costs of hydrogen production, making it more competitive with other forms of energy. Conversely, the growth of the hydrogen market can provide additional revenue streams for CCS projects, enhancing their financial sustainability.

Linkages with Renewable Energy: The synergy between CCS and renewable energy sources, such as wind and solar, offers a unique opportunity to address the intermittency of renewable power generation. Gas-fired power plants with CCS could provide a stable and reliable energy source during times when renewable output is low, thereby balancing the grid and ensuring a continuous supply of low-carbon energy.

4.3 Risk Assessment for the UK CCS Supply Chain

The deployment of CCS in the United Kingdom presents numerous opportunities. Still, it is also fraught with various risks that need to be carefully managed to ensure successful outcomes. These risks span technical, financial, regulatory, and environmental dimensions, and addressing them is critical to the resilience and sustainability of the UK's CCS supply chain.

4.3.1 Challenges in Project Design and Procurement Processes

A critical challenge within the UK CCS supply chain is the inefficiency in project design processes, particularly the duplication of design efforts across various stages of project development. This duplication often arises due to a lack of coordination and standardisation across teams and stakeholders, leading to redundant work that increases costs and extends project timelines.

Figure 2illustrates a common issue in projects: the duplication of designs for the same project by the same subcontractor. This situation typically occurs when different teams or contractors work in silos, unaware of existing designs that could be reused or adapted. As a result, similar or identical designs are recreated multiple times throughout the project lifecycle. This redundancy not only consumes additional resources but also delays project progress, impacting the overall efficiency and cost-effectiveness of the CCS supply chain. This situation is especially pertinent to CCS due in part to the lack of supply chain firms with the right capability and to the government's requirement to demonstrate the best value for each component.

The diagram below shows that three different EPC contractors will develop slightly different solutions for the same project. Due to the few options for supply firms in the UK, all the EPC's may ask the supplier to design and quote for slightly different specifications and designs. That supplier will, therefore, have to take on the time, cost and burden of designing three different components for the same project.

By highlighting the areas where design duplication occurs, Figure 2 highlights the need for more integrated and collaborative approaches to project design. It suggests that better communication, design standardisation, and the use of shared digital platforms or digital twins could significantly reduce these inefficiencies, enabling faster project completion and lower costs.

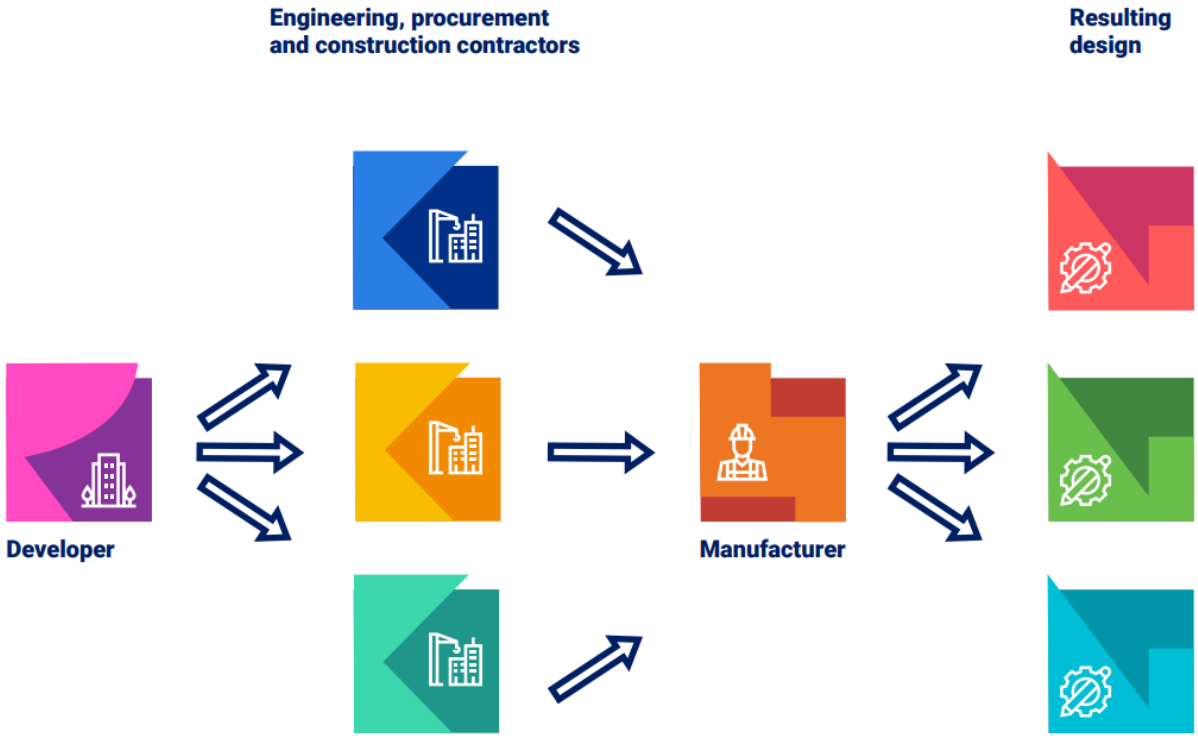


Figure 2 - Diagram showing the duplication of designs for the same project

4.3.2 Supply Chain Disruption Risks

One of the most significant risks to the CCS supply chain is its reliance on global supply chains for key components and materials. The UK's dependency on imports for critical items like CO_2 compressors, pipelines, and storage vessels exposes the supply chain to disruptions caused by geopolitical tensions, trade restrictions, and international competition from similar projects. Such disruptions can lead to delays in project timelines, increased costs, and potential shortages of essential materials, all of which threaten the viability of CCS projects.

To mitigate these risks, the UK needs to diversify its supply chain by expanding domestic production capabilities. This involves investing in local manufacturing facilities that can produce the critical components needed for CCS projects, thereby reducing reliance on international suppliers. Additionally, the development of strategic reserves for essential materials and the establishment of alternative supply routes can provide a buffer against global supply chain shocks. By building a more self-reliant supply chain, the UK can enhance its resilience to external disruptions and ensure that CCS projects remain on track.

4.3.3 Sequencing of Manufacturing and Pre-Contract Preparation

Ensuring the timely and efficient manufacturing of components is critical for the successful delivery of CCS projects. Given the unique challenges associated with these projects, particularly their novel nature and the significant infrastructure required, the sequencing of manufacturing activities and early preparation before contract awards are pivotal. Figure 3 illustrates the sequencing of manufacturing activities within the CCS project development process, highlighting the necessary preparation time required before contracts are awarded. This preparation phase is crucial for suppliers to retool, scale up production capabilities, and align their operations with project specifications, depending upon the level of difference from existing operations.

Key insights from Figure 3 include:

- **Pre-Contract Preparation Time**: To meet tight project timelines, suppliers must begin preparations well in advance of contract awards. This includes securing materials, adjusting manufacturing processes, and investing in necessary technology upgrades.
- **Manufacturing Sequencing**: Figure 3 underscores the importance of a carefully planned manufacturing sequence to avoid bottlenecks and ensure a smooth flow of materials and components throughout the supply chain. This is particularly important for components with longer lead times or those requiring specialised production techniques.
- **Strategic Investment Needs**: The need for anticipatory investment is evident. Manufacturers must have the confidence to invest in scaling up production and enhancing capabilities without the guarantee of immediate contracts. This requires a coordinated approach involving clear communication from Developers, potential financial incentives from the government, and robust supply chain management.

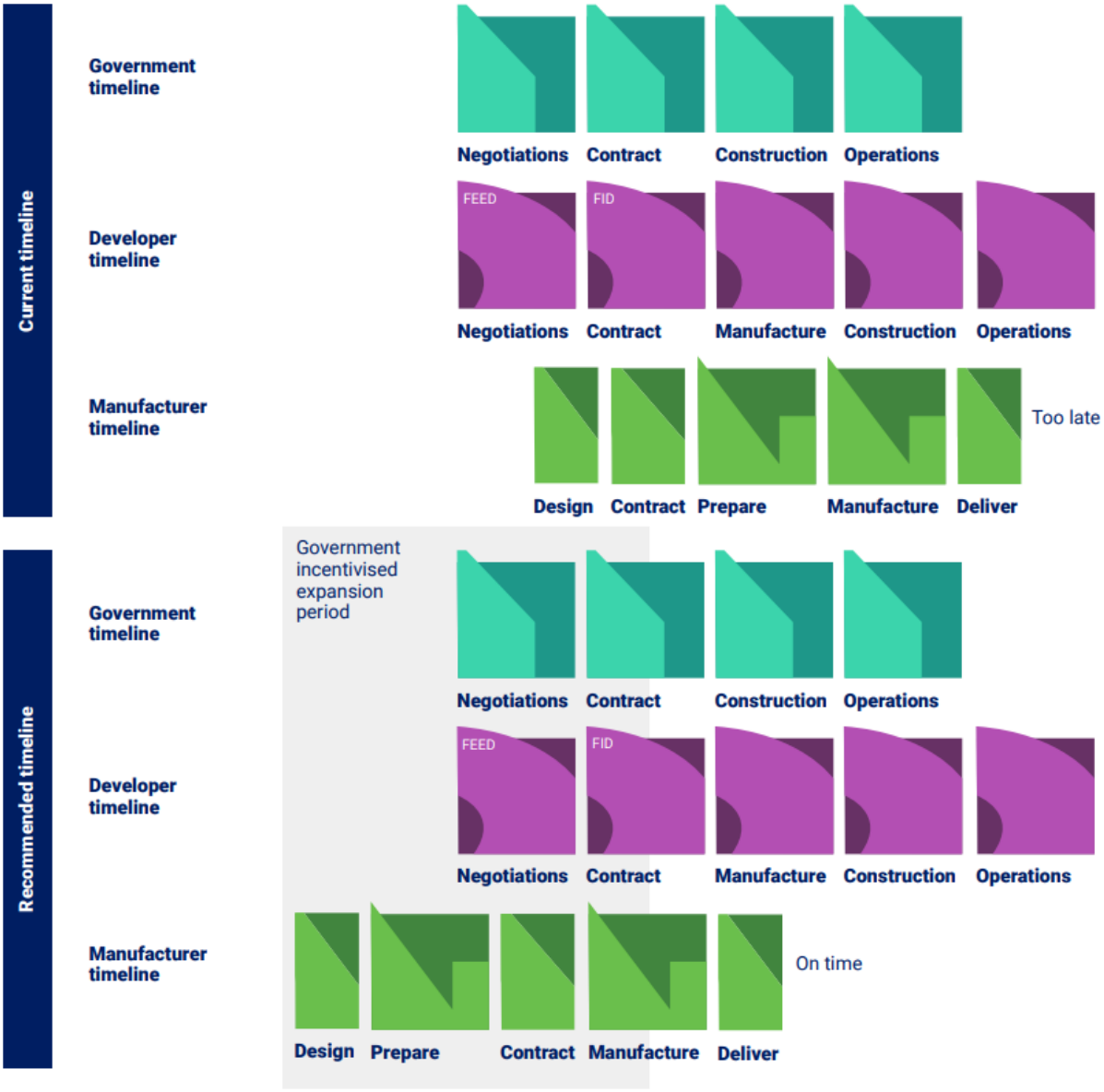


Figure 3 - Diagram showing the sequencing of manufacturing in the CCS Project development process and the time needed to prepare pre-contract

4.3.4 Redundancy in Design Phases

In addition to the challenges of duplicated designs across different project teams, there is a significant redundancy that occurs between the Front-End Engineering Design (FEED) phase and the Final Investment Decision (FID) stage. This repetition could be a critical issue within the project development lifecycle, leading to wasted resources and increased project costs. Figure 3 illustrates the repetition of designs that often takes place at both the FEED and FID stages of CCS project development. During FEED, initial design and engineering work is completed to define the scope, costs, and schedule of the project. However, as the project progresses to the FID stage, many of these designs are revisited or reworked, sometimes from scratch, due to changes in procured contractors, project scope, cost of materials and labour, stakeholder feedback, or regulatory requirements.

This repeated design effort between FEED and FID creates several inefficiencies:

- **Increased Costs**: Reworking designs at the FID stage can lead to significant cost overruns as initial designs are modified or entirely redone.
- **Extended Timelines**: The need to revisit and revise designs adds time to the project schedule, delaying project milestones and overall completion.
- **Resource Drain**: Redundant design work consumes valuable engineering and design resources that could be better utilised elsewhere.

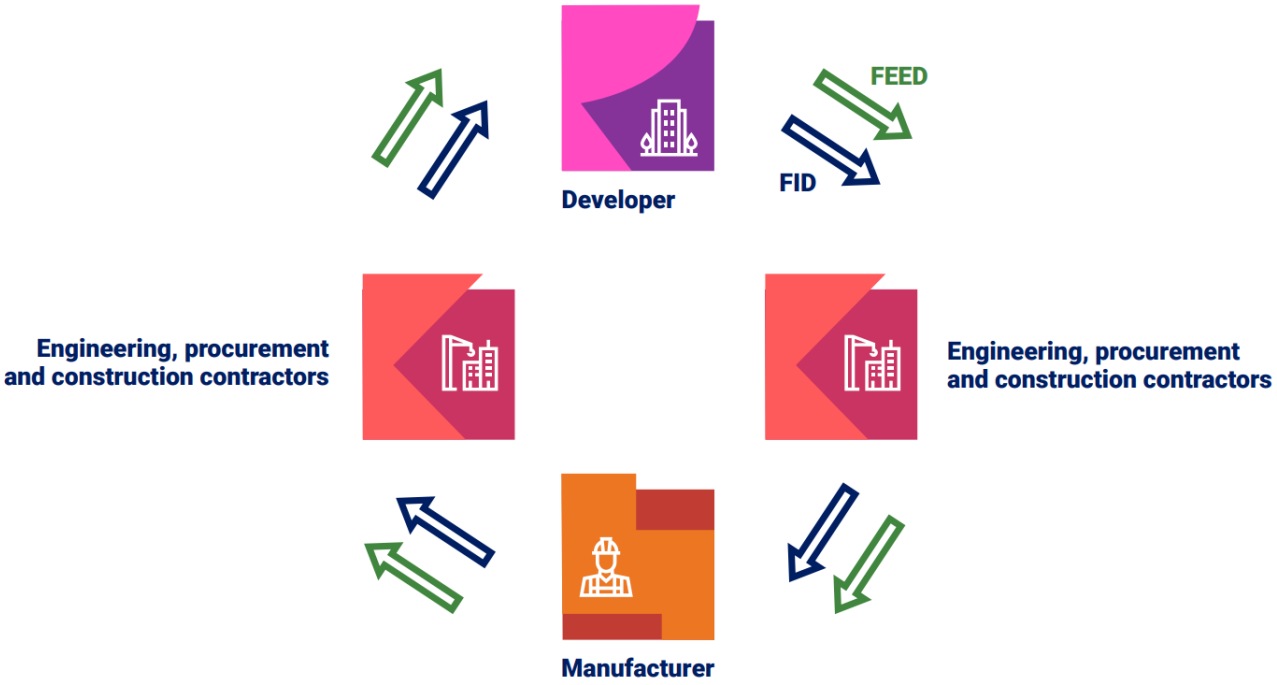


Figure 4 - Diagram showing the repetition of designs for the same project at FEED and then again at FID

Figure 4 highlights these inefficiencies by showing how similar designs are re-created or heavily modified at both the FEED and FID stages. To mitigate these issues, it is crucial to implement strategies that promote better continuity and alignment between these phases, such as:

- **Improved Design Reviews**: Conducting more thorough design reviews during the FEED phase to ensure that designs meet all necessary criteria and reduce the need for major revisions at FID.
- **Stakeholder Alignment**: Ensuring that all stakeholders are aligned on design expectations early in the project to minimise changes and revisions later on.
- **Adopting Flexible Design Practices**: Using modular and adaptable design practices that can accommodate changes without requiring complete redesigns.

By addressing these areas, CCS projects can reduce redundancy, lower costs, and accelerate project timelines, enhancing overall supply chain efficiency and project outcomes.

Technological and Operational Risks:

The technological complexity of CCS introduces significant operational risks, particularly during the capture, transport, and storage phases of the process. The capture of CO_2 , for instance, requires sophisticated technology that is still evolving. The potential for technical failures, such as malfunctions in capture equipment or leaks in pipelines, poses serious risks to the operational efficiency and environmental safety of CCS projects.

The storage of CO_2, especially in deep geological formations like depleted oil fields or saline aquifers, carries the risk of leakage, which could have severe environmental consequences. Ensuring the integrity of storage sites over the long term is a critical challenge, requiring advanced monitoring and maintenance protocols. The implementation of rigorous testing and real-time monitoring systems is essential to detect and address potential issues promptly. Furthermore, developing robust emergency response plans, informed by best practices from other industries, will be crucial in managing any incidents that may arise.

This is an area that the UK supply chain is uniquely well-placed to support. The services provision & manufacture of CO_2 instrumentation and monitoring, which is a largely unfilled area globally, is an area where the UK Supply Chain could provide this capability domestically and for export. This is a very similar capability to the one that is needed for the Hydrogen sector, making it increasingly viable as a cross-sector service.

There is currently a lot of innovation in this area, with many different types of instrumentation being offered, but with no clear leader. Legislation and standardisation could be used to ensure that a UK model of instrumentation and monitoring is adopted nationally. This base of operations could then be used to expand internationally as more countries adopt carbon capture and storage and need to monitor transport as well as long-term storage monitoring. This legislation and standardisation would also open opportunities for hydrogen monitoring, especially when hydrogen production is collocated with CCS.

4.3.5 Environmental and Social Risks:

The CCS industry must engage proactively with local communities and stakeholders to build public trust and address any concerns related to the safety and environmental impact of CCS projects. Transparency and effective communication are key to gaining public support and ensuring that CCS projects proceed without significant opposition. Addressing environmental risks requires the implementation of stringent environmental impact assessments and the adoption of best practices in site selection, monitoring, and maintenance.

In addition to environmental concerns, the construction of new infrastructure, such as pipelines and storage facilities, poses potential social risks. These projects can disrupt local communities and ecosystems, leading to opposition from residents and environmental groups. To manage these risks, it is essential to involve local communities in the planning process, ensure that projects comply with environmental regulations, and implement mitigation measures to minimise any negative impacts.

5 Recommendations

This section outlines detailed recommendations aimed at overcoming the key barriers identified in the UK's CCS supply chain and maximising opportunities for growth. These recommendations are grounded in a thorough analysis of the current state of the CCS sector and are supported by evidence from successful strategies in related industries.

5.1 Ensure CCS Remains a Core Component of National Industrial Strategy

Objective: Ensure CCS remains a core component of any new National Industrial Strategy, enabling the 2030 Clean Power Mission and providing long-term certainty for the supply chain.

Rationale and Evidence: The UK's experience in offshore wind demonstrates how long-term policy stability, combined with government-backed incentives, can accelerate industry growth. A similar strategy is required for CCS to provide the same level of certainty and drive for private sector investment, which is crucial to scaling up CCS infrastructure. Integrating CCS with other key green energy sectors, such as hydrogen and offshore wind, will also allow the UK to leverage synergies, reduce costs, and enhance efficiency in achieving its Net Zero goals.

Key Actions:

- **Policy Integration:** CCS should be fully embedded within the National Industrial Strategy, with explicit targets and milestones that align with the 2030 Clean Power Mission and beyond. This should include commitments to carbon pricing mechanisms and tailored funding support mechanisms, such as CfDs, to de-risk CCS projects.
- **Regulatory Streamlining:** Simplify the regulatory landscape to reduce the time and complexity of securing project approvals. This could involve establishing a dedicated regulatory body for CCS or revising existing frameworks to facilitate faster deployment.
- **Supply Chain Investment:** Establish a body akin to the Offshore Wind Growth Partnership to support early-stage investment in the CCS supply chain, ensuring it is ready to meet the demands of large-scale deployment.
- **Public and Stakeholder Engagement:** Launch initiatives to increase awareness and understanding of CCS among stakeholders, including industry players, policymakers, and the general public. This could involve educational campaigns, industry consultations, and public forums.

5.2 Enhance Investment in Supply Chain Capabilities

Objective: Reduce reliance on international suppliers by strengthening domestic production of critical CCS components and encouraging innovation within the UK.

Rationale and Evidence: The UK's dependence on imports for essential CCS components, such as CO_2 compressors and pipelines, introduces significant risks, particularly in light of recent global supply chain disruptions. Building domestic capabilities is not only a matter of supply

chain security but also a strategic economic opportunity. Investing in local manufacturing can create jobs, stimulate regional economies, and position the UK as a leader in CCS technology.

Key Actions:

- **Incentivise Domestic Manufacturing:** Provide financial incentives, such as grants and tax breaks, to companies that invest in domestic production of CCS components. These incentives should target both established manufacturers and SMEs looking to expand into the CCS sector.
- **Develop Regional clusters:** Identify regions with existing industrial bases and proximity to geological storage sites, such as the Humber and Teesside, to establish specialised manufacturing clusters. These clusters should receive targeted support to build the necessary infrastructure, establish improved transport connectivity, and attract skilled workers.

5.3 Address Workforce Development Needs

Objective: Close the skills gap in the CCS sector by developing targeted training programs and promoting diversity and inclusion within the workforce.

Rationale and Evidence: Workforce development is critical for the success of the CCS sector. The UK currently faces a significant skills shortage in areas essential to CCS, such as engineering, project management, and subsurface geology. Industry reports highlight that without targeted intervention, these shortages could lead to delays and increased costs for CCS projects. Furthermore, promoting diversity and inclusion within the workforce can lead to better decision-making and innovation, as evidenced by research across various industries.

To address these challenges, it is essential to develop comprehensive training programs in partnership with educational institutions and industry stakeholders. These programs should focus on both technical skills and leadership development, ensuring that the workforce is equipped to meet the demands of the growing CCS sector.

Key Actions:

- **Create Specialised Training Programs:** Collaborate with universities, technical colleges, and industry bodies to develop training programs that focus on the specific skills needed for CCS. These programs should include apprenticeships, certifications, and continuous professional development opportunities.
- **Promote EDI Initiatives:** Launch initiatives to increase diversity within the CCS workforce. This could include targeted outreach to underrepresented groups, scholarship programs, and mentorship schemes.

5.4 Position the UK as a Global Leader in CCS Technology and Services

Objective: Develop exportable capabilities in CCS technologies and services to strengthen the UK's position in the global market.

Rationale and Evidence: The global market for CCS is expected to expand significantly in the coming decades, providing the UK with an opportunity to lead in this emerging sector. The UK already has a strong foundation in offshore engineering and environmental monitoring, which can be leveraged to develop exportable CCS technologies and services. By investing in research and development (R&D) and promoting UK expertise internationally, the UK can capture a significant share of the global CCS market.

Historically, the UK's leadership in sectors such as offshore wind or Defence has been driven by a combination of government support and private-sector innovation. A similar approach can position the UK as a leader in CCS, creating new economic opportunities and driving growth in the green economy.

Key Actions:

- **Increase R&D Investment:** Enhance government and private sector investment in R&D to drive innovation in CCS technologies, particularly in areas where the UK has a competitive advantage, such as deep-sea storage and advanced capture techniques.
- **Develop an Export Strategy:** The Department of Business and Trade should create a coordinated strategy to promote UK CCS technologies and services in international markets. This could include trade missions, participation in global CCS forums, and partnerships with international organisations.
- **Design and Technology:** By increasing the design capability of CCS components and offshore modules, a greater volume of design work can be retained in the UK. This could be further enhanced by developing the artificial intelligence capability of detailed design, reshoring this capability that has been largely lost.
- **Monitoring Services:** The development and support of carbon monitoring services by introducing the regulations and standardisation of this service will allow UK supply chain firms the opportunity to become global leaders. This will be beneficial domestically and can be expanded to be an exportable service in the future.

5.5 Enhance Collaboration and Communication

Objective: Foster collaboration across the CCS supply chain to overcome challenges, accelerate deployment, and create synergies with other sectors.

Rationale and Evidence: Collaboration is essential for addressing the complex challenges of the CCS supply chain. The success of the UK's offshore wind sector was largely due to effective collaboration between stakeholders, including developers, government agencies, and supply chain partners. By establishing similar collaborative frameworks in the CCS sector, the UK can facilitate knowledge sharing, standardise processes, and reduce costs.

Furthermore, cross-sector collaboration, particularly with the hydrogen and renewable energy sectors, can create significant synergies. These synergies can lead to shared infrastructure, reduced costs, and improved efficiency, contributing to the overall success of the UK's energy transition.

Key Actions:

- **Establish CCS Forums:** The government should encourage the creation of formal forums and working groups that bring together developers, EPCs, SMEs, and other stakeholders to share knowledge and best practices. These forums should focus on standardising processes and addressing common challenges.
- **Promote Cross-Sector Collaboration:** DESNZ should encourage partnerships between the CCS sector and related industries, such as hydrogen production and renewable energy, to create synergies and integrate CCS into broader decarbonisation efforts.

5.6 Develop Industrial Clusters

Objective: Enhance Industrial Clusters' activities so they concentrate more on a broader range of CCS activities, facilitating local supply chain development and expertise.

Rationale and Evidence: Regional leadership groups have been a key factor in the success of industries such as aerospace, automotive, and offshore wind. By concentrating expertise, resources, and infrastructure in specific locations, they create centres of excellence that drive innovation, reduce costs, and accelerate deployment. The UK's CCS sector can benefit from a similar approach, particularly in regions with high industrial CO_2 emissions and proximity to geological storage sites. The current Industrial Clusters are well-placed to develop into these regional leadership groups.

These Clusters can also support the development of local supply chains, providing opportunities for SMEs and creating jobs in regions that may otherwise face economic challenges. The establishment of regional CCS clusters aligns with broader industrial strategy goals, ensuring that the benefits of the energy transition are distributed across the UK.

Key Actions:

- **Identify and Develop Key Regions:** Focus on regions with high industrial CO_2 emissions and proximity to storage sites, such as the North West, Humber, Teesside, and Scotland's Central Belt. These regions should be prioritised for infrastructure development, including CO_2 transport networks and storage facilities.
- **Support Local Supply Chains:** Provide targeted support to local businesses in these regions to enable them to participate in CCS projects. This could include funding for R&D, skills development, and capacity building.
- **Upgrade Local Infrastructure:** Aid the movement of large components by widening roads and addressing roadside and low (e.g. bridge) obstructions. This action is particularly important between regional clusters and local ports.

6 Implementation Plan

Successfully implementing the strategic recommendations outlined in this report requires a structured and phased approach. This ensures that both short-term and long-term goals are met efficiently and effectively. The implementation plan is divided into several key phases: immediate actions, medium to long-term actions, stakeholder roles and responsibilities, monitoring and verification, and risk management.

6.1 Phased Implementation Approach

The implementation of the UK's CCS strategy must be approached in phases to manage complexity and ensure that each stage of development builds on the previous one. This phased approach allows for flexibility, enabling the plan to adapt to changes in technology, market conditions, and policy environments.

Phase 1: Immediate Actions (0-12 months) This phase focuses on establishing the foundational elements required to kickstart the CCS supply chain. The emphasis is on policy adjustments, how the already secured funding is utilised, and engaging stakeholders. These actions are critical to creating the conditions necessary for rapid progress in subsequent phases.

Phase 2: Medium-Term Actions (1-5 years) As the CCS strategy matures, the focus shifts to building and expanding the necessary infrastructure, enhancing supply chain capabilities, and developing a skilled workforce. These actions will ensure that the UK can scale its CCS operations to meet national and international demands. Deliver a programme of industry engagement so a larger proportion of the supply chain is aware of the opportunities presented by CCS and has the information they need to enter into it.

Phase 3: Long-Term Actions (5-10 years) The final phase aims at consolidating the UK's position as a global leader in CCS technology and services. This includes expanding domestic manufacturing capabilities, enhancing global competitiveness, and implementing continuous monitoring and adaptation mechanisms to ensure long-term success.

6.2 Immediate Actions (0-12 months)

The first phase of implementation is crucial for setting the stage for the UK's CCS strategy. Immediate actions focus on policy reforms, securing initial funding, and facilitating stakeholder collaboration.

6.2.1 Policy Adjustments and Funding Allocations

The success of the UK's CCS strategy depends heavily on the alignment of government policy with industry needs. In the initial phase, it is imperative to streamline regulatory processes that currently hinder the swift approval and development of CCS projects and to introduce policies that will support the supply chain, such as increasing the level of expected UK content. The complexity and length of the regulatory approval process have been identified as major bottlenecks. Simplifying these processes by reducing bureaucratic hurdles, standardising

application procedures, and providing clear, concise guidance can significantly accelerate the pace of CCS deployment.

The Clusters, other regional bodies, CCS leadership organisations, local government and Central Government should work together to plan the transition of Industrial Clusters into Regional leadership bodies that will support the development of their local supply chains. This planning should detail the specific interventions and activities that will take place across all the clusters.

The levels of expected UK Content required to gain Government support and planning approval should be increased and communicated to developers at the earliest opportunity. Raising this expectation will give the EPC Contractors and Developers the clarity and certainty to insist on greater UK content and thus be able to include new UK suppliers who would otherwise be prevented from participation by the investors due to their lack of track record. Lessons from the approach for Contracts for Difference Supply Chain Plans and the emerging Sustainable Industry Rewards scheme for offshore wind could be applied here.

In parallel, the government must allocate targeted funding to de-risk early-stage CCS projects. These funds should be directed toward critical areas such as infrastructure development, precontract preparation, research and development (R&D), and workforce training. Early investment in these areas will kickstart the CCS supply chain, thereby encouraging private-sector investment.

6.2.2 Stakeholder Engagement and Coordination

Effective coordination among government bodies, industry players, and academic institutions is vital for the success of the CCS strategy. To this end, establishing a high-level industry leadership forum within the first six months is a priority. This group should be composed of representatives from key sectors and will serve as the central body overseeing the implementation of the CCS strategy. The industry leadership forum's responsibilities will include resolving conflicts, aligning stakeholder objectives, and ensuring that all parties are progressing towards the shared goal of a robust and sustainable CCS supply chain.

In addition to the industry leadership forum, ongoing stakeholder engagement will be critical. Regular meetings, workshops, and consultations should be organised to keep stakeholders informed, solicit feedback, and adjust strategies as needed. This continuous dialogue will help maintain alignment across different sectors and ensure that the implementation plan remains responsive to emerging challenges and opportunities.

6.3 Medium to Long-Term Actions (1-10 years)

As the CCS strategy enters the medium-term phase, the focus will shift towards scaling up operations and infrastructure while ensuring that the workforce and supply chain are equipped to support these developments.

6.3.1 Infrastructure Development

The development of critical infrastructure, including CO_2 transport networks, storage facilities, and manufacturing hubs, is central to the success of the UK's CCS strategy. This phase will involve significant investment in both new infrastructure and the upgrading of existing facilities. For instance, the construction of CO_2 pipelines that connect major industrial clusters to offshore storage sites is essential for enabling large-scale CCS operations. These pipelines must be designed with the capacity to handle the expected volumes of CO_2 and should be built with future expansion in mind.

The planning policy must be changed to ensure that these movement corridors are not negatively affected by future infrastructure later on.

6.3.2 Workforce Development

To ensure a steady pipeline of qualified workers, it is essential to create clear career pathways within the CCS industry. These pathways should be supported by continuous professional development opportunities, enabling workers to advance their skills as the industry evolves. For example, training programs could start with basic certifications in CO_2 capture technology and progress to advanced qualifications in subsurface storage management or pipeline integrity monitoring.

In addition to technical skills, these programs should emphasise cross-disciplinary knowledge, preparing workers to adapt to the rapidly changing technological landscape of the CCS sector. Partnerships with universities and technical colleges will be critical in developing curricula that are both forward-looking and aligned with industry needs. Furthermore, addressing diversity and inclusion within the workforce is paramount. Initiatives to attract underrepresented groups into the CCS sector will help ensure that the industry benefits from a wide range of perspectives, encouraging innovation and resilience.

6.3.3 Promotion of UK Content

Maximising the use of UK-sourced materials and services in CCS projects is vital not only for building a resilient supply chain but also for supporting the national economy. The UK government should implement policies that incentivise companies to prioritise domestic suppliers. The expected level of UK Content required to receive Government funding and support with planning should be increased from the current NSTA level of 50% to a higher level. This will give the EPC Contractors and Developers the rationale for making purchase decisions from local supply chains that the investors won't challenge.

The government should also provide financial and technical support to local businesses, particularly SME's, to help them scale up and meet the demands of the CCS sector. This could involve grants for capacity building, subsidies for upgrading equipment, and assistance with certification processes that enable companies to compete in the CCS market. By strengthening the local supply chain, the UK can reduce its reliance on imports, lower the carbon footprint of its CCS projects, and create jobs across the country.

6.3.4 Expansion of Domestic Capabilities

The expansion of domestic manufacturing capabilities for key CCS components is a long-term goal that will require sustained investment and strategic planning. As global demand for CCS technology grows, the ability to produce critical components, such as pressure vessels, chemical absorbers, and CO_2 compressors, within the UK will become increasingly important. This not only enhances supply chain security but also positions the UK as a leader in the global CCS market.

A major increase in UK content in the longer term will be the domestic production of the amine absorbers required throughout the operational phase of a capture plant's lifetime. A strategic Government promotion would be to negotiate or incentivise the production of proprietary amines in the UK. This would cut down on the longer-term transport requirements of this substance, which will have beneficial effects on carbon reduction and deliver high-value jobs.

To achieve this, the government should direct investments towards expanding existing manufacturing facilities and establishing new ones. Public-private partnerships can play a crucial role in financing these expansions, with the government providing initial capital and private sector partners contributing technological expertise and operational management. In addition, technology transfer initiatives and collaborative R&D programs will be essential to ensure that UK manufacturers remain at the cutting edge of CCS technology. By focussing on innovation and encouraging the adoption of best practices, the UK can build a competitive and resilient manufacturing sector that meets both domestic and international demand.

6.3.5 Global Competitiveness and Export Strategy

As the UK's CCS sector matures, it is essential to develop a strategy that positions the country as a global leader in CCS technology and services. This strategy should focus on promoting UK-designed solutions in international markets, leveraging the country's strengths in offshore engineering, environmental monitoring, and advanced manufacturing.

The UK government, in collaboration with industry stakeholders, should develop a coordinated export strategy that includes participation in global CCS forums, trade missions, and international partnerships. This strategy should highlight the UK's expertise in areas such as offshore engineering, deep-sea CO_2 storage, pipeline integrity management, and CO_2 capture technologies. By showcasing these capabilities on the global stage, the UK can attract foreign investment, forge strategic alliances, and open new markets for its CCS technologies and services.

Moreover, establishing export-oriented partnerships with other countries will be crucial for scaling up the deployment of UK CCS technologies. These partnerships could involve joint ventures, technology licensing agreements, and collaborative R&D projects that enable the UK to tap into international markets while sharing the risks and rewards of CCS deployment. By taking a proactive approach to global competitiveness, the UK can ensure that its CCS industry remains at the forefront of innovation and economic growth.

6.4 Stakeholder Roles and Responsibilities

The effective implementation of the UK's CCS strategy is contingent upon the coordinated efforts of a range of stakeholders. Each group, from government bodies to industry players and educational institutions, has a critical role to play. Their collective actions will determine the success of this plan to establish the UK as a global leader in carbon capture and storage.

6.4.1 Government Bodies

Government agencies, particularly the Department for Energy Security and Net Zero (DESNZ), HM Treasury, and the Department for Business and Trade (DBT) are at the forefront of setting the strategic direction for the UK's CCS initiative. These bodies are responsible for establishing a policy framework that supports the deployment of CCS technologies across the country. This includes crafting legislation that provides clarity and stability to investors and industry participants, encouraging long-term investment in CCS projects.

DESNZ is leading the policy formulation process, ensuring that CCS is integrated into the UK's broader energy and environmental strategies. This involves not only setting targets for CO_2 capture and storage but also ensuring that these targets are achievable through supportive policies and allocating the necessary financial resources, with HM Treasury support, to de-risk early-stage CCS projects and fund the development of essential infrastructure.

Furthermore, DBT's involvement is crucial for promoting UK CCS technologies and expertise in the global marketplace. By forging international partnerships and representing the UK in global forums, DIT can help position the UK as a leader in the emerging CCS industry, driving export growth and attracting foreign investment.

6.4.2 Industry Stakeholders

Industry stakeholders, including CCS developers, EPC firms, and SMEs, are responsible for the on-the-ground execution of the CCS strategy. These entities are tasked with developing, constructing, and operating the necessary infrastructure for CCS, including CO_2 capture facilities, transport pipelines, and storage sites. The complexity of these projects requires a high degree of coordination and innovation within the industry.

CCS developers must focus on advancing the technological capabilities required to meet the UK's CCS targets and support the achievement of the low carbon hydrogen targets. EPC firms, which are responsible for the engineering, procurement, and construction aspects of CCS projects, must ensure that these projects are delivered on time, within budget, and to the highest standards of safety and environmental compliance.

SMEs play a vital role in the CCS supply chain, particularly in the areas of component manufacturing, maintenance services, and innovation. The success of the CCS strategy depends on the ability of SMEs to scale up their operations to meet the increasing demand for CCS technologies and services. This requires not only financial support but also access to new markets and the ability to compete with larger, established companies. An important part of the

CCS supply chain strategy will be to engage the SMEs and communicate the opportunity in the sector and how they can best engage with Developers and EPC contractors to submit successful bids for products and services.

6.4.3 Educational Institutions

Educational institutions, including universities and technical colleges, are critical for addressing the skills gap in the CCS sector. These institutions are responsible for developing and delivering specialised training programs that prepare the next generation of engineers, technicians, and project managers for careers in CCS. The curriculum must be aligned with the needs of the industry, ensuring that graduates possess the practical skills and theoretical knowledge required to succeed in this rapidly evolving field.

Beyond training, universities have a significant role in driving research and development in CCS technologies. Academic research can lead to breakthroughs in CO_2 capture efficiency, safety, and cost reduction, all of which are essential for the long-term viability of CCS. By facilitating collaboration between academia and industry, universities can help accelerate the commercialisation of new technologies and processes.

In addition, educational institutions must work closely with industry stakeholders to provide opportunities for hands-on learning through internships, apprenticeships, and collaborative research projects. This not only enhances the learning experience for students but also ensures that the industry has access to a skilled and experienced workforce.

6.5 Monitoring, Measurement, and Verification (MMV)

Monitoring, Measurement, and Verification (MMV) are critical to ensuring that the UK's CCS strategy is implemented effectively and achieves its intended outcomes. A robust MMV framework not only tracks progress but also identifies areas for improvement, enabling continuous refinement of the strategy.

6.5.1 Key Performance Indicators (KPIs)

To accurately measure the success of the CCS strategy, a comprehensive set of Key Performance Indicators (KPIs) should be established. These KPIs serve as measurable benchmarks that provide insights into the effectiveness of various strategic actions. In workforce development, KPIs might include metrics such as the number of workers trained, retention rates within the CCS sector, and diversity indicators that measure the inclusiveness of the workforce. Supply chain KPIs would focus on the percentage of UK-sourced materials used in CCS projects, the resilience of the supply chain, and the growth of domestic manufacturing capabilities.

For global competitiveness, KPIs would track the UK's market share in global CCS technologies, the value of international contracts secured by UK companies, and the number of UK-designed

CCS solutions exported to other countries. These KPIs provide a clear picture of how well the UK is performing in its goal to become a leader in the global CCS industry.

6.5.2 Regular Reporting

Regular reporting is essential for maintaining transparency and accountability throughout the implementation of the CCS supply chain strategy. When supported by public funds, stakeholders should be required to submit detailed progress reports on a regular basis, providing updates on their achievements relative to the established KPIs. These reports should include both quantitative data and qualitative assessments, offering a comprehensive view of the implementation's status. This will allow for the monitoring of the volume of UK content and will also provide an opportunity for Developers to demonstrate the additional supply chain support they are providing compared to their initial expectations. The delivery of all the Developer's supply chain achievements should be compiled together, anonymised but aligned to a Cluster and then published so that communities can perceive the benefit they are receiving.

6.6 Risk Management and Contingency Planning

Effective risk management and contingency planning are crucial components of the UK's CCS supply chain strategy, ensuring that the implementation plan remains resilient and adaptable in the face of potential challenges. As the CCS sector evolves, it will inevitably encounter various risks that could impede progress or derail projects. To safeguard against these possibilities, it is essential to develop a proactive approach to identifying, assessing, and mitigating risks, coupled with robust contingency plans that can be activated if necessary.

6.6.1 Identifying Risks

The first step in any risk management strategy is the systematic identification of potential risks. These risks can be broadly categorised into supply chain risks, regulatory risks, technological risks, environmental risks, and reputational risks. Each category encompasses a range of specific challenges that could arise during the implementation of the CCS supply chain strategy.

Supply Chain Risks

The global nature of the CCS supply chain presents several vulnerabilities. The UK's reliance on imported components, such as CO_2 compressors and pipelines, exposes the sector to geopolitical tensions, trade disruptions, and logistical challenges. For example, unexpected trade restrictions, sudden global demand, or natural disasters in supplier countries could lead to significant delays in the delivery of essential materials. Additionally, the concentration of manufacturing in a few regions increases the risk of bottlenecks or shortages, particularly if demand for CCS technologies outpaces production capacity.

To mitigate these risks, it is vital to diversify the supply chain by developing domestic manufacturing capabilities and establishing alternative suppliers. This approach not only reduces dependency on external factors but also strengthens the UK's strategic autonomy in the CCS sector. Regular supply chain audits should be conducted to identify potential vulnerabilities and ensure that contingency plans are in place for critical components

Regulatory Risks

Regulatory frameworks are fundamental to the successful deployment of CCS technologies, but they can also pose significant risks if they are not well-aligned with industry needs. Changes in environmental regulations, safety standards, or carbon pricing mechanisms can have profound impacts on the financial viability of CCS projects. For instance, a sudden increase in carbon prices could make certain projects economically unfeasible, while overly stringent environmental regulations might delay project approvals or increase compliance costs.

To manage regulatory risks, ongoing dialogue between the government and industry stakeholders is essential. This dialogue should focus on creating a regulatory environment that is both robust and flexible (e.g., allowing for risk sharing) and capable of accommodating the rapid technological advancements and evolving market conditions that characterise the CCS sector. Additionally, the establishment of clear, consistent, and long-term regulatory frameworks will provide the stability needed to attract investment and ensure project continuity.

Technological Risks

The CCS sector is heavily dependent on the development and deployment of advanced technologies, which inherently carry risks related to innovation, reliability, and scalability. For example, new CO_2 capture technologies may not perform as expected when scaled up from pilot projects to full-scale operations, leading to technical failures, cost overruns, or safety issues. Similarly, the long-term integrity of CO_2 storage sites, particularly in geological formations, remains a critical concern that requires rigorous monitoring and verification.

To address technological risks, it is crucial to invest in research and development (R&D) to refine existing technologies and develop new solutions. Pilot projects should be rigorously tested under a variety of conditions to identify potential weaknesses before full-scale deployment. Additionally, implementing robust monitoring systems for storage sites will help detect and address any issues early, minimising the risk of environmental harm or public backlash. This would also give reassurance to investors that risks are being appropriately managed or mitigated.

Environmental Risks

The environmental implications of CCS projects are a significant concern, particularly the risk of CO_2 leakage from storage sites or pipelines. Such incidents could not only negate the environmental benefits of CCS but also lead to significant legal liabilities and reputational damage. Furthermore, the construction and operation of CCS infrastructure may have localised environmental impacts, such as habitat disruption or pollution, which could provoke opposition from local communities or environmental groups.

Environmental risks must be managed through comprehensive environmental impact assessments (EIAs) and the adoption of best practices in environmental management. These assessments should cover the entire lifecycle of CCS projects, from site selection and

construction to operation and decommissioning. In addition, proactive community engagement is essential to address local concerns, build trust, and secure social license to operate. By involving stakeholders in decision-making processes and transparently communicating the benefits and risks of CCS, project developers can reduce the likelihood of opposition and foster public support.

Reputational Risks

Public perception of CCS technology plays a critical role in its adoption and success. Negative perceptions, whether due to environmental concerns, safety issues, or distrust of the technology, can lead to opposition, project delays, and challenges in securing funding. In the age of social media, reputational risks can escalate quickly, with misinformation or isolated incidents potentially undermining public confidence in CCS as a viable solution to climate change.

To mitigate reputational risks, a comprehensive public relations strategy is essential. This strategy should focus on educating the public about the benefits of CCS, addressing common misconceptions, and highlighting successful case studies. Engaging with the media, policymakers, and local communities early and often can help build a positive narrative around CCS. Additionally, transparency in operations and a commitment to high safety and environmental standards will reinforce public trust in the technology.

6.6.2 Contingency Measures

Even with rigorous risk management processes in place, unexpected challenges are inevitable. Contingency measures are therefore necessary to ensure that the CCS strategy can adapt to unforeseen events and continue progressing towards its objectives.

Supply Chain Contingencies

To address potential supply chain disruptions, the UK should establish a network of alternative suppliers and logistics routes. This could involve entering into strategic partnerships with suppliers in different geographic regions or investing in domestic production capabilities for critical components. Maintaining strategic reserves of key materials, such as CO_2 absorbents or pipeline components, will also provide a buffer against supply shortages. Additionally, building flexibility into contracts with suppliers can help manage delays or price fluctuations without derailing project timelines.

Regulatory Contingencies

Regulatory changes can be mitigated by developing flexible project plans that allow for adjustments in response to new regulations. This might involve building regulatory compliance buffers, such as adopting more stringent environmental standards than currently required, to future-proof projects against potential regulatory shifts. Regularly updating the regulatory impact assessments and maintaining close communication with regulatory bodies will also ensure that projects can adapt quickly to new requirements.

6.6.3 Ongoing Risk Assessment

Risk management is not a static process but requires continuous assessment and adaptation. As the CCS strategy progresses, new risks may emerge, and existing risks may evolve. To ensure that the strategy remains resilient, ongoing risk assessment must be an integral part of the implementation process.

In conclusion, a robust risk management and contingency planning framework is essential for the successful implementation of the UK's CCS strategy. By proactively identifying and mitigating risks and by preparing for unforeseen challenges, the strategy can maintain its momentum and achieve its long-term goals.

7 Conclusion

The UK's CCS strategy represents a critical component of the nation's broader efforts to achieve Net Zero by 2050. This strategy is not merely a collection of discrete projects, but a comprehensive plan aimed at transforming the UK's industrial base, reducing greenhouse gas emissions, and positioning the UK as a global leader in carbon management technologies. The successful implementation of this strategy will require a concerted effort from government, industry, and academia, each bringing their strengths to bear in a coordinated and collaborative manner.

7.1 Summary of Key Points

The UK's CCS strategy is built on a phased approach that balances the immediate need for action with the long-term goal of establishing a robust, self-sustaining CCS sector. The immediate phase focuses on laying the groundwork through policy adjustments, funding allocations, and stakeholder engagement. This phase is crucial for creating a stable environment in which CCS projects can be initiated and expanded. It includes efforts to streamline regulatory processes, de-risk early-stage projects through targeted funding, and establish a framework for ongoing collaboration among key stakeholders.

The medium-term phase (1-5 years) shifts the focus to scaling up operations, with an emphasis on infrastructure development, workforce training, and the expansion of domestic manufacturing capabilities. This phase is about building the physical and human capital needed to support a growing CCS industry. It also involves strengthening the supply chain, ensuring that the UK can produce key components domestically, thereby reducing reliance on imports and enhancing supply chain security.

The long-term phase (5-10 years) is centred on securing the UK's position as a global leader in CCS. This involves not only the continued expansion of infrastructure and capabilities but also the strategic positioning of the UK in the global market for CCS technologies and services. By encouraging innovation, enhancing global competitiveness, and ensuring that the strategy remains adaptable to changing circumstances, the UK can solidify its leadership role in the fight against climate change.

7.2 The Path Forward: Realising the UK's CCS Potential

The road to realising the UK's CCS potential is fraught with challenges, but it also offers significant opportunities. The successful implementation of the CCS strategy will hinge on several key factors.

Firstly, sustained political and financial commitment from the government is essential. The initial phases of the CCS strategy require significant public investment to de-risk projects and attract private-sector participation.

Secondly, the development of a skilled workforce is critical to the success of the CCS supply chain strategy. The UK must address the skills gap in the CCS sector by investing in education and training programs that equip workers with the knowledge and expertise needed to build, operate and manage CCS technologies. This involves not only creating new curricula but also facilitating partnerships between industry and educational institutions to ensure that training programs are aligned with the needs of the sector.

Thirdly, the UK must focus on innovation and the development of cutting-edge CCS technologies that can be delivered via the supply chain. The global market for CCS is highly competitive, and the UK must ensure that its technologies are at the forefront of this rapidly evolving industry and made available to Developers via a domestic supply chain.

Moreover, the UK's approach to CCS must be holistic, integrating CCS into broader energy and industrial strategies and the supply chain that supports the wider energy sector. This means recognising the role of CCS not only in reducing emissions but also in supporting the decarbonisation of other sectors, such as hydrogen production and industrial processes, including the commonality of components and services. By positioning CCS as a key component of a broader decarbonisation strategy, the UK can maximise the impact of its CCS supply chain and infrastructure investments and ensure that the benefits are felt across the economy. This will produce a supply chain that is capable of supporting the wider sector.

Finally, the UK must engage actively in the global CCS market. The export of UK-designed CCS technologies and services represents a significant economic opportunity for the supply chain, but it also requires strategic positioning in international markets. The UK must leverage its expertise in CCS to forge international partnerships, participate in global forums, and secure contracts for CCS projects abroad. This will not only enhance the UK's global standing but also create jobs and drive economic growth at home.

APPENDICES

8 Appendix A: Detailed Methodology

8.1 Introduction to Methodology

This appendix provides an in-depth overview of the methodology employed in developing the Carbon Capture and Storage Supply Chain Plan. The approach integrated both qualitative and quantitative research methods to provide a thorough analysis of the current state and readiness of the UK CCS supply chain. The methodology was designed to ensure comprehensive data collection, effective stakeholder engagement, and rigorous analysis, all of which were essential for generating well-informed findings and recommendations.

8.2 Project Initiation

The primary goal was to assess the readiness of the UK CCS supply chain, identify existing barriers, and formulate strategic recommendations to help the industry and government facilitate effective supply chain mobilisation. To achieve this, it was crucial to understand both the current capabilities within the supply chain and the future requirements as the CCS sector expands. There was a focus on the Developers' perspectives on the current level of readiness and capability of the UK supply chain to support the initial roll out of the CCS projects in each of the five IDC clusters.

A comprehensive list of stakeholders was identified to capture diverse perspectives across the supply chain. This list included government departments, such as the Department for Energy Security and Net Zero (DESNZ), industry bodies like the Carbon Capture and Storage Association (CCSA), cluster project managers, Engineering, Procurement, and Construction (EPC) contractors, and representatives from Small and Medium-sized Enterprises (SMEs). Engaging with this broad range of stakeholders ensured a holistic view of the supply chain's challenges and opportunities.

8.3 Data Collection

Data collection was a critical component of the methodology, encompassing a broad review of existing literature and the gathering of new data through direct stakeholder engagement.

The literature review involved a systematic examination of previous reports and studies to compile existing knowledge on the UK CCS supply chain. Key documents reviewed included the "CCUS Supply Chains – A roadmap to maximise the UK's potential" (BEIS 2021), "Industrial CCUS UK Supply Chain Capabilities" (WSP 2022), "Supply Chain Excellence for CCUS" (CCSA 2021), and "Enabling Skills for the Industrial Decarbonisation Supply Chain" (University of Chester and Mace 2023). These documents provided a foundational understanding of the current landscape, highlighting supply chain gaps, potential areas for improvement, and strategic opportunities for enhancing UK-based manufacturing and service provision.

In addition to secondary research, primary data was collected through various stakeholder engagement activities. This included in-depth interviews, surveys, and site visits designed to validate findings from the literature review and provide up-to-date insights into the real-world

state of the CCS supply chain. This multi-pronged approach ensured that the data collected was both comprehensive and representative of the various viewpoints within the industry.

8.4 Workforce Planning Methodology

The workforce planning methodology used for this report is based on the same key assumptions and inputs that Opergy used to produce the DESNZ Regional Employment Estimates Calculators. As part of this work, Opergy was commissioned to complete several robust, interactive calculations that forecasted workforce demand by region, asset stage, and sector. CCS was one of these sectors.

The methodology began with an extensive stakeholder engagement process, which included consultations with key CCS industry organisations such as bp, CCSA, and DRAX. These engagements provided a substantial volume of qualitative and quantitative data regarding workforce expectations and the types of skills likely to be required by both planned and archetypal CCS projects.

Based on internal expertise, Opergy aligned all CCS employment activities into one of four asset stages: Development, Manufacturing, Construction, and Operations & Maintenance. Standard corporate service roles, expected to take place off-site, were also included. By matching the industry-derived employment figures with these asset stages and the confirmed pipeline of CCS projects, the number of jobs was calculated for each project and in each UK region.

These figures were then subjected to a range of variables, including the impact of increased productivity and technological advancements on job numbers. For example, due to the unknown exact number of emitters that will eventually be built in each cluster, it was assumed that ten emitter projects would enter operations for each cluster. Specifically, it was estimated that these would be sequenced, with two projects entering operations every two years.

Several assumptions were used in these calculations. For the various employment scenarios presented in this report, four UK content scenarios were used for each of construction and manufacturing. For Construction, it is estimated that 80% of all CCS jobs are UK-based. Since construction is site-specific, the analysis could be run on a regional basis. The regional graphs compared the expected proportion of UK content of 80% with estimates of UK content at 60%, 70%, and 90%.

A similar methodology was used for estimating UK-wide manufacturing jobs, which are expected to be 20%. However, 10%, 30%, and 40% of the total requirement were modelled, reflecting the lower proportion of UK manufacturing overall.

8.5 Stakeholder Engagement

Stakeholder engagement was integral to the research process, allowing for the collection of qualitative data and insights directly from those involved in the CCS supply chain. A series of engagement activities were conducted to gather a broad spectrum of perspectives.

The engagement process began with one-on-one interviews with key stakeholders, including developers, government officials, cluster managers, and industry experts. These interviews provided in-depth insights into current barriers and potential solutions for enhancing supply chain readiness. Following the interviews, workshops were held to facilitate collaborative discussions among stakeholders from across the supply chain. These workshops were instrumental in identifying key challenges and opportunities, enabling stakeholders to share their experiences and insights in a structured setting.

In addition to workshops, roundtable discussions were organised to explore specific issues in greater detail. These discussions focused on critical topics such as the role of SMEs in the CCS supply chain and the impact of regulatory policies on supply chain mobilisation. To complement these qualitative approaches, surveys were distributed to a broader group of stakeholders. The surveys captured quantitative data on supply chain readiness, investment needs, and strategic priorities, helping to validate the qualitative findings further.

Through these engagement activities, several key themes emerged. One prominent theme was the identification of significant gaps in the UK-based manufacturing capacity for critical CCS components, such as large pressure vessels and proprietary amines. Another theme was the need for substantial public and private investment to expand the UK's manufacturing capabilities and develop the necessary workforce skills. Additionally, there was a clear recognition of strategic opportunities to leverage existing expertise in the oil and gas sector to support the emerging CCS market. These insights were critical in shaping the report's recommendations and ensuring they were aligned with industry needs and expectations.

8.6 Report Writing Process

The report writing process involved synthesising the collected data and insights into a cohesive narrative that supported the findings and recommendations of the Carbon Capture and Storage Supply Chain Plan. This synthesis was crucial to ensure a comprehensive understanding of the CCS supply chain's current state and the steps needed to enhance its readiness.

Data from the literature review, primary research, and stakeholder engagement were meticulously reviewed and integrated to identify commonalities and differences across data sources. This process was essential for developing strategic recommendations that were both evidence-based and actionable. To ensure the accuracy and relevance of the findings, a validation process was undertaken, which involved presenting preliminary findings to stakeholders for feedback. Their input was invaluable in refining the recommendations and ensuring they were practical and aligned with both industry and government objectives.

This iterative process of synthesis and validation helped to create a robust and comprehensive report that accurately reflected the current state of the UK CCS supply chain and provided clear, actionable recommendations for its development.

9 Appendix B: Data Sources

This appendix lists all the data sources referenced throughout the CCS Supply Chain Implementation Plan report. These sources are essential for understanding the foundations of the analysis, findings, and recommendations presented in the report.

9.1 Government Reports

- **BEIS (2021)**: "CCUS Supply Chains – A Roadmap to Maximise the UK's Potential." Department for Business, Energy & Industrial Strategy.
- **DESNZ (2023)**: "Carbon Capture, Usage and Storage: A Vision to Establish a Competitive Market." Department for Energy Security and Net Zero.
- **DESNZ (2024)**: "Green Industries Growth Accelerator: Hydrogen and Carbon Capture, Usage and Storage Supply Chains." Department for Energy Security and Net Zero.
- **BEIS (2021)**: "North Sea Transition Deal." Department for Business, Energy & Industrial Strategy.
- **UKRI (2023)**: "Enabling Net Zero: A Plan for UK Industrial Cluster Decarbonisation." UK Research and Innovation.
- **DESNZ (2022)**: "UK Energy Security and Net Zero Strategy." Department for Energy Security and Net Zero.

9.2 Industry Publications

- **CCSA (2021)**: "Supply Chain Excellence for CCUS." Carbon Capture and Storage Association.
- **CCSA (2023)**: "CCUS Supply Chain Good Practice Guidance." Carbon Capture and Storage Association.
- **HVM Catapult, Nuclear AMRC (2022)**: "CCUS Supply Chain Intervention Strategy."
- **BP, CCSA & ECITB (2024)**: "Green Jobs Delivery Group – CCS Task and Finish Group Findings and Recommendations."
- **OEUK (2022)**: "Carbon Capture and Storage and the Opportunity for the Oil & Gas Supply Chain." Offshore Energies UK.
- **ETZ (2023)**: "ETZ Ltd Partners with Net Zero Technology Centre and National Manufacturing Institute Scotland to Deliver Countries First Energy Incubator & Scale Up Hub."
- **National Grid (2020)**: "Building the Net Zero Energy Workforce."
- **RenewableUK/OWIC/Crown Estate (2024)**: "Offshore Wind Industrial Growth Plan."
- **Stratasys (2024)**: "Reshaping Success: Navigating Supply Chain Challenges through Reshoring Strategies."
- **MAKEuk (2024)**: "More Women in Engineering is Key to Filling Skills Gaps and Apprenticeships."
- **Shell (2019)**: "SHELL CANSOLV® CO_2 CAPTURE SYSTEM."

9.3 Academic Studies and Research

- **University of Chester and Mace (2023)**: "Enabling Skills for the Industrial Decarbonisation Supply Chain."
- **IDRIC (2022)**: "Enabling Skills for the Industrial Decarbonisation Supply Chain."
- **IDRIC (2024)**: "Policy Brief: Understanding Jobs Demand and Displacement Outcomes of Decarbonising UK Industry Clusters."
- **Cambridge Industrial Innovation Policy (2023)**: "Empowering Women in Manufacturing: Unlocking the Potential of Gender-Inclusive Digitalisation."
- **LSE (2021)**: "Seizing Sustainable Growth Opportunities from Carbon Capture, Usage and Storage in the UK."
- **Journal of Cleaner Production (2024)**: "Industrial Carbon Capture Utilisation and Storage in the UK: The Importance of Wage Responses in Conditioning the Outcomes of a New UK CO_2 Transport and Storage Industry Emerging in a Labour Supply Constrained Economy."
- **European Commission (2024)**: "Industrial Carbon Management: Capturing, Storing and Using CO_2 to Reach Our Climate Goals."
- **Joint Research Centre (2024)**: "Shaping the Future CO_2 Transport Network for Europe."
- **Jon Gibbins (2024)**: "Significant Updates in Amine Selection for the UK's Track 1 Cluster Post-Combustion Capture Projects."

9.4 Stakeholder Engagements

- **Interviews**: A series of in-depth interviews were conducted with key stakeholders, including industry leaders, government officials, and regional cluster managers. These interviews provided qualitative data on the readiness, barriers, and opportunities within the UK CCS supply chain.
- **Workshops**: Several workshops were facilitated with stakeholders across different sectors to discuss challenges and strategies for CCS deployment. The findings from these workshops significantly informed the report's recommendations.
- **Surveys**: Surveys were distributed to a broad range of stakeholders to capture quantitative data on supply chain readiness, investment needs, and strategic priorities. The survey responses helped validate the qualitative findings and provided a more comprehensive understanding of stakeholder perspectives.

9.5 Technical Databases and Online Resources

- **UKCCS Research Community**: "Best Available Techniques (BAT) Information for CCS" and "Front-End Engineering Design (FEED) Study for a Carbon Capture Plant Retrofit to a Natural Gas-Fired Gas Turbine Combined Cycle Power Plant."
- **International Energy Agency (IEA) Database**: Used to obtain global data on CCS technologies, deployment rates, and economic impacts.
- **Office of National Statistics (ONS)**: "Average Weekly Earnings, June 2024," "International Comparisons of UK Productivity (ICP), Final Estimates: 2021," "Productivity Flash Estimate and Overview, UK: January to March 2024 and October to December 2023."

9.6 Other Reports and Publications

- **ARUP (2023)**: "A Remarkable New Infrastructure System: Opportunities for Economic Growth in the UK's Carbon Capture & Storage Industry."
- **Cogent Skills (2023)**: "A Greenprint for Skills for the Low-Carbon Industries."
- **Aberdeen & Grampian Chamber of Commerce (2024)**: "Energy Transition."
- **IChemE (2022)**: "Chemical Engineering and the Future of CCS." Institution of Chemical Engineers.
- **WSP (2022)**: "Industrial CCUS UK Supply Chain Capabilities." Williams Sale Partnership.

10 Appendix C: Regional Economic Impact Breakdown

This appendix provides a detailed analysis of the economic impact of CCS (Carbon Capture and Storage) deployment across various regions in the UK under different scenarios. These scenarios explore the potential employment and economic outcomes based on varying levels of domestic construction and manufacturing content.

To highlight the sensitivity of UK Content to the different phases of the Capital Spend the table below demonstrates 4 different scenarios (N.B. this is just the initial capital spend and does not include operations which has a large effect due to its high UK Content proportion and 25 year duration)

	Design	Manufacturing and Fabricated parts	Construction, Commissioning and Owners Costs	TOTAL
Proportion of Total	12%	37%	51%	100%
Proportion of Total	£1,232,876,712	£3,698,630,137	£5,068,493,151	£10,000,000,000
UK Content 1	60%	10%	75%	**49%**
UK Content 1	£739,726,027	£369,863,014	3,801,369,863	£4,910,958,904
UK Content 2	60%	10%	80%	**52%**
UK Content 2	£739,726,027	£369,863,014	£4,054,794,521	£5,164,383,562
UK Content 3	60%	15%	80%	**53%**
UK Content 3	£739,726,027	£554,794,521	4,054,794,521	£5,349,315,068
UK Content 4	70%	20%	85%	**59%**
UK Content 4	£863,013,699	£739,726,027	4,308,219,178	£5,910,958,904

This shows that for a typical £10bn project spent with design and construction at its likely lowest UK Content levels and with Manufacturing at 10%, the project would fail to achieve the industry-expected level of 50% UK Content. Construction would need to be at least 80% to achieve 50% UK Content. If Manufacturing increases from 10% to 20% UK Content, then this will add 7% of the total spend as UK Content resulting in almost an extra £400 million spend in the UK.

10.1 Introduction

The deployment of CCS technologies across the UK is expected to yield diverse economic impacts depending on regional capabilities, existing infrastructure, and policy support. This appendix

outlines four scenarios, each based on different levels of UK content in construction and manufacturing, to demonstrate the potential economic benefits and challenges associated with CCS deployment.

This modelling provides the economic impact in terms of jobs from the proportion of activity delivered by the UK supply chain for the achievement of the current planned pipeline of power sector CCS projects. The different economic impacts for the 5 Cluster regions are shown graphically.

10.2 Methodology for Job Calculations

For the modelling, our approach was:

- Data was gained from employers for power sector CCS from their own planning expectations.
- Researched data is cross-checked with other sources and again aligned to the employers' data.
- The number of jobs in each project for each year was assigned.
- This is completed for all the known pipeline projects that Opergy has gained from verifiable sources. Projects were modelled out to 2050 although the planning pipeline only has data from 5 to 8 years in the future.
- Different proportions for UK Content were then inputted into the assumptions to allow for the differential modelling.

Location of workforce is very important. The methodology used, in brief, for ascertaining the site of the work was:

- Roles that are based at the site of the CCUS project were attributed to the location of the project.
- Roles in manufacturing were attributed to the region where the manufacturing is conducted informed by NOMIS data using a detailed industry analysis of CCS manufacturers.
- Roles in headquarters and regional offices was again attributed using NOMIS data and the known office locations of the developers and supply chain in the CCS sector.

This methodology allows us to identify the likely location of employment allowing the calculator to identify the workforce size and role types for each region based on the CCS projects taking place in that region as well as UK wide.

Only the power sector was modelled, other hard to abate sectors were not included in the study.

10.3 Scenarios Overview

The scenarios are designed to assess the impact of different levels of UK-based content in the construction and manufacturing phases of CCS projects. Each scenario examines the implications for employment, investment, and economic growth across regions.

10.3.1 Construction Content Scenarios

These scenarios evaluate the economic impact based on the percentage of construction work conducted within the UK:

Scenario 1: 60% UK Construction Content

- Assumes that 60% of construction activities for CCS projects are carried out domestically.
- Expected to generate significant employment in construction sectors, with a moderate economic impact due to reliance on imported goods and services.
- **Key Regions Impacted**: North East, North West, Scotland.

Scenario 2: 70% UK Construction Content

- Assumes 70% domestic construction content, leading to higher employment and economic benefits.
- Emphasises the importance of local workforce development and infrastructure investment.
- **Key Regions Impacted**: North East, North West, Scotland, and Wales.

Scenario 3: 80% UK Construction Content

- With 80% of construction content sourced domestically, this scenario sees increased employment in both skilled and unskilled labour sectors.
- Significant regional economic growth, especially in areas with strong industrial bases.
- **Key Regions Impacted**: All major CCS clusters, including the Midlands.

Scenario 4: 90% UK Construction Content

- This is the most ambitious scenario, with 90% of construction activities conducted within the UK.
- Maximises employment benefits and regional economic activity, with strong growth in ancillary sectors such as logistics and materials supply.
- **Key Regions Impacted**: Comprehensive national impact, with all regions benefiting from increased economic activity.

10.3.2 Manufacturing Content Scenarios

These scenarios focus on the proportion of manufacturing content that is retained domestically:

Scenario 1: 10% UK Manufacturing Content

- Low level of domestic manufacturing, leading to minimal local economic benefits and high reliance on imports.
- Modest employment gains, primarily in assembly and installation phases.
- **Key Regions Impacted**: Limited impact across all regions.

Scenario 2: 20% UK Manufacturing Content

- Increased domestic manufacturing content leads to moderate economic benefits and reduced reliance on imports.
- Potential for growth in regions with existing manufacturing capabilities.
- **Key Regions Impacted**: North East, North West, Midlands.

Scenario 3: 30% UK Manufacturing Content

- A higher level of manufacturing content is retained domestically, resulting in significant employment and economic benefits.
- Focus on developing local supply chains for key CCS components to help UK manufacturers build components of the scale required and to deliver the necessary volumes required.
- **Key Regions Impacted**: North East, North West, Scotland.

Scenario 4: 40% UK Manufacturing Content

- Maximum domestic manufacturing content scenario, leading to substantial economic growth and job creation.
- Enhanced regional capabilities in manufacturing, with strong growth in engineering and technical services.
- **Key Regions Impacted**: All regions, with significant impacts in Scotland and the North East.

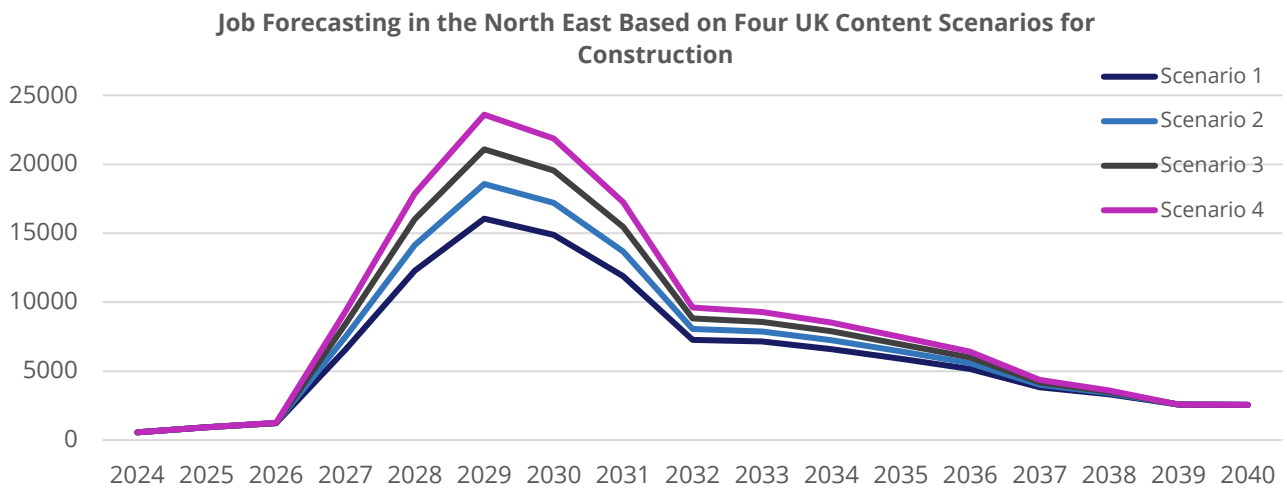
10.4 Regional Breakdown of Economic Impacts

The following sections provide a breakdown of the economic impacts for each region based on the scenarios outlined above.

10.4.1 North East England

The North East centred around the Net Zero Teesside cluster, is expected to see substantial growth in employment and economic impact due to its industrial base and proximity to biomass emitters and storage options.

Employment Impact: The region is projected to experience a peak employment of over 21,000 jobs in a single year, with a total of approximately 115,000 job years over 17 years.



Investment Needs: Economic benefits could reach nearly £3.4 billion, assuming 80% UK content in construction. This emphasises the importance of maximising local content to enhance regional economic outcomes.

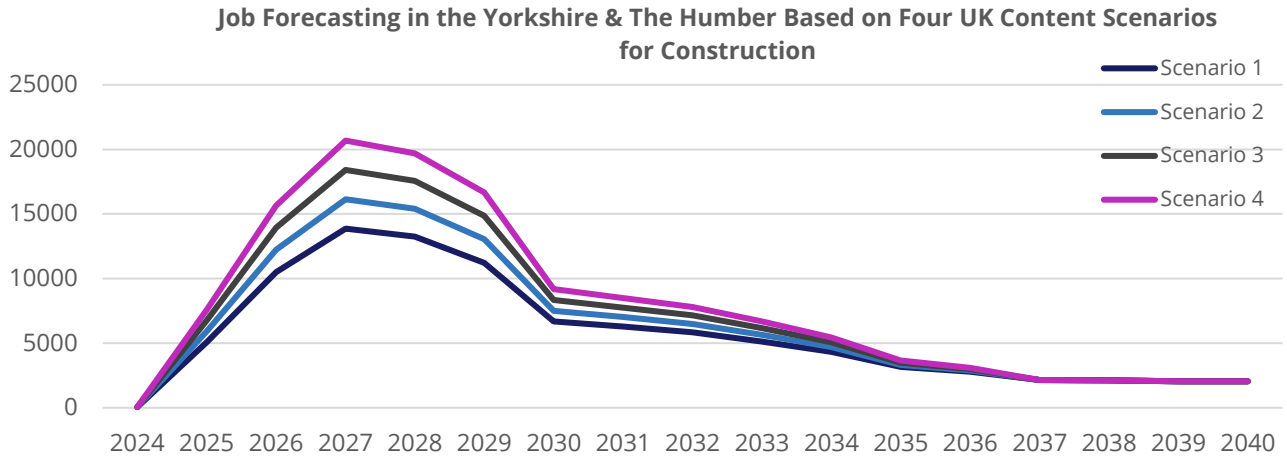
Key Opportunities:

- Developing the Net Zero Teesside cluster Leveraging existing industrial infrastructure and expertise in biomass and storage technologies.
- Focusing on high-value construction activities to maintain local economic benefits.

10.4.2 Yorkshire and Humber

Yorkshire and Humber, home to the Humber Zero Industrial Cluster and to Zero Carbon Humber are poised to gain significantly from CCS deployment due to their industrial base and access to North Sea storage sites.

Employment Impact: The region could benefit from an average of over 5,000 jobs per year, totalling over 91,000 job years up to 2040. This employment could generate approximately £3 billion in income over 17 years.



Investment Needs: Investment requirements could range significantly, with a potential difference of £800 million between high (80%) and lower (60%) local content scenarios in construction. A decrease in construction content could result in a loss of £15 million annually, highlighting the importance of maximising local construction activities.

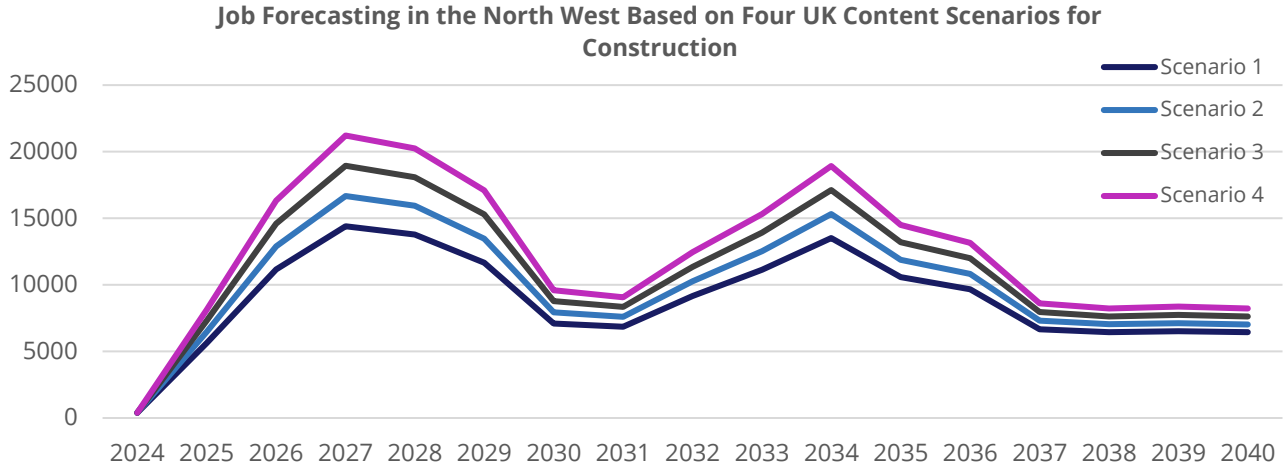
Key Opportunities:

- Maximising local content in construction to boost job creation and regional economic output.
- Leveraging the existing industrial base within the Humber Cluster.
- Investing in workforce development and infrastructure upgrades to support CCS activities.

10.4.3 North West England

The North West, encompassing HyNet and the potential Morecambe Net Zero cluster, stands to benefit from significant job creation and economic contributions due to its strategic position within the CCS deployment.

Employment Impact: The region could generate over 11,000 jobs per year on average, representing more than £6 billion in income over 17 years. The employment profile is expected to have two peaks: an early peak in 2027 (HyNet) and a later peak in 2034 (Morecambe Cluster).



Investment Needs: Investment requirements are aligned with the dual-cluster development strategy, emphasising the need for sustained investment throughout the project lifecycle.

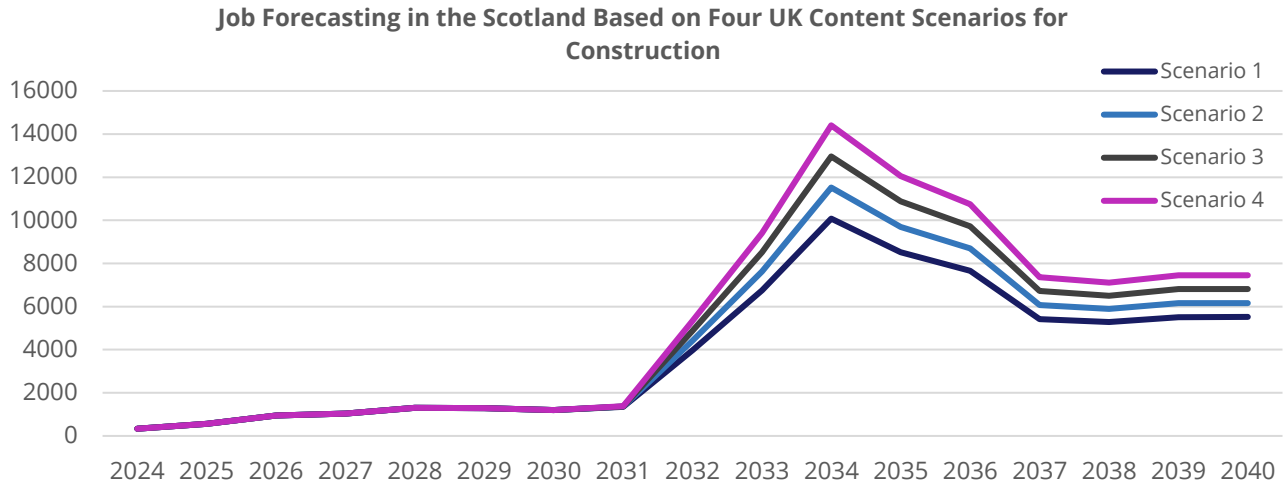
Key Opportunities:

- Expanding regional capabilities in chemical processing and CCS technologies.
- Strengthening infrastructure to support sequential peaks in construction and operation activities.
- Optimise supply chain efficiency by ensuring that infrastructure is planned on a regional basis.

10.4.4 Scotland

Scotland is expected to see a substantial increase in CCS-related employment and economic activities starting in the early 2030s.

Employment Impact: The region is projected to generate a substantial number of jobs, with over £1.8 billion in income over 17 years. There is a potential loss of over £0.5 billion if the construction proportion drops from 80% to 60%, demonstrating the impact of high local content.



Investment Needs: Continued investment is critical to capitalise on Scotland's expertise in oil and gas and to develop its offshore storage capabilities.

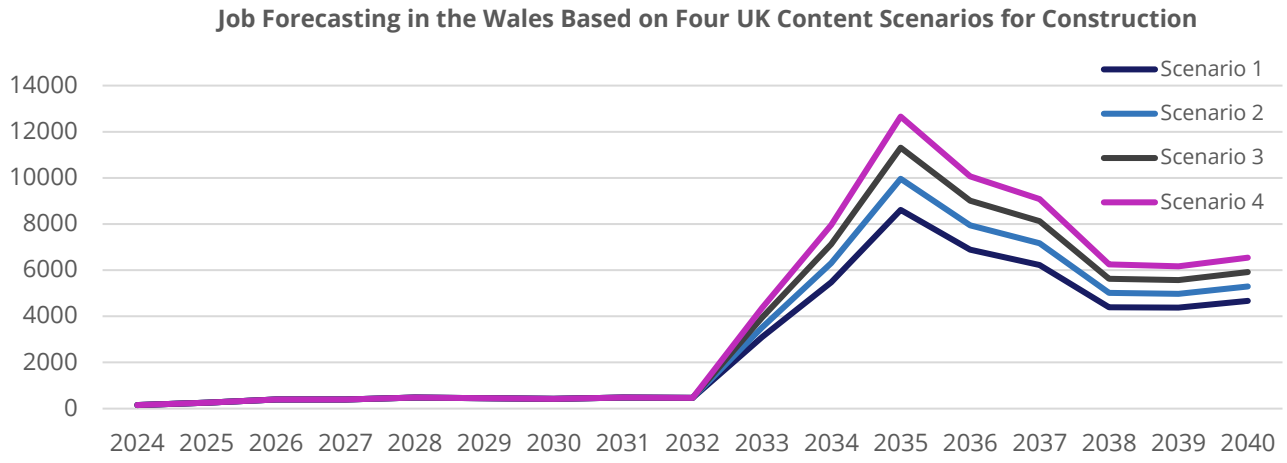
Key Opportunities:

- Retrofitting oil and gas infrastructure for CCS applications.
- Developing skills and training programs to transition the workforce to CCS roles.

10.4.5 South Wales

South Wales is anticipated to benefit from CCS deployment, particularly if local content in construction and manufacturing activities remains high.

Employment Impact: The region is expected to create a significant number of jobs, with potential losses of £400 million if construction content decreases from 80% to 60%.



Investment Needs: Focused investments are necessary to support ongoing construction activities beyond 2040, given the lack of local storage capacity.

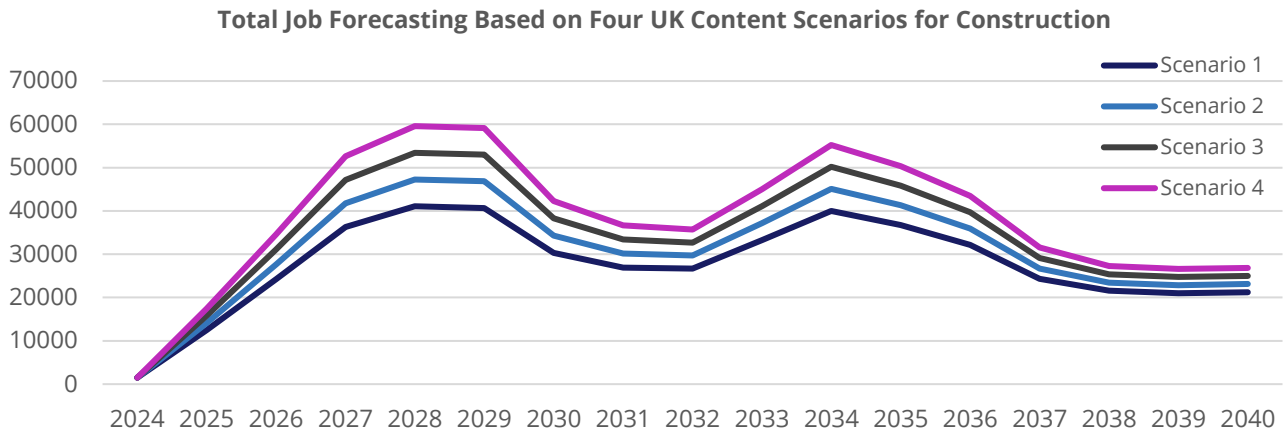
Key Opportunities:

- Building local manufacturing hubs to support CCS development.
- Enhancing logistics and transport capabilities to facilitate component movement.
- Establishing partnerships to strengthen the regional supply chain and economic impact.

10.4.6 UK Total

The deployment of CCS technology across the UK presents a significant opportunity to boost economic growth, create jobs, and strengthen the domestic supply chain. By maximising local content in manufacturing and construction, the UK can enhance its competitive position in the global CCS market and ensure that the benefits of this transition are broadly shared across all regions.

Total Employment Impact: Across all regions, CCS deployment is expected to create a substantial number of jobs, with peak employment reaching over 40,000 jobs in a single year under high-content scenarios. Cumulatively, this represents hundreds of thousands of job years over the project lifespan, translating into several billion pounds in income distributed across various regions.



Total Investment Needs: The total investment required for CCS deployment in the UK varies depending on the scenario, with estimates ranging from £1.8 billion to £4.2 billion. This investment will be crucial for developing infrastructure, upgrading existing facilities, and supporting local manufacturing and construction activities.

Key National Opportunities:

- **Maximising Economic Impact**: By focusing on high UK content scenarios, the UK can maximise job creation and economic output, particularly in regions with strong industrial bases and proximity to storage sites.
- **Developing a Robust Supply Chain**: Investing in domestic supply chain capabilities, including manufacturing, logistics, and services, will be essential to support CCS projects and enhance national energy security.
- **Promoting Regional Collaboration**: Encouraging collaboration between regions and clusters can foster innovation, improve efficiency, and ensure that the benefits of CCS deployment are widely distributed across the UK.
- **Skills and Workforce Development**: Developing targeted training programs and upskilling initiatives will be critical to preparing the workforce for the opportunities presented by the CCS sector, ensuring that workers across the UK can benefit from this emerging industry.

11 Appendix D: Workshop and Stakeholder Engagement Summaries

11.1 Introduction to Workshops and Stakeholder Engagement

This appendix provides a detailed summary of the workshops and stakeholder engagement activities conducted as part of the CCS Supply Chain Implementation Plan. These workshops were essential for gathering diverse perspectives from across the industry, government, and academia, which helped identify key challenges and opportunities within the UK CCS supply chain. The insights gained through these engagements were crucial in shaping the findings and recommendations of this report.

11.2 Workshop Overview

The workshops were structured to facilitate discussions among a diverse group of stakeholders, including representatives from industry, government bodies, regional cluster managers, and academia. The aim was to comprehensively understand the current state of the UK CCS supply chain, explore barriers to mobilisation, and identify strategies for enhancing supply chain readiness.

The **workshop structure** agreed upon with the Industrial Decarbonisation Challenge (IDC) is detailed in the table below:

Item	Key Points
Welcome and Introduction	• Welcome note by the IDC team. • Introduction of participants, their roles, and projects.
Project Overview Presentation	• Presentation by the team outlining the project scope, objectives, and expected impact.
Current Capability of the Supply Chain and Stakeholder Discussion	• Outline of readiness judgements. • Time for each stakeholder to express their project's vision, progress, barriers, expectations, and initial ideas. • Facilitated discussion on potential challenges and opportunities.
Supply Chain Process Analysis & Barriers and Stakeholder Discussion	• Facilitated journey through the supply chain processes to identify barriers. • Group discussion on each barrier and collective viewpoint on their significance.
Opportunities and Solutions and Stakeholder Discussion	• Each breakout group presents their findings and suggestions. • Open floor for feedback and additional insights from all participants.
Component Opportunities and Stakeholder Discussion	• Discussion on manufactured components that could be suitable for a UK Supply Chain.
Other Points of Note and Stakeholder Discussion	• Identification of other issues and areas of improvement, followed by group feedback.

Wider Environment	• Examination of how the suggested improvements will complement or be affected by other ongoing initiatives.
Workshop Synthesis and Next Steps	• Summary of key points from discussions and presentations. • Outline of next steps for the project.

Table 1 - Workshop Structure and Key Points

11.3 Summary of Workshop Sessions

The workshops were organised into several sessions, each focusing on different aspects of the CCS supply chain. Participants were encouraged to share their insights and experiences, which helped to identify both existing challenges and potential opportunities for development.

Session 1: Understanding Current Supply Chain Capabilities

This session focused on assessing the existing capabilities within the UK CCS supply chain. Stakeholders shared their experiences regarding the availability of components, services, and skilled labour required for CCS projects. It became evident that while the UK has some capabilities, significant gaps exist, particularly in manufacturing critical components such as large pressure vessels and proprietary amines. The discussions highlighted the need for targeted investments to enhance domestic capacity and reduce reliance on imports.

Session 2: Barriers to Supply Chain Mobilisation

In this session, stakeholders discussed the barriers that prevent the effective mobilisation of the UK CCS supply chain. Regulatory challenges, financial constraints, and logistical difficulties were among the key issues raised. There was a consensus that investor confidence in new suppliers, especially SMEs, is limited due to a lack of proven track records in the CCS sector. Additionally, the high costs and extended timelines associated with scaling up manufacturing capabilities for specialised components were highlighted as significant challenges.

To provide a comprehensive overview of these barriers and potential solutions, the following table has been included:

Barrier	Description	Suggested Mitigations
Regulatory Challenges	Inconsistent regulations across regions create uncertainty and delay project timelines.	Develop a unified regulatory framework for CCS projects across the UK.
Financial Constraints	High upfront investment costs deter new entrants, particularly SMEs.	Introduce government-backed financial support programs, such as grants or low-interest loans.
Logistical Difficulties	Limited domestic manufacturing capabilities for specialised CCS components, leading to reliance on imports.	Invest in expanding domestic manufacturing capabilities and provide incentives for local production.

Lack of Investor Confidence in SMEs	SMEs are perceived as high-risk due to their limited track record in CCS.	Create support mechanisms to de-risk SME participation in CCS projects, such as partnering with larger firms.
Skills Gaps	Shortage of skilled labour in key areas, such as engineering and construction, limits the ability to scale up CCS projects.	Develop targeted training programs and partnerships with educational institutions to build the necessary skills.

Table 2 - Summary of Barriers to Supply Chain Mobilisation and Suggested Mitigations

Session 3: Opportunities for Enhancing Supply Chain Readiness

The third session was dedicated to exploring opportunities to enhance the readiness of the UK CCS supply chain. Participants discussed strategies such as increasing investment in domestic manufacturing capabilities, leveraging expertise from the oil and gas sector, and developing targeted training programs to address skills shortages. There was also a strong emphasis on the need for strategic partnerships to foster innovation and strengthen the supply chain.

11.4 Participant Overview

The workshops involved a diverse group of participants representing different clusters, companies, and regions. The breadth of participation in the workshops ensures a comprehensive representation of the CCS supply chain across various regions and companies. The inclusion of different clusters and companies allowed for a diverse set of perspectives to be shared, contributing to a more robust understanding of the challenges and opportunities within the supply chain.

11.5 Key Findings from Stakeholder Engagement

The workshops and stakeholder engagements revealed several critical findings that informed the recommendations of this report. A significant insight was the recognition of the diverse challenges faced by different regions and clusters. For example, participants from the North East emphasised the need for enhanced manufacturing capabilities to support the large-scale deployment of CCS projects. At the same time, those from the North West highlighted the importance of developing a skilled workforce to meet future demand.

Another key finding was the identification of specific components and processes within the supply chain that present opportunities for development. Discussions highlighted the potential for UK-based manufacturing of certain components, such as pressure vessels and heat exchangers, which could reduce reliance on imports and enhance the resilience of the supply chain.

Stakeholders also noted the importance of aligning CCS projects with other ongoing initiatives to maximise synergies and avoid duplication of efforts. This broader perspective on the CCS supply chain's role within the wider decarbonisation landscape was seen as crucial for ensuring long-term success and sustainability.

11.6 Conclusion

The workshops and stakeholder engagements were instrumental in providing a comprehensive view of the current state of the UK CCS supply chain. The structured discussions facilitated a deep exploration of both barriers and opportunities, resulting in a set of well-informed recommendations that are responsive to the needs and priorities of the industry. The insights gained through these activities will be vital for guiding future efforts to enhance the readiness and capability of the UK CCS supply chain.

12 Appendix E: Economic Impact Modelling and Forecasts

12.1 Introduction to Economic Modelling

This appendix outlines the high-level economic impact modelling conducted to assess the potential effects of the CCS Supply Chain Plan on the UK economy. The modelling provides an analysis of both national and regional impacts, focusing on factors such as employment, GDP contribution, and sectoral growth. These forecasts are based on data drawn from industry reports, stakeholder engagements, and established economic models.

12.2 Data Sources and Methodology

The economic impact modelling relied on a combination of data sources:

- **Industry Reports**: Key reports such as "CCUS Supply Chains – A roadmap to maximise the UK's potential" (BEIS 2021) and "Industrial CCUS UK Supply Chain Capabilities" (WSP 2022) were integral to understanding baseline capabilities and future projections.
- **Stakeholder Engagements**: Data collected from stakeholder engagements provided real-world insights into current supply chain readiness, potential barriers, and opportunities. These engagements included interviews, surveys, and workshops with industry leaders, government representatives, and regional cluster managers.
- **Economic Modelling Techniques**: The modelling approach used recognised economic multipliers and growth rates tailored to the CCS sector. Assumptions were aligned with standard economic forecasting methods and validated against historical data from similar industrial transformations.

The following tables reflect projections based on this blended approach, combining quantitative data and qualitative insights.

12.3 National Economic Impact Analysis

The table below summarises the projected national economic impact under different investment scenarios. These figures are derived from combining data from the aforementioned reports

Economic Indicator	Low Investment Scenario	Moderate Investment Scenario	High Investment Scenario
GDP Contribution (£ billion)	2.5	4.8	7.2
Total Employment (jobs)	25,000	45,000	70,000
Export Opportunities (£ billion)	0.8	1.5	2.5

Table 3 - Projected National Economic Impact of CCS Supply Chain Expansion by 2030 - Source: Compiled from "CCUS Supply Chains – A roadmap to maximise the UK's potential" (BEIS 2021), "Industrial CCUS UK Supply Chain Capabilities" (WSP 2022), and stakeholder engagement data

12.4 Regional Economic Impact Analysis

The table below details the projected regional economic impacts under a high investment scenario. The projections are based on regional data and tailored economic multipliers, which consider the unique industrial compositions of each area.

Region	GDP Contribution (£ million)	Manufacturing Employment (jobs)	Construction Employment (jobs)	Other Employment (jobs)
North East	1,200	6,000	3,000	2,000
North West	1,000	4,000	5,500	1,500
Scotland	900	3,500	4,000	1,200
Other Regions	1,400	7,000	4,500	2,100

Table 4 - Projected Regional Economic Impact of CCS Supply Chain Expansion by 2030 - Source: Based on regional economic data from "CCUS Supply Chains – A roadmap to maximise the UK's potential" (BEIS 2021) and adjusted using regional economic multipliers and insights from stakeholder engagements

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12.5 Key Drivers and Assumptions

The modelling relied on several key drivers and assumptions:

1. **Investment Levels**: Assumptions regarding low, moderate, and high investment scenarios were derived from stakeholder feedback and aligned with historical investment patterns in similar sectors.
2. **Economic Multipliers**: Employment and GDP multipliers specific to the CCS sector were used to project economic impacts. These were validated against similar industries and adjusted for regional variances.
3. **Supply Chain Development**: Projections considered the potential for developing a domestic supply chain for CCS components, including manufacturing capabilities and workforce skills.

12.6 Conclusion

The economic impact modelling demonstrates significant potential benefits of expanding the UK CCS supply chain, contingent on strategic investment and coordinated policy efforts. The projections provide a roadmap for maximising economic returns across the UK, emphasising the importance of leveraging regional strengths and developing a skilled workforce to support the CCS sector's growth.

13 Appendix F: Literature Review Findings

13.1 Introduction to the Literature Review

This appendix presents a summary of the literature review conducted to support the development of the CCS Supply Chain Implementation Plan. The review aimed to collate existing knowledge, identify gaps in the current research, and provide a foundation for understanding the challenges and opportunities within the UK CCS supply chain. By examining a wide range of documents, including government reports, industry studies, and academic papers, the review provided a comprehensive understanding of the current state and potential future developments in the CCS sector.

13.2 Scope of the Literature Review

The literature review focused on several key areas relevant to the CCS supply chain, including technological advancements, economic impacts, policy frameworks, and strategic growth opportunities. The review drew from a broad array of sources to ensure a well-rounded perspective, including:

- Government reports such as "CCUS Supply Chains – A roadmap to maximise the UK's potential" (BEIS 2021) and "Industrial CCUS UK Supply Chain Capabilities" (WSP 2022).
- Industry publications, including the "Supply Chain Excellence for CCUS" report by the Carbon Capture and Storage Association (CCSA 2021).
- Academic studies that provide insights into the skills requirements for the industrial decarbonisation supply chain, such as "Enabling Skills for the Industrial Decarbonisation Supply Chain" (University of Chester and Mace 2023).

13.3 Key Findings from the Literature

13.3.1 Technological Advancements and Gaps

The literature review highlighted significant advancements in CCS technology, particularly in carbon capture methods and storage solutions. Several reports, including the BEIS (2021) roadmap, underscored the evolution of capture technologies from post-combustion and pre-combustion to more advanced methods like oxy-fuel combustion and direct air capture. These advancements have been pivotal in reducing the costs and increasing the efficiency of CCS projects.

13.3.2 Economic Impacts and Opportunities

The reviewed literature provided an analysis of the economic impacts of CCS deployment, highlighting both costs and potential benefits. Reports like WSP (2022) noted that while the initial capital expenditures for CCS projects are high, the long-term benefits, including job creation, GDP growth, and enhanced energy security, outweigh these costs. The potential for the UK to develop a robust domestic supply chain for CCS components was also a recurring theme, with several studies advocating for investment in local manufacturing capabilities to reduce reliance on imports and strengthen economic resilience.

A notable opportunity identified was the potential for the UK to become a leader in the export of CCS technologies and services. By leveraging its existing industrial base and investing in skills development, the UK could position itself as a global hub for CCS, providing technology, expertise, and components to projects worldwide.

13.3.3 Comparative Analysis of UK CCS Supply Chain Components

To further understand the economic opportunities and areas for development within the UK CCS supply chain, a comparative analysis was conducted using data from multiple reports, including those by ARUP, NAMRC, and WSP. The analysis is presented in Table 4 below, which evaluates various components of the CCS supply chain based on a range of measures, including capacity, capability, cross-sector support, intellectual property (IP), ability to repurpose legacy infrastructure, and financial value.

Component	Capacity (ARUP)*	Capability (ARUP)	Cross-sector support (ARUP)	IP (ARUP)	Financial Value (ARUP)	Capability (NAMRC)	Capability (WSP)	Overall
Absorption columns								
Amine treatment								
Basic Process Controls System (BPCS)								
Column internals								
Column vessels								
CO_2 compressors								
CO_2 stripper columns								
Direct contact coolers								
Filters								
Flue gas blowers								
Gas-gas exchangers								

Component	Capacity (ARUP)*	Capability (ARUP)	Cross-sector support (ARUP)	IP (ARUP)	Financial Value (ARUP)	Capability (NAMRC)	Capability (WSP)	Overall
Heat exchangers								
Jackets								
Line pipes/CO_2 Pipes								
Metering								
Pumps								
Tanks								

Table 5: matrix combines overall assessments (using a range of measures) from reports by ARUP, NAMRC and WSP. The legend is as follows: green = 'high', amber = 'medium', red = 'low', grey = 'no data'/'component' in one report was not assessed in another

**ARUP document refers to the UK experience. Assumed as synonymous with capability*

This matrix highlights several critical insights into the current state of the UK CCS supply chain:

1. **Strengths and Opportunities**: Components such as **Basic Process Control Systems (BPCS)** and **Column Vessels** are generally well-regarded across multiple criteria, indicating strong existing capabilities in these areas.
2. **Gaps and Challenges**: **CO_2 Compressors** and **Flue Gas Blowers** are noted with several "Red" (low) ratings, signalling areas where the UK supply chain may need additional investment or development to meet future demand.
3. **Cross-Sector Comparisons**: The varying assessments across different reports (ARUP, NAMRC, WSP) also highlight discrepancies in perceived capabilities and readiness, suggesting a need for further alignment and clarification within the industry. N.B. the reports were spread over five years, and so the differences in readiness may be substantially due to the year of report delivery.

13.3.4 Policy Frameworks and Regulatory Environment

The literature review also examined the role of policy and regulation in shaping the CCS supply chain. Several documents, including the CCSA (2021) report, highlighted the importance of a stable and supportive policy environment in fostering investment and encouraging innovation in the CCS sector. Key recommendations included the need for clearer regulatory frameworks, streamlined permitting processes, and financial incentives to de-risk investments in CCS projects.

Moreover, the literature emphasised the importance of alignment between national and regional policies to ensure a coordinated approach to CCS deployment across the UK. This alignment is crucial for creating a consistent regulatory environment that supports both small-scale and large-scale CCS projects.

13.3.5 Strategic Opportunities for Growth

The literature review identified several strategic opportunities for growth within the CCS supply chain. One of the primary opportunities is the development of regional industrial clusters that can serve as hubs for CCS activity. Reports like BEIS (2021) suggest that clusters in the North East, North West, and Scotland, with their established industrial bases and proximity to potential storage sites, are well-positioned to lead the development of the UK's CCS supply chain.

Additionally, the review highlighted the potential for integrating CCS with other decarbonisation initiatives, such as hydrogen production and renewable energy deployment. By leveraging synergies between these sectors, the UK can create a more holistic approach to reducing carbon emissions and enhancing energy security.

13.3.6 Skills and Workforce Development

An important theme in the literature was the need for targeted skills development to support the CCS supply chain. The University of Chester and Mace (2023) study pointed out that while the UK has a strong foundation in engineering and technical skills, there is a need for specialised training programs to equip the workforce with the skills required for CCS projects. This includes not only technical skills in areas like engineering and construction but also broader competencies in project management, regulatory compliance, and environmental stewardship.

13.3.7 Modularisation vs Specialisation

The reviewed literature highlights the debate between modularisation and specialisation within the UK CCS supply chain. The UK faces international competition from countries like Germany, Italy, and Poland, which have different industrial setups. The UK's higher proportion of SMEs specialising in cutting-edge technology presents both challenges and opportunities, particularly in sectors requiring advanced R&D and bespoke manufacturing.

- **Challenges**: Competing with larger fabrication yards in other countries and higher land costs in the UK, leading to increases in build expenses and operational costs.
- **Opportunities**: Leveraging the UK's strengths in R&D and bespoke manufacturing, especially in SMEs that can rapidly innovate and adapt to new CCS technologies.

13.3.8 Supply Chain Strengths and Weaknesses

The literature review identifies key strengths and weaknesses in the UK CCS supply chain:

- **Strengths**: Strong capabilities in certain components, such as CO_2 piping and column vessels, and a well-developed foundation in offshore operations and engineering design.
- **Weaknesses**: Gaps in areas like compressors and pipework, Strategic and a need for improved infrastructure and technological innovation.

13.4 Conclusion of the Literature Review

The literature review provided valuable insights into the current state and future potential of the UK CCS supply chain. By identifying key technological advancements, economic opportunities, policy needs, and strategic growth areas, the review has helped to shape the recommendations of this report. The findings underscore the importance of continued investment in research and development, targeted skills training, and a supportive policy environment to enable the successful deployment of CCS in the UK.

14 Appendix G: Glossary of Terms and Acronyms

This appendix contains a glossary of key terms and acronyms used throughout the Carbon Capture and Storage Supply Chain Plan report. This glossary is designed to help readers understand technical language and abbreviations commonly used in the context of CCS and related sectors.

Acronym/Term	Definition
BECCS	Bioenergy with Carbon Capture and Storage - A process that combines biomass energy production with CCS technology to achieve net-negative CO_2 emissions.
BEIS	Department of Business, Energy, and Industrial Strategy
BP	British Petroleum - A major energy company involved in CCS and other decarbonisation initiatives.
CCS	Carbon Capture and Storage - Technology that captures CO_2 emissions from industrial sources and stores them underground to prevent atmospheric release.
CCSA	Carbon Capture and Storage Association - An industry association representing the interests of CCS stakeholders in the UK.
CCUS	Carbon Capture, Utilisation, and Storage - An extension of CCS where captured CO_2 is also utilised for commercial purposes.
CO_2	Carbon Dioxide - A greenhouse gas emitted from burning fossil fuels and a key target for capture in CCS processes.
DBT	Department for Business and Trade - UK government department involved in promoting business and trade, including CCS investments.
DESNZ	Department for Energy Security and Net Zero - UK government department responsible for energy policy and net-zero initiatives, including CCS.
ECC	Energy and Climate Change - Refers to regional clusters focused on CCS and decarbonisation.
EPC	Engineering, Procurement, and Construction - A contract model in which the contractor delivers the entire project, including design, procurement, and construction.
IDC	Industrial Decarbonisation Challenge - A UK government initiative aimed at accelerating industrial decarbonisation, including CCS.
NET	Negative Emissions Technology - Technologies that remove CO_2 from the atmosphere, such as BECCS and direct air capture.
NEP	Northern Endurance Partnership - A regional initiative focused on achieving net-zero emissions through various projects, including CCS.
NZIW	Net Zero Industrial Wales - A regional initiative aimed at achieving net-zero emissions in Wales, including through CCS projects.
NZT	Net Zero Teesside - A major CCS project in the Teesside region aimed at capturing CO_2 emissions from a new-build gas-fired power plant and industrial sources in the region.
SME	Small and Medium-sized Enterprises - Businesses with fewer than 250 employees, often involved as suppliers in CCS supply chains.
SWIC	South Wales Industrial Cluster - A cluster of industries in South Wales collaborating on CCS and other decarbonisation initiatives.
Sequestration	The process of storing captured CO_2 in geological formations underground to prevent it from entering the atmosphere.
Flue Gas	The gas that exits to the atmosphere via a flue, often containing CO_2, which is targeted for capture in CCS processes.