ARUP

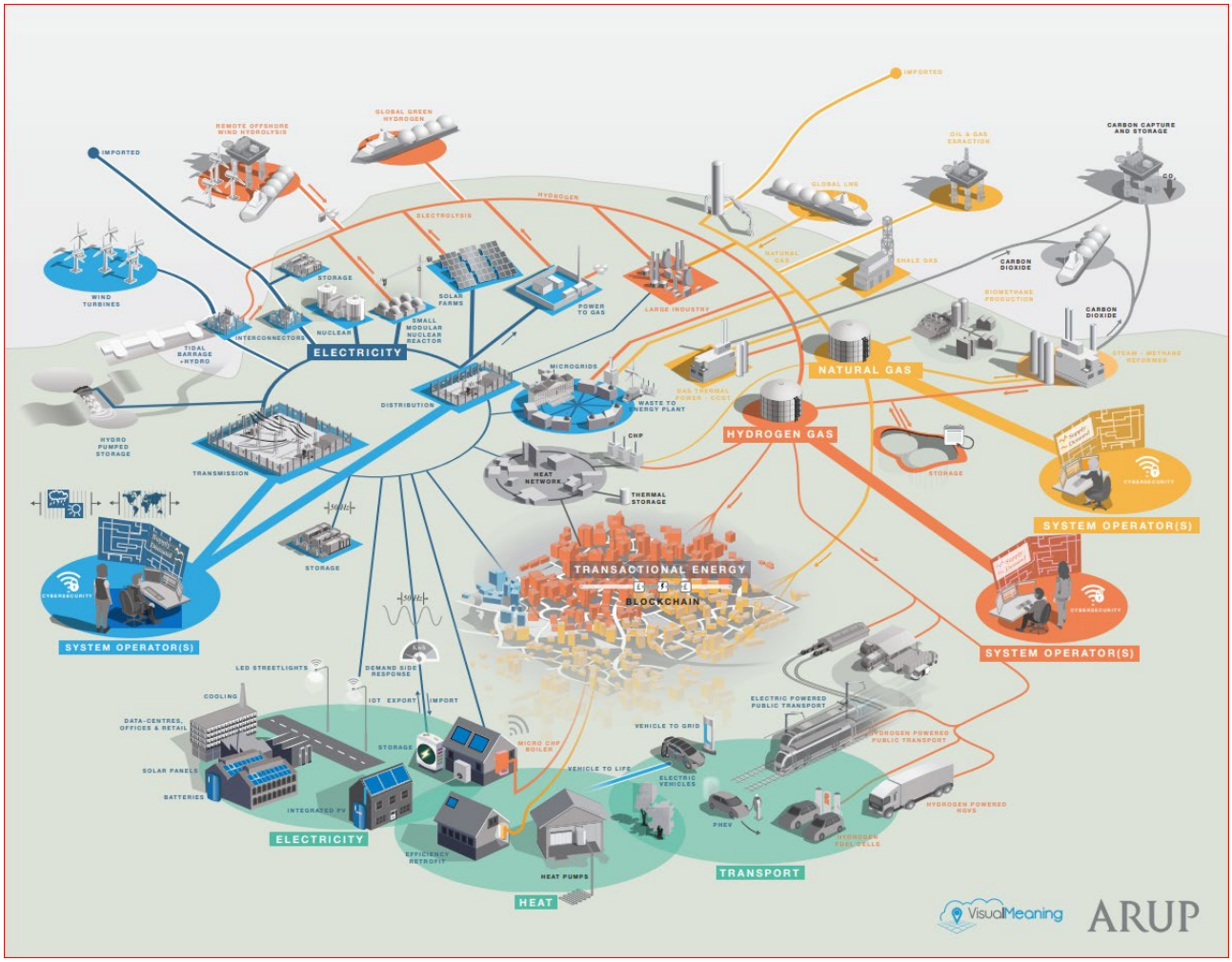
Department for Energy Security and Net Zero

‘A Remarkable New Infrastructure System’

Opportunities for economic growth in the UK’s Carbon Capture & Storage Industry

Reference: UK Carbon Capture & Storage Supply Chain Study

7th July 2023



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Ove Arup & Partners Limited
8 Fitzroy Street
London
W1T 4BJ
United Kingdom
arup.com

ARUP

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	Prepared by	**Checked by**	**Approved by**
Name	Jemima Bruin-Bland Henry Williams Tom Phillips	Rob Duffin Heidi Genoni	Mark Neller
Signature	JBB		

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Contents

Glossary of Terms

	List of Abbreviations
AI/ ML	Artificial Intelligence/ Machine Learning
ASTI	Accelerated Strategic Transmission Investments
ATR	Autothermal Reforming
BECCS	Bio-Energy with Carbon Capture And Storage
BEIS	The Department for Business, Energy & Industrial Strategy
BPCS	Basic Process Control System
BSI	British Standards Institution
CAD	Computer-Aided Design
CAPEX	Capital Expenditure
CCS	Carbon, Capture and Storage
CCSA	Carbon, Capture and Storage Association
CCUS	Carbon, Capture, Utilisation, and Storage
CfD	Contracts For Difference
CO_2	Carbon Dioxide
Cop26	Conference of the Parties 2026
DAC	Direct Air Capture
DEH	Direct Electric Heating
DESNZ	Department For Energy Security and Net Zero
DRI	Direct Reduced Iron
EAF	Electric Arc Furnaces
ECC	East Cost Cluster
EfW	Energy from Waste
EIC	European Innovation Council
EPC	Engineering, Procurement and Construction
EPCm	Engineering, Procurement and Construction Management
ETS	Emissions Trading System
FEED	Front-End Engineering and Design
FID	Final Investment Decision
GHR	Gas-Heated Reformer
Gt	Gigaton
HS2	High Speed 2
HyNET	A Carbon Capture and Storage Cluster
ICCUS	Industrial Carbon Capture Usage and Storage
ICE	Institute For Civil Engineers
IEA	International Energy Agency
IP	Intellectual Property
IPA	Infrastructure Projects Authority
IR	Industrial Relations
ISO	Internal Standard Organisation
KO drum	Knock Out Drum
LNG	Liquified Natural Gas
LPG	Liquified Petroleum Gas
LTCS	Low Temperature Carbon Steel
MDEA	Mono-Di-Ethyl-Amine
MEA	Mono-Ethyl-Amine
MPS	Mandatory Product Standards
Mt	Millitonnes
Mtpa	Million Tonnes Per Annum
NAMRC	Nuclear Advanced Manufacturing Research Centre
NDT	Non-destructive Testing
NOx	Oxides of Nitrogen
NSTA	North Sea Transition Authority

O&G	Oil & Gas
O&M	Operations & Maintenance
OEUK	Offshore Energies UK
R&D	Research & Development
RAG	Red, Amber, Green
SCAPs	Supply Chain Action Plan
SCR	Selective Catalytic Reduction
SME	Subject Matter Experts
SMR	Steam-Methane Reforming
SS	Stainless Steel
STEM	Science, Technology, Engineering, Maths
TCE	The Crown Estate
TEG	Triethylene Glycol
TRL	Technology Readiness Level
UK SIC	UK Standard Industrial Classification of Economic Activities
UKCS	United Kingdom Continental Shelf
UNSPSC	United Nations Standard Products and Services Code

1. Executive Summary

"The goal… is to change the nature and shape of our global civilisation, so that we stop using the sky as an open sewer. If you could drive a car straight up from the ground at autobahn speeds you would reach the top of the sky in 5 minutes, and that very thin shell is where we are dumping 162 million tons of man-made global warming pollution, every single day.''

– **Al Gore**, Glasgow, November 2021 (Cop26)

The International Energy Agency (IEA) estimates that to reach their Net Zero scenario for the global energy sector by 2050, 1286 million tonnes (Mt) of carbon dioxide (CO_2) must be captured and stored per year by 2030, compared to the 44 Mt per year in operation across the globe in May 2023. As a result of our geology, our historical strength in North Sea energy, and the proximity of these UK assets to multiple major industrial hubs, we are uniquely well placed to provide this decarbonising service to our own industrial and power sectors, and to those of our neighbours.

Carbon Capture, Utilisation and Storage (CCUS) has the power to rapidly decarbonise our existing industry and power sectors and support the production of low carbon hydrogen, while enabling growth and the creation of high-value UK jobs. As we progress towards our national target of capturing between 20 and 30Mt of CO_2 per year by 2030, we will only be just beginning to take advantage of our estimated 78 gigatonnes (Gt) total national reserve of CO_2 storage. CCUS can establish in time, supported by technologies such as Direct Air Capture (DAC), a means of achieving our emissions reduction requirements and de-polluting our skies. In the UK, as this report sets out, CCUS has a potential role in kickstarting the UK's return to growth in industrial centres around the country.

This report looks in detail at the CCS value chain: from capture, through filtration, compression, and transport, and through further compression and processing prior to subsea storage and monitoring. We have drawn on previous reports from the UK's energy industry representatives such as Offshore Energies UK (OEUK), the Carbon Capture and Storage Association (CCSA) and the Nuclear Catapult (NAMRC), as well as some commissioned directly by the UK government. Following a detailed analysis of the UK's capabilities and capacities in design engineering, manufacturing, fabrication, construction and associated services, we have produced here a report in two main parts.

Firstly, we have set out the main goods and services which comprise the CCS value chain, itemised to a level of detail which we believe can be both useful and usable in the context of this emerging new industry. The audience for this first Full Value Chain UK CCS Taxonomy are the project developers and engineering professionals from across the UK's CCS value chain, as well as government and policy makers who are working to support the emergence of this new industry. The intention is that this tool will serve as a baseline for the development of the necessary tracking and monitoring of the potential 'value pools' which we believe can be realised for UK companies in the development of this new infrastructure system.

Secondly, we have worked with industry stakeholders to define 'High Value' in terms of CCS goods and services and to identify the 'high value' goods and services from the UK CCS value chain. Our first step here was to establish that high value would be measured and evaluated against a range of metrics, including both the capacity of the UK supply chain and the criticality of the goods and services to the delivery of the UKs near term and longer-term ambitions in CCS. In this section of the report, we set out in detail our analysis of the strengths and limitations of the UK's supply chain according to the best available current data in this area, as measured against the assessment criteria which we established as jointly indicating 'high value' for the UK CCS value chain. Our analysis in this area has benefited from the involvement of a wide range of subject-matter experts and analysts from the Arup team as well as the expert views of CCSA members, the NSTA, the OEUK and EIC representatives, as well as wider industry participants through the CCS Council Supply Chain Working Group and other forums. We would like to offer our thanks to all of the many industry and government participants who have contributed to the study.

This analysis has been developed through a series of engagements and consultations in order to ensure that alongside the UK government's wider CCS Supply Chain Strategy, this work represents, as far as is possible, a consensus view of industry and policymaker stakeholders. Following a series of workshops, consultations, and engagements, as well as desk-top analysis of the pre-existing studies, we now have a single collated view of the existing supply chain and its 'high value' risks and opportunities.

Summary of 'high value' items for the UK in the CCS Value Chain

1. Construction & construction management services: anticipated to present major constraint to the UK CCS sector and wider UK Energy Transition without increased coordination across UK sectors, the construction (and wider EPC) sector is expected to face significant constraint and require enablement and coordination to ensure that demand can be met ahead of 2030.

2. Engineering design: a major economic opportunity for the UK, playing to a nationwide strength in high-value technical design, building on our active national on- and off-shore energy industries and drawing on the skills of the 5.6 million people employed in the UK engineering sector, of which an estimated 330,000 are employed in the advanced fuels and chemicals sector.

3. Column vessel manufacture, assembly and internals present the major single source of opportunity for UK companies of the equipment needed to serve the UK CCS sector. Column vessels are the largest item in a capture plant by both physical size and capital expenditure. This presents both an opportunity and a constraint in terms of UK fabrication yard capacity and leads us to recommend an early and wide-ranging consultation with existing UK fabrication yards in order to establish the possibilities for their expansion in strategic locations.

4. There is significant UK capability and capacity in heat exchanger manufacture and assembly in the UK. Given the range of sizes of heat exchangers required across industrial carbon capture, processing, compression and transport, we consider that heat exchanger production also presents a significant potential growth area for the UK and one in which the UK could gain competitive advantage in the light of the emergence of new UK CCS infrastructure.

5. Process controls, including controls interfaces and dashboards, as well as connected linear monitoring and controls, SCADA, BPCS or other infrastructure control system monitoring technologies present a UK opportunity area due to the importance of balancing demands across the emerging CCS infrastructure system and communication across the networked assets, as well as the sensitivity and variability across store types.

6. Packaged CCS provisions, occasionally including operation and maintenance within the CCS value chain have become an increasingly established element of the international CCS value chain. In the course of this study we have noted that several UK companies are now offering capture packages for industrial customers, and that the supply chain is now developing rapidly. We anticipate the emergence of wider range of companies with competitive offerings in this space.

2. Introduction

2.1 Purpose

The UK is uniquely well-positioned to lead the global development and deployment of carbon capture and storage (CCS). The breadth of industrial experience, including substantial oil and gas engineering heritage, world-leading capital investment landscape and the storage supporting geography and geology all provide the UK with a clear opportunity to develop and maintain a CCS focussed industry and supply chain.

The purpose of this report is to bring together evidence of current UK CCS supply chain capabilities and present a consistent methodology for the comparison of data across the full CCS value chain. This will support work being led by the UK CCUS industry to develop a national CCUS Supply Chain Strategy.

2.2 Report Objectives

The outcome of this report is to provide insight against two key questions:

- What are the "high value" opportunities within the CCUS supply chain that UK industry is well placed to take advantage of in creating or growing capacity; and,
- What are the areas of risk to UK CCUS deployment caused by gaps or bottlenecks in the current supply chain capabilities and capacity.

These insights will act as a precursor to potential policy initiatives, whose ambition is to maximise the return on investment made by the UK government, while minimising deployment risk, in supporting the evolution of this sector in the UK

In delivering its outcome, the report will respond to the following objectives:

- Build on and consolidate existing studies conducted on the UK supply chain capabilities to form a single, comparable data set;
- Establish a single taxonomy for the CCUS supply chain in the UK, for use by all stakeholders including regulators and supply chain participants. The aim of this is to provide a tool that supports the streamlining of procurement, allows tracking of local content in UK projects, and aids the acceleration of project deployment; and,
- Provide a tangible contribution to the CCUS Supply Chain Strategy being produced by UK Industry (led by the Carbon Capture and Storage Association, CCSA).

2.3 Report Scope

2.3.1 Scope Inclusions

The scope of the study is set out under three considerations:

- **Full value-chain of technology** - This study looks to assess the CCS supply chain covering capture, transport, and storage:
    - Capture: The requirements for extracting the CO_2 from emitter waste streams. This considers both existing plants (retrofit) and new build facilities and includes the conditioning necessary to prepare the CO_2 for onward transport;
    - Transport: The requirements to move CO_2 from capture locations to eventual storage sites; and,
    - Storage: The offshore requirements to inject for long-term sequestering in depleted oil and gas fields.
- **Primary near-term emitter sources (or uses) for Carbon Capture and Storage technologies in the UK:**

- Power Generation: Large-scale dispatchable power is required for grid stability and resilience which renewables are not currently able to provide. This is currently provided by existing natural gas-fired plants in the UK. Additionally, power generation via BECCS would provide negative emissions which are required to offset remaining sectors for net zero. Both bio and fossil fired power generation with CCS is considered in this study.
- Industrial: CO_2 intensive industries that emit CO_2 either through chemical reactions of feedstock, or through energy intensive heating and powering. This includes (for example) cement, chemicals, iron, and steel production as well as certain forms of energy generation from waste (EfW)[1].
- CCUS-enabled, 'blue' Hydrogen: Low carbon hydrogen production can be achieved through steam-methane reforming (SMR) or autothermal reforming (ATR) with carbon capture facilities. This reduces the CO_2 emitted from hydrogen production when the captured CO_2 is transported for long-term underground storage. The UK is progressing a twin track approach of both electrolytic green hydrogen and CCUS-enabled blue hydrogen. . CCUS-enabled blue hydrogen offers more rapid deployment, or large-scale hydrogen production, and avoids challenges faced for electrolytic hydrogen sector, such as bottlenecks in the heavily constrained international electrolyser supply chains.

Although not an explicit focus, the report allows for the future potential of storage of imported CO_2 in the UK, in addition to domestic emissions.

Both the **equipment and services** required across the supply chain are considered:

- Equipment: Physical infrastructure, materials and technology required for CO_2 capture, transport, and storage; and,
- Services: The people and utilities required to undertake CCS projects across the full life cycle.

2.3.2 Scope Exclusions

For clarity, the following aspects were deemed outside the scope of the study:

- **CO_2 Utilisation**[2] – The re-use of CO_2 has not been focused on within this report for the following reasons:
  - The potential range of uses is extensive and includes existing markets in food production and storage and chemical processing to industrial use as a feedstock and in construction materials. The assessment would consequently have been extensive, and would not maintain the commonality of the capture, transport, and storage components within scope.
  - With generally less mature markets, there is limited information with the necessary robustness to fully assess the capacity and capability.
  - In some cases, markets have more interdependencies with other developing energy transition technologies, such as green hydrogen for e-fuels. Given the timeframes, this has not been included in this work.
- **Export Capabilities** – In identifying UK based suppliers of equipment and services, detailed assessment has not been made of the current scale of exports of each organisation, and it is assumed that output is therefore available to the UK market.

[1] This is in line with shortlist for CCUS emitter projects, on August 2022, from UK Government – Link

[2] As a consequence, subsequent reference to CCUS in the report, has been reduced to CCS to reflect the remit of the report.

3. UK Opportunity

3.1 Introduction to the CCS and CCUS Process and Technologies

Carbon Capture and Storage (CCS) and Carbon Capture Utilisation and Storage (CCUS) are technologies designed to address the challenge of reducing CO2 emissions and combating climate change. CCS focuses on the capture, transport, and storage of CO_2, while CCUS explores potential uses for the captured carbon in addition to storage. There is only a small market for the use of carbon to produce products such as food and drink, fertiliser, and transport fuels; the captured CO_2 will eventually be released back into the atmosphere when the products are consumed, meaning CCUS only delays carbon emissions.

The engineered solution of CCS involves:

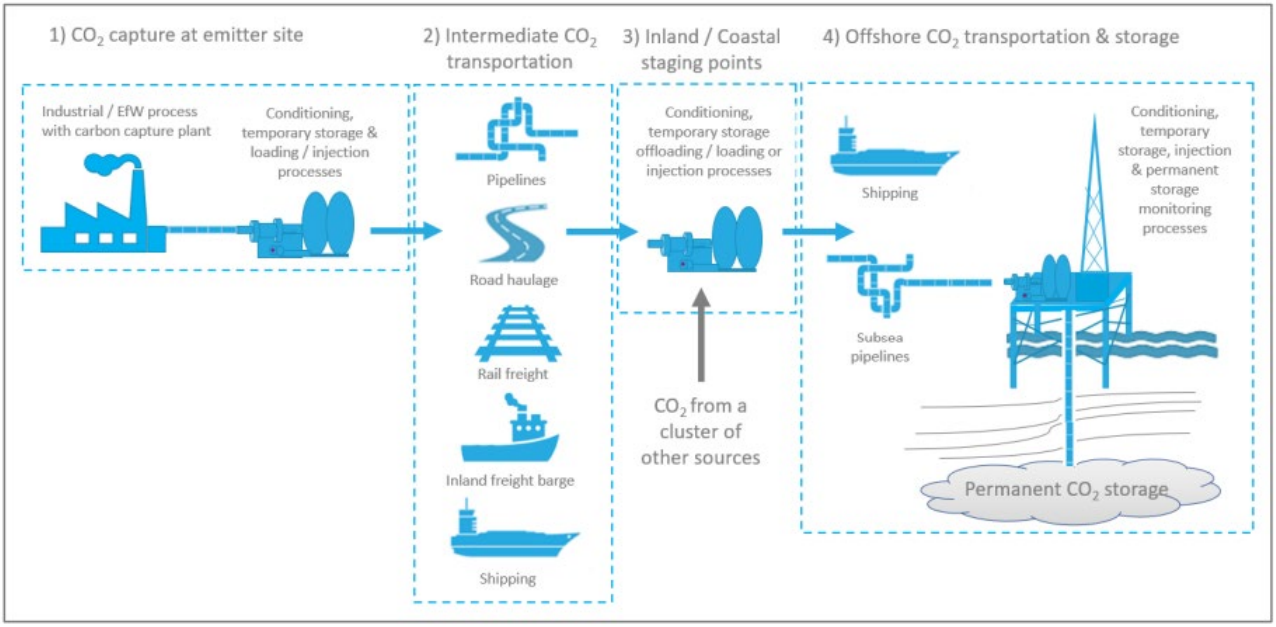
- Capturing CO_2 before it is emitted into the atmosphere through a complex chemical process.
- Transporting the CO_2 from an emitter site to a permanent storage site through one or more modes of transport, such as pipelines, ships, or trucks. The selection of transport mode can depend on the distance and volume of CO_2 to be transported; pipelines are the most common method due to their efficiency. CO_2 is compressed to a supercritical state, reducing its volume, and allowing for efficient transportation.
- Storing the CO_2 by injecting the CO_2 into shared permanent storage. Geological storage is the most widely used method, where CO_2 is injected deep underground into suitable geological formations such as depleted oil and gas fields, saline aquifers, or deep coal seams. The CO_2 is stored in these formations, trapped by impermeable rock layers that prevent its migration. This is typically in subsea locations for the UK.

There are several methods of capturing CO_2 before it is emitted into the atmosphere from industrial processes, including:

1. Direct Air Capture (DAC), where CO_2 is captured directly from ambient air using chemical adsorption or solvent-based processes.
2. Oxyfuel, where fuel is combusted in oxygen rather than air to produce flue gas that is rich in CO_2;
3. Pre-combustion, where CO_2 is removed from a synthesis gas prior to combustion; and
4. Post-combustion, where CO_2 emissions are captured after the combustion of fossil fuels using technologies like solvent scrubbing or membrane separation.

Figure 1 provides an overview of the CCS value chain, which is complex including the three main elements mentioned above. The successful deployment of CCS infrastructure relies on a close partnership and collaboration between government and industry to deliver against the ambition to reduce CO_2 emissions into the atmosphere and mitigate climate change.

Figure 1 Overview of carbon capture and storage value chain



3.2 Introduction to CCS in the UK

As set out in the UK's CCS Net Zero Investment roadmap, reissued in April 2023, the UK has an opportunity, through its natural geology and oil and gas industry heritage, to meet steep demand increases expected in CCS. The UK's competitive advantage in CCS includes:

- The proximity of an estimated 78Gt offshore CO_2 stores to major emissions sources in UK and European waters (Source: UK CCUS Investor Roadmap, April 2023)
- A mature offshore and subsurface supply chain, serving an advanced fuels and chemicals sector employing approximately 333,000 people
- Mature offshore infrastructure
- Stable regulatory regime
- Active and deep capital markets.

To accelerate CCS deployments the UK launched the £1 billion industrial cluster sequencing fund in 2021[3], and selected HyNET in the north-west and the East Coast Cluster in the north-east to be the first CCS clusters in the UK. CCS is yet to be deployed within a complex multi-sector network that connects multiple industrial emitters with storage sites, via a nationwide CO_2 network. The UK is an early mover in the development of complex and interconnected regional decarbonisation hubs with CCS, with the aim of operation of the first clusters by the mid-2020s.

In April 2023 the UK added to previous support for CCS by committing £20 billion of funding support for carbon capture[4] and recently announced selection of emitter projects for the industrial cluster Track-1 projects selected to enter negotiations with government[5]. The UK is advanced in developing frameworks and business models for each of these sectors, so early projects get the correct policy support[6]. The first projects

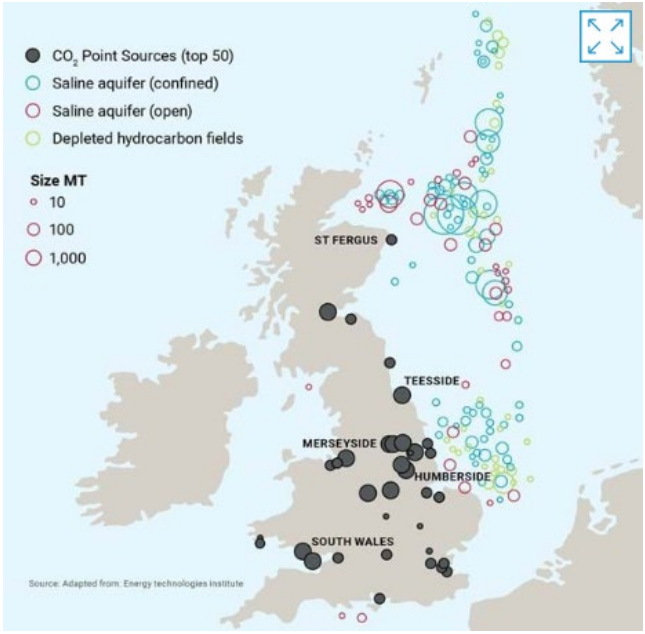
[3] UK Government, 2021, Phase 1 eligible cluster announcement – Link

[4] UK Government spring budget 2023 – Link

[5] UK Government, Department for Energy Security and Net Zero, Press Notice, Track 1 cluster projects negotiations list – Link

[6] UK Government business models, Industrial Carbon Capture draft front end agreement – Link, Dispatchable Power CCUS front end agreement draft – Link , Low Carbon Hydrogen Production business model - Link – December 2022

within each of these sectors are currently in negotiations with government[7]. While the UK CCS sector is in this nascent state there is a unique opportunity to set policies and mechanisms, that target the CCS supply chain, and maximise the opportunity to add value to the UK economy, whilst also minimizing risks to deployment and ultimately the transition to net zero.



3.3 Oil and Gas: Strengths, Skills & Heritage

One of the key reasons that the UK is well positioned to execute CCS projects is the nation's experience and skills in developing and managing the offshore oil and gas industry. OEUK estimated that in 2022 almost 120,000 jobs were supported directly or indirectly by upstream oil & gas sector with an additional 60,000 in the wider economy.

Hydrocarbon production now comes from almost 300 UK fields, many of unique technical complexity which have resulted in a highly skilled workforce across the supply chain with mature procurement infrastructure. Analysis of synergies between the oil and gas supply chain and CCS forms a part of the high-value assessment within this study.

The North Sea Transition Deal has set targets for reduction of offshore production emissions against a baseline figure of 2018 emissions, working towards a net zero basin by 2050. These targets are supported by investment in new energy technologies with a voluntary industry target of 50% local UK content across the lifecycle, including oil and gas decommissioning.

3.4 UK CCS Cluster Development

First commercial UK CCS projects are due to begin operations from the Mid 2020s, under the Track 1 cluster program. The eight projects selected to enter negotiations are summarised below. These projects promise deep-decarbonisation on ambitious timeframes. Some projects have indicated plans to achieve final investment decisions before the end of 2023.

[7] UK Government, Cluster sequencing Phase 2: Track 1 project negotiation list, March 2023 – Link

Table 1: Eight Track-1 CO_2 emitter projects selected to enter negotiations

Project	Cluster	Type	Sector	Scale (ktpa CO_2)
Net Zero Teesside Power	ECC	Power	Power	2,000
bpH2teesside	ECC	Hydrogen	Hydrogen	2,000
HyNET Hydrogen Production	HyNET	Hydrogen	Hydrogen	890
Teesside H_2 CO_2 Capture	ECC	Industrial	Chemicals	Unknown – retrofit to a 32 ktpa H_2 SMR
Hanson Padeswood Cement CCS	HyNET	Industrial	Lime/Cement	800
Viridor Runcorn CCS	HyNET	Industrial	Energy from Waste	380
Protos Energy Recovery Facility	HyNET	Industrial	Energy from Waste	900
Buxton Lime Net zero	HyNET	Industrial	Lime/Cement	20

The eight projects cover all 3 main markets identified for CCS. Power and blue hydrogen projects selected for negotiations have been large scale (100's ktpa), whereas the industrial projects selected across cement/lime, chemicals and EfW facilities are more varied in scale, 10s to 100s ktpa. Across the eight projects CCS will be both retrofitted to facilities in operation and installed as part of the development of new facilities.

The government has set a target of commencing CCS operations in two more clusters by 2030, totalling four across the UK[8]. Clusters in Scotland, South Wales and the Northeast of England are being progressed for Track 2. Clusters have been centred around industrial hubs, enabling multiple emitter projects to use centralised CO_2 transport and storage.

Table 2: Eight Track-1 CO_2 emitter projects selected to enter negotiations

Most recently, the UK Government has announced ambition to be capturing 20-30Mtpa CO_2 per year by 2030[9]. Enablement of all four networked CCS clusters will be required to meet this target.

Beyond 2030 the CCS market is forecast to continue to grow. Several previous studies have looked to estimate the role CCS will play in net zero at 2050. Demand is predicted to increase across all CCS market and will therefore require growth in a range of carbon capture technologies.

[8] UK Government, Cluster Sequency Track 2 program – Link

[9] UK Government, Policy Paper, Powering Up Britain: Net Zero Growth Plan, April 2023 – Link

4. CCS supply chain taxonomy

4.1 Purpose of a CCS taxonomy

The purpose of the CCS Supply Chain taxonomy is to enable greater transparency and consistency in the monitoring of procurement across the CCS supply chain. This in turn is intended to support the development of policy interventions to ensure that UK supply chain companies can successfully compete and secure valuable opportunities as the new UK CCS Infrastructure system takes shape.

This first Full Value Chain UK CCS Taxonomy can be used to track the value of spend in each of the items listed in Level 4 of the taxonomy, for each UK CCS project. This will provide insight as to the distribution of income to UK suppliers for each key component and service package (see section 4.2 for definitions) across the CCS value chain, and enable the identification of high-value items. These are further assessed in the 'High Value' section 5 below.

Using a numerical coding system, the Taxonomy simplifies the detail of components and parts to a level at which we believe that procurement can be tracked with consistency. A unique name and number per key component will enable labelling and tracking across multiple projects and plants, and can be aligned to automated systems including ERP tools such as SAP and other accounting systems, logistics enablers such as IBM Maximo or UNSPC codes.

4.2 Methodology

At the start of the process of framing the taxonomy, it was deemed that two separate taxonomies would be created for each market type of equipment and services. This reflected the diversity between the nature of the two and enables each to have a taxonomy specific to its contents.

The study utilised Arup subject-matter expert knowledge of project structure, literature review and additional primary research, to populate the taxonomy down to a consistent level of granularity between equipment & services. Within the scope of this report, the smallest level of detail defined, which was intended to ensure that a reasonably accurate taxonomy was produced within the project schedule, was Level 4, which in the taxonomy is non-specific equipment and services (e.g. Heat Exchanger / Legal Services).

It is our view that at this level of detail, projects/developers will readily be able to identify the spend associated with the package/service or equipment item at the development stage. Product codes were excluded at this stage since they would provide a specific coding useful where purchasers are currently using them, but not intended to provide the overall transparency of the UK value chain which policy makers and industry leaders are seeking to achieve. Product codes such as the UNSPC could subsequently be mapped to this taxonomy if deemed necessary or useful for integration with existing systems, but would not be intended to replace this taxonomy.

When spend is tracked at the level of detail proposed here (Level 4), industry and regulators can readily identify the parts of the UK supply chain which are benefiting or so far failing to benefit from the development of this new infrastructure system, and thereby establish which may merit attention or intervention, by equipment or service type.

4.3 Equipment Taxonomy

4.3.1 Structure

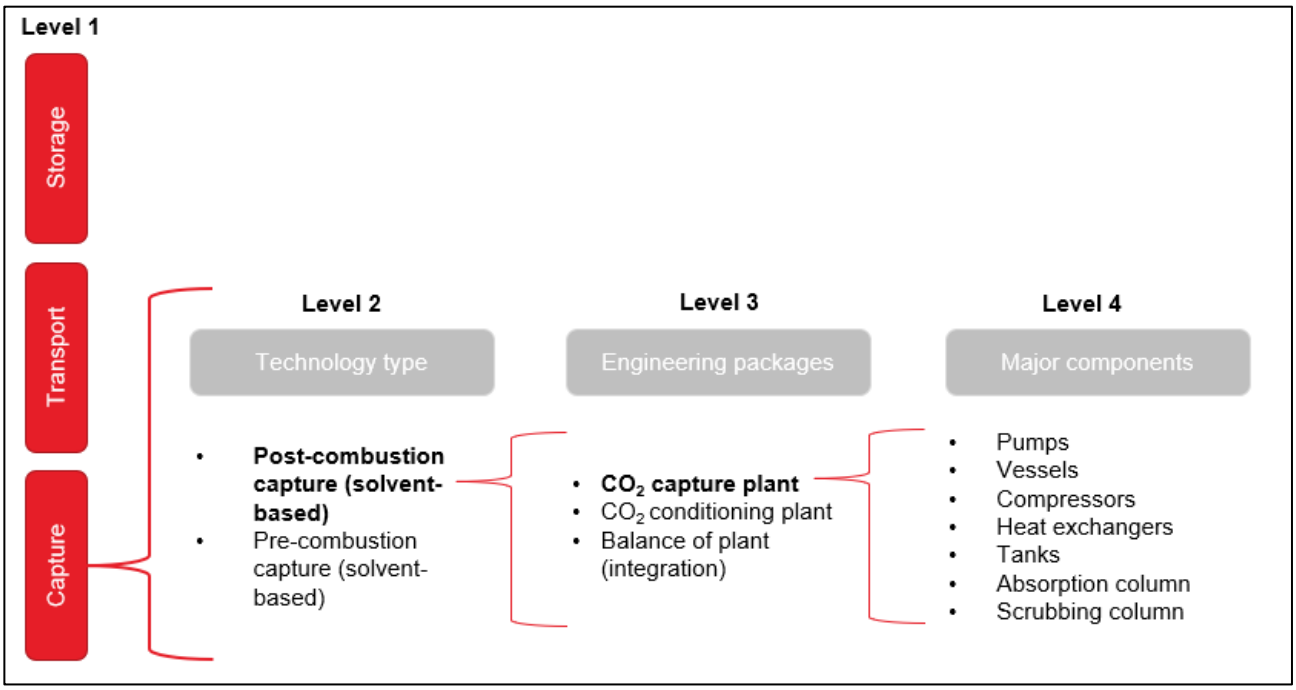
To identify items for the equipment taxonomy, a detailed literature review of engineering designs was undertaken, in addition to inputs from industry specialists. The aim of this was to develop a complete list of components required across the CCS chain, covering CO_2 capture, transport, and storage.

To ensure a comprehensive list of components across the supply chain it has been structured across the following levels, which are also reflected in :

- **Level 1: Full Value-chain** – The high-level division of capture, transport and storage

- **Level 2: Technology Type** – Reflecting the methodology used within the function.
- **Level 3: Engineering package** – A collection of components required to deliver a process within the chain. An additional note is included below in relation to this.
- **Level 4: Major components** – Individual, but significant components within an engineering package

Figure 3 Equipment taxonomy structure - example



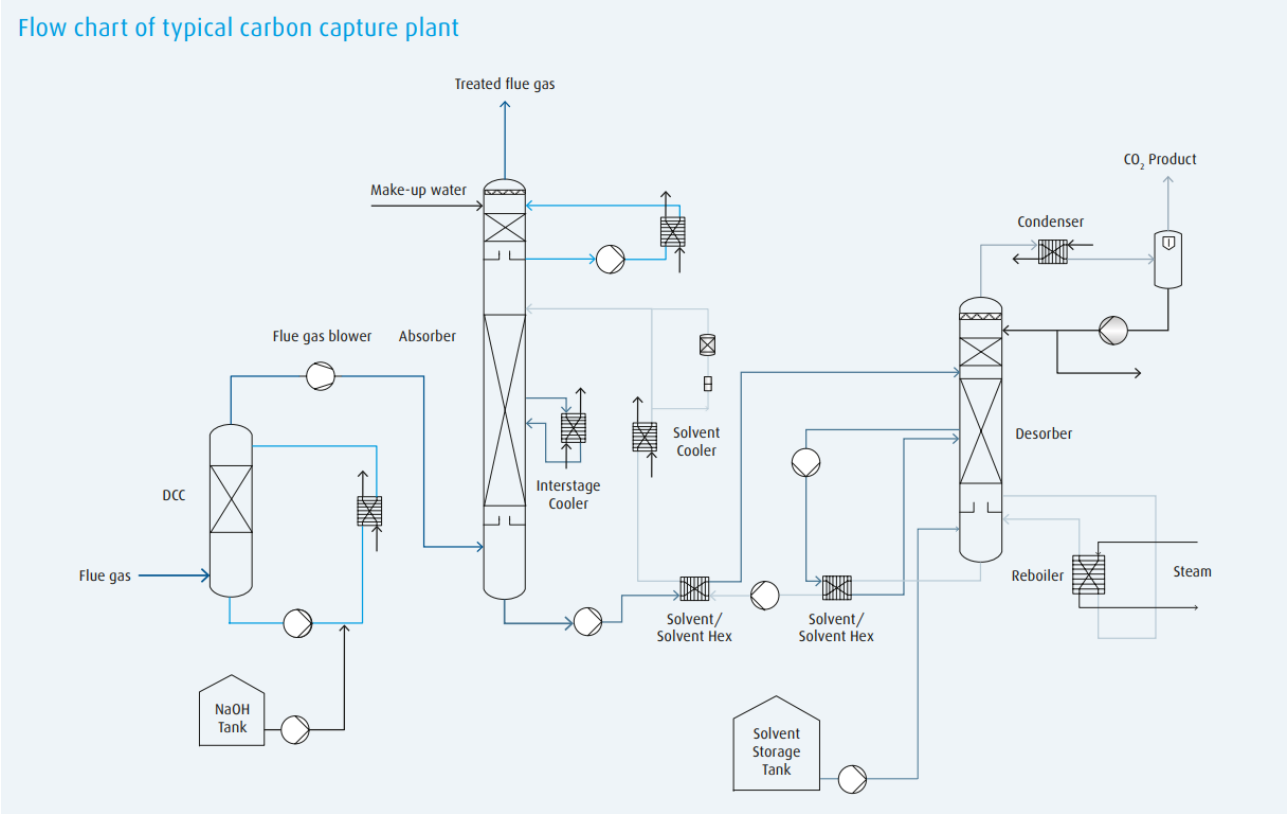
4.3.2 Engineering Packages

Carbon capture projects will require manufactured components, such as column vessels, heat exchangers and compressors etc, and in addition companies to perform the assembly of these components into the plant, either onsite or via a 'skid' or module. On a carbon capture project, there may be a number of sub-packages required to operate the whole plant, e.g., CO_2 capture and CO_2 conditioning. Several companies offer delivery and installation of these packages, comprising of an assembly of manufactured components. Engineering packages have therefore been included as an intermediate Level 3 before components for two reasons:

- To offer further granularity on where components will be required in the CCS chain.
- Engineering packages are often delivered by a single contractor, who will separately procure components, assemble, deliver, and install either on site or via a skid. These contractors who supply technology are critical to the CCS chain and are therefore require visibility in taxonomies.

Packages have been selected based on review of technology provider offerings, (see example of Linde in Fig. 3 above) covering a post-combustion capture facility, and CO_2 conditioning facility. Each diagram represents and engineering package (Level 3), with the major components (Level 4) detailed in the diagrams.

Linde post combustion CO_2 capture technology (top - Link), CO_2 conditioning unit (bottom - Link)



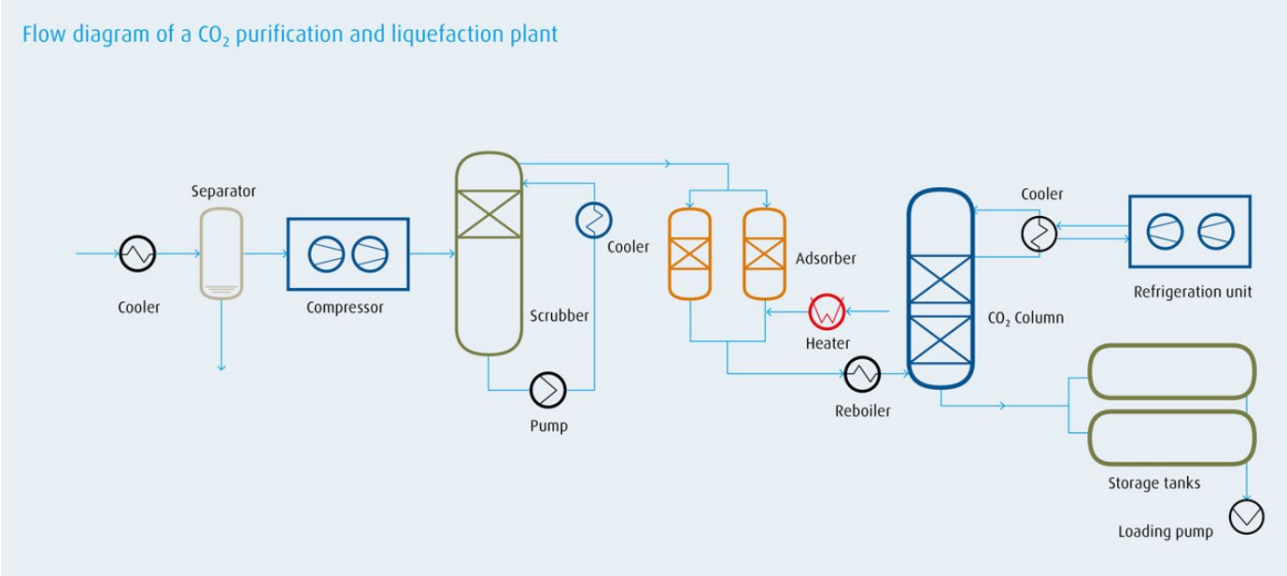


Figure 4 Linde post combustion CO_2 capture technology (Linde.com), CO_2 conditioning unit (Linde.com)

4.3.3 Scope of equipment taxonomy

Technologies have been selected that are likely to make up the majority of UK CCS deployments in the UK in the near future. These have been identified from public project announcements to date. The CO_2 capture engineering package for each of the recently selected emitter projects within Track 1 has been reviewed and is shown here in Table 3: Track 1 emitter projects selected for negotiations, by capture technology type, *Capture technology for Net Zero Teesside power, assumed based on FEED contractors selected and **for Teesside H2 CO2 capture on parent company, Linde, of project developer

Project	Cluster	Type	Capture technology	**Technology provider**

Net Zero Teesside Power	ECC	Power	Post-Combustion	Aker Carbon Capture/Shell*
bpH2teesside	ECC	Hydrogen	Pre-Combustion	Unknown
HyNET Hydrogen Production	HyNET	Hydrogen	Pre-Combustion	Johnson Matthey/BASF
Teesside H2 CO2 Capture	ECC	Industrial	Post-Combustion	Linde (assumed)**
Hanson Padeswood Cement CCS	HyNET	Industrial	Post-Combustion	Unknown
Viridor Runcorn CCS	HyNET	Industrial	Post-Combustion	Aker Carbon Capture
Protos Energy Recovery Facility	HyNET	Industrial	Unknown	Unknown
Buxton Lime Net zero	HyNET	Industrial	Other	Leilac

Table 3: Track 1 emitter projects selected for negotiations, by capture technology type, *Capture technology for Net Zero Teesside power, assumed based on FEED contractors selected and **for Teesside H_2 CO_2 capture on parent company, Linde, of project developer

Project	Cluster	Type	Capture technology	**Technology provider**
Net Zero Teesside Power	ECC	Power	Post-Combustion	Aker Carbon Capture/Shell*
bpH2teesside	ECC	Hydrogen	Pre-Combustion	Unknown
HyNET Hydrogen Production	HyNET	Hydrogen	Pre-Combustion	Johnson Matthey/BASF
Teesside H_2 CO_2 Capture	ECC	Industrial	Post-Combustion	Linde (assumed)**
Hanson Padeswood Cement CCS	HyNET	Industrial	Post-Combustion	Unknown
Viridor Runcorn CCS	HyNET	Industrial	Post-Combustion	Aker Carbon Capture
Protos Energy Recovery Facility	HyNET	Industrial	Unknown	Unknown
Buxton Lime Net zero	HyNET	Industrial	Other	Leilac

Most will use higher-TRL technology such as pre or post combustion, solvent-based capture, and therefore these are the only two capture technologies that have been examined in detail. Selecting established

technologies, with a range of technology licensors, limits risks to the 2027 deployment timeline for Track 1 projects. The broader range of technology licensors also improves the competitive aspect of tendering for project developers.

Other capture technologies such as oxy-fuel or cryogenic capture may be developed in the future, and some examples of these project types were shortlisted by UK government but not selected for negotiations e.g., Origen's oxyfuel technology in ZeroCaL250[10,11]. However, while engineering packages may differ for different capture technologies, there will be a lot of overlap with major component types[12,] with more mature technologies (pre and post combustion) and therefore integrating additional capture technologies into the taxonomy will be possible once they mature.

For long term storage of CO_2, depleted oil and gas fields are considered as the main technology type, as these are the technologies used in HyNET CO_2 storage, and the Northern Endurance Partnership which the government is progressing through the Track 1 clusters. Other storage technologies such as saline aquifers have not been included, but again there is expected to be significant overlap with the components required for CO_2 storage in depleted oil and gas fields.

Major components for each engineering package are deliberately exhaustive. Engineering package designs will be unique to individual projects and therefore, not every component will be required for every plant. For example, NOx removal and desulphurization packages have been included in the capture gas pre-treatment for both pre and post CO_2 combustion. However, carbon capture plant feasibility work highlights this will be a design decision, bespoke to different projects and applications:

- In the Scottish cluster, the Acorn carbon capture feasibility study expects no need for NOx removal or desulphurisation at feasibility stage[13].
- HyNET highlight NOx removal and/or desulphurisation could be required in their refinery feasibility study, depending on feed gas composition[14].

4.4 Services Taxonomy

4.4.1 Structure

Similarly, to the goods taxonomy, a detailed literature review was carried out along with a review of standard project structures and organisation charts.

The level structure for the service taxonomy is as follows:

- **Level 1: Full-Value Chain Function**: The high-level division of capture, transport and storage, with an additional category for Essential Functions that operate across the chain.
- **Level 2: Project stage** - the life-cycle phase of project execution in which a service operates, from concept through to decommissioning.
- **Level 3:** Service Category (Discussed in more detail below)
- **Level 4:** Service

4.4.2 Scope of Service Taxonomy

Firstly, we separated out a series of Essential Functions into their own level-2 division. This was done to make the taxonomy more concise, as each of these services offerings would be repeated in every stage of

[10] Origen Carbon Solution press releases – Link & Technology overview – Link

[11] Baxter et al, Cryogenic Carbon Capture (CCC) Statue Report, GHGT, 2021 – Link

[12] Tigre Technologies limited, Feasibility Study: Integration of CCUS technology with a 200MW OCGT TiGRE™ Project located in the UK Southern North Sea KKD2: Basis of Design, 2020 – Link

[13] Acorn CCS project: D24 Concept Options Report, Pale Blue Dot, 2021 – Link

[14] HyNET CCUS Pre-FEED, WP2: Refinery capture concept study Report, 2019 – Link

each project. Then using a combination of literature review and Arup's project execution experience, Level 4 of the methodology was populated. Once the first iteration of the taxonomy was filled, we began to collate the services into logical groups, at Level 3, which could be individually assessed in terms of opportunity value in the next stage of the study, and therefore highlight the areas which industry should give focus to. The services were categorised on a basis of best-fit, as some services may operate across multiple categories. Best fit was determined using project execution knowledge and the wider context within the CCS supply chain, to allow the categories to represent the value opportunities without being double counted. A full list of the categories is available in section 4.3.2.

4.5 Taxonomy Table

4.5.1 Equipment Taxonomy

Figure 5 Full taxonomy for equipment.

Level 1	Ref	Level 2	Ref	Level 3	Ref	Level 4	Ref	Component type
Capture	1	Post-Combustion - Solvent	1.1	Flue gas collection/pre-treatment	1.1.1	Skimmer	1.1.1.1	skimmer
						Catalytic Reduction Package	1.1.1.2	sub package
						Filter	1.1.1.3	Filter
						Cooler	1.1.1.4	Heat exchanger/fan
						Pump	1.1.1.5	Pump
						Fan	1.1.1.6	Fan
						Flue gas blower	1.1.1.7	Gas blower
						Nox Removal (SCR) package	1.1.1.8	sub package
						Desulfurisation package	1.1.1.9	sub package
				Capture	1.1.2	Direct Contact Cooler	1.1.2.1	Column vessel
						Absorber Column	1.1.2.2	Column vessel
						Water Wash	1.1.2.3	sub package
						Absorber wash Column	1.1.2.4	Column vessel
						Rich/lean heat exchanger	1.1.2.5	Heat Exchanger
						Stripper Column	1.1.2.6	Column vessel
						Reboiler	1.1.2.7	Heat Exchanger
						Condensor	1.1.2.8	Heat Exchanger
						Stripper wash column	1.1.2.9	Column vessel
						Solvent (MEA)	1.1.2.10	Chemical
						Solvent tank	1.1.2.11	Tank
						Pumps	1.1.2.12	Pump
				CO_2 conditioning (molecular sieve de-hydration assumed)	1.1.3	CO_2 compressor	1.1.3.1	Compressor
						Compressor KO drums	1.1.3.2	Tank
						Coolers	1.1.3.3	Heat exchanger/fan
						Lube oil unit	1.1.3.4	sub package
						Motor	1.1.3.5	sub package
						Knock out drum (de-hydration unit)	1.1.3.6	Column Vessel
						Coalescer Filter	1.1.3.7	Filter
						Adsorber Column	1.1.3.8	Column vessel
						Regeneration Column	1.1.3.9	Column vessel
						Regeneration Gas Steam Heater	1.1.3.10	Heater
						Regeneration Gas Electric Heater	1.1.3.11	Heater
						Regeneration Gas Cooler	1.1.3.12	Heat exchanger/fan
						Regeneration Gas Separator	1.1.3.13	Column vessel
						Dust Filters	1.1.3.14	filter
						Condensate Vessel	1.1.3.15	Tank
						Regeneration gas blower	1.1.3.16	Gas blower
				Balance of plant (integration)	1.1.4	Demineralised water supply package	1.1.4.1	sub package
						Waste water treatment	1.1.4.2	sub package
						Cooling water supply	1.1.4.3	sub package
						Steam supply	1.1.4.4	sub package
						Valves	1.1.4.5	Valve
						Pipes	1.1.4.6	Pipe
						Flue gas, pre-capture meter	1.1.4.7	sub package
						CO_2 exit meter	1.1.4.8	sub package
						Housing	1.1.4.9	sub package
						Controls	1.1.4.10	sub package
						Monitoring	1.1.4.11	sub package
						Instrumentation	1.1.4.12	sub package
						Power supply/connections/Switchgear	1.1.4.13	sub package

Capture	1	Pre-Combustion - Solvent	1.2	Flue gas pre-treatment	1.2.1	Skimmer	1.2.1.1	skimmer
						Catalytic Reduction Package	1.2.1.2	sub package
						Filter	1.2.1.3	Filter
						Cooler	1.2.1.4	Cooler
						Pump	1.2.1.5	Pump
						Fan	1.2.1.6	Fan
						Flue gas blower	1.2.1.7	Gas blower
						Nox Removal (SCR) package	1.2.1.8	sub package
						Desulfurisation package	1.2.1.9	sub package
				Capture	1.2.2	Direct Contact Cooler	1.2.2.1	Column vessel
						Absorber Column	1.2.2.2	Column vessel
						Water Wash	1.2.2.3	
						Absorber wash Column	1.2.2.4	Column vessel
						Rich/lean heat exchanger	1.2.2.5	Heat Exchanger
						Stripper Column	1.2.2.6	Column vessel
						Reboiler	1.2.2.7	Heat Exchanger
						Condensor	1.2.2.8	Heat exchanger
						Stripper wash column	1.2.2.9	Column vessel
						Solvent (MDEA)	1.2.2.10	Chemical
						Solvent tank	1.2.2.11	Tank
						Pumps	1.2.2.12	Pumps
				Post- capture CO_2 conditioning (molecular sieve de-hydration assumed)	1.2.3	CO2 compressor	1.2.3.1	Compressor
						Compressor KO drums	1.2.3.2	Column Vessel/Separator/
						Coolers	1.2.3.3	Heat exchanger/fan?
						Lube oil unit	1.2.3.4	sub package
						Motor	1.2.3.5	sub package
						Knock out drum (de-hydration unit)	1.2.3.6	Column Vessel/Separator/
						Coalescer Filter	1.2.3.7	Filter
						Adsorber Column	1.2.3.8	Column vessel
						Regeneration Column	1.2.3.9	Column vessel
						Regeneration Gas Steam Heater	1.2.3.10	Heater
						Regeneration Gas Electric Heater	1.2.3.11	Heater
						Regeneration Gas Cooler	1.2.3.12	Heat exchanger/fan?
						Regeneration Gas Separator	1.2.3.13	Column vessel
						Dust Filters	1.2.3.14	filter
						Condensate Vessel	1.2.3.15	Tank
						Regeneration gas blower	1.2.3.16	Gas blower
				Balance of plant (integration)	1.2.4	Demineralised water supply package	1.2.4.1	sub package
						Waste water treatment	1.2.4.2	sub package
						Cooling water supply	1.2.4.3	sub package
						Steam supply	1.2.4.4	sub package
						Valves	1.2.4.5	Valve
						Pipes	1.2.4.6	Pipe
						Housing, base plates, mounts	1.2.4.7	sub package
						Flue gas pre-capture meter	1.2.4.8	sub package
						CO_2 exit meter	1.2.4.9	sub package
						Power supply/connections/Switchgear	1.2.4.10	sub package
						Monitoring	1.2.4.11	sub package
						Controls	1.2.4.12	sub package
						Instrumentation	1.2.4.13	sub package
						Fittings and seals	1.2.4.14	sub package

Transport	2	Transportation conditionining	2.1	Liquefaction (Cryogenic Transport only)	2.1.1	Distillation Column	2.1.1.1	Column vessel
						Condensor	2.1.1.2	Heat Exchanger
						Reflux Pump	2.1.1.3	Pump
						Reflux Drum	2.1.1.4	Column vessel
						Compressor KO Drum	2.1.1.5	Column vessel
						Refrigerant Compressor	2.1.1.6	Compressor
						Scrubbing Column	2.1.1.7	Column vessel
						Adsoroption Column	2.1.1.8	Column vessel
						Refrigerant Compressor	2.1.1.9	Chemical
						Cooler Column	2.1.1.10	Column vessel
						Pumps	2.1.1.11	Pump
				Regasifacation (cryogenic transport only)	2.1.2	Electric heater	2.1.2.1	Heater
						Heat Exchanger	2.1.2.2	Heat Exchanger
						Gasification pump	2.1.2.3	pump
						Manifold	2.1.2.4	
						Control Valve	2.1.2.5	valve
		Land	2.2	Pipeline	2.2.1	Pipe fabrication	2.2.1.1	Pipes
						Insulation/casing	2.2.1.2	Insulation
						Valves	2.2.1.3	Valves
						Coatings	2.2.1.4	Coatings
						Compressors	2.2.1.5	Compressor
						Meter points	2.2.1.6	Sub-package
						Leakage detectors	2.2.1.7	Sub-package
						Pig Launcher / Receiver	2.2.1.8	Sub-package
						Fibre Optic Cabling (Telemetry)	2.2.1.9	Sub-package
						Chemical Injection Package	2.2.1.10	Chemical/Sub-package
						Cathodic protection	2.2.1.11	Sub-package (if inlcuded)
				Rail	2.2.2	Rolling Stock	2.2.2.1	Wagons
						ISO tanks for wagons (incld	2.2.2.2	Tanks
						Cryogenic CO_2 filling connections	2.2.2.3	Sub package
						Cryogenic CO_2 Emptying	2.2.2.4	Sub package
				Road	2.2.3	ISO tanks	2.2.3.1	Tanks
						Tractors	2.2.3.2	Tractor
						Cryogenic CO_2 filling connections	2.2.3.3	Sub package
						Cryogenic CO_2 Emptying	2.2.3.4	Sub package
		Marine	2.3	Port Loading/unloading infrastrucutre - cryogenic	2.3.1	CO_2 pressurised storage tanks	2.3.1.1	Tank
						Cryogenic Loading/Unloading arms	2.3.1.2	sub package
						Pumps	2.3.1.3	Pump
						Boil-off vent	2.3.1.4	valve
						Insulated pipeline	2.3.1.5	Pipe
						Re-circulation loop	2.3.1.6	sub package
				Port Loading/unloading infrastrucutre - pressurised gas	2.3.2	CO_2 pressurised storage tanks	2.3.2.1	Tank
						Pumps	2.3.2.2	Pump
						Pressurised loading/unloading arms	2.3.2.3	sub-package
						Pipeline	2.3.2.4	Pipe
				Ships - retrofit (cryogenic assumed)	2.3.3	Retrofitting of existing ships (LNG /	2.3.3.1	subpackage
						Storage tanks	2.3.3.2	tanks
						Pumps	2.3.3.3	pumps
				Ships - new build (cryogenic assumed)	2.3.4	Onboard storage (pressurised/cryogenic)	2.3.4.1	tanks
						Topsides	2.3.4.2	strucutre
						Loading/offloading equipment	2.3.4.3	subpackage
						Direct offshore injection equipment	2.3.4.4	subpackage
Storage	3	Depleted Oil / Gas Field	3.1	Structures	3.1.1	Subsea Pipeline	3.1.1.1	Pipe
						Offshore platform	3.1.1.2	strucutre
						Subsea distribution unit	3.1.1.3	subpackage
						Subsea Umbilicals	3.1.1.4	subpackage
						Risers	3.1.1.5	subpackage
						Flowlines - with insulation or Direct electric heating (DEH)	3.1.1.6	subpackage
						Compressors	3.1.1.7	Compressors
						Pumps	3.1.1.8	pumps
				Store	3.1.2	Christmas Tree	3.1.2.1	subpackage
						Wellhead	3.1.2.2	Strucutre
						Manifold	3.1.2.3	Strucutre
						Drilling rig	3.1.2.4	Strucutre
				Asset Management equipment	3.1.3	Inhibitors	3.1.3.1	subpackage
						Leakage Detection	3.1.3.2	subpackage
						pH Monitoring instruments	3.1.3.3	subpackage
						Seismic monitoring instruments	3.1.3.4	subpackage
						Metering, detection / monitoring	3.1.3.5	subpackage
						Pressure Monitor	3.1.3.6	subpackage

4.5.2 Services Taxonomy

Figure 6 Full taxonomy for services

Level 1	R	Level 2	R	Level 3	Re	Level 4	Ref
Essential Functions	1	Essential Functions	1.1	Industry Organisations	1.1.1	Development of Safety Standards	1.1.1.1
						Development of Quality Standards	1.1.1.2
						Development of Environmental Standards	1.1.1.3
						Procurement Planning Tools	1.1.1.4
						Supply Chain Action Plans	1.1.1.5
				Hospitality & Accommodation	1.1.2	Hotels	1.1.2.1
						Serviced Apartments / Other temporary housing	1.1.2.2
				HR & Recruitment Services	1.1.3	HR / Admin	1.1.3.1
						Recruitment	1.1.3.2
						Training	1.1.3.3
				Legal & IP Services	1.1.4	Legal Services	1.1.4.1
						IP Services	1.1.4.2
				Financial Services	1.1.5	Financial Services	1.1.5.1
						Insurance	1.1.5.2
				IT / Digital Services	1.1.6	IT Consultancy	1.1.6.1
						Software Developer/Engineer	1.1.6.2
						IT Infrastructure	1.1.6.3
						Data/Cyber Security	1.1.6.4
						AI/ML	1.1.6.5
Capture	2	Initiation - Concept	2.1	Engineering & Design	2.1.1	Feasiblity study	2.1.1.1
				Management	2.1.2	Project Management	2.1.2.1
						Project Planning	2.1.2.2
		Development - Pre-FID	2.2	Engineering & Design	2.2.1	pre-FEED	2.2.1.1
						FEED	2.2.1.2
				Management	2.2.2	Consenting	2.2.2.1
						Funding Acquisition	2.2.2.2
						Wider Stakeholder Engagement	2.2.2.3
						Project Management	2.2.2.4
		Development, post-FID	2.3	Engineering & Design	2.3.1	Detailed design	2.3.1.1
						Owners Engineer	2.3.1.2
						EPCm	2.3.1.3
				Management	2.3.2	Project Management	2.3.2.1
						Wider Stakeholder Engagement	2.3.2.2
						Land Acquisition	2.3.2.3
		Construction	2.4	Fabrication of Key Equipment	2.4.1	Machine Assembly	2.4.1.1
						Welding	2.4.1.2
				Manufacturing	2.4.2	Machining, casting & moulding	2.4.2.1
						Component Quality checks	2.4.2.2
				Logistics	2.4.3	Long distance transport	2.4.3.1
						Cargo handling / heavy lifting	2.4.3.2
				Construction, Installation & Site Services	2.4.4	Site Studies	2.4.4.1
						Plant housing	2.4.4.2
						Installation of components	2.4.4.3
						Connections and integration	2.4.4.4
		Commissioning	2.5	Testing & Inspection	2.5.1	Electrical testing	2.5.1.1
						Quality testing / NDT	2.5.1.2
						Safety inspections	2.5.1.3
				Construction, Installation & Site Services	2.5.2	Security	2.5.2.1
						Waste Management	2.5.2.2
						Communications	2.5.2.3
		Operations & Maintenance	2.6	Testing & Inspection	2.6.1	Safety	2.6.1.1
						Quality	2.6.1.2
				Monitoring/Data Collection	2.6.2	Leakages	2.6.2.1
						Predictive Maintenance	2.6.2.2
						Metering	2.6.2.3
				Construction, Installation & Site Services	2.6.3	Security	2.6.3.1
						Waste Management	2.6.3.2
						Communications	2.6.3.3
				Operations	2.6.4	Shutdown/Turnaround Services	2.6.4.1
						Process Operators	2.6.4.2
				Maintenance	2.6.5	On-site Maintenance Services	2.6.5.1
		Decommissioning	2.7	Testing & Inspection	2.7.1	Quantity Surveying	2.7.1.1
						Safety	2.7.1.2
				Management	2.7.2	Project Management	2.7.2.1
						Project Planning	2.7.2.2

Transport	3	Pipeline	3.1	Engineering & Design	3.1.1	Engineering contractors (concept, pre-FEED/FEED)	3.1.1.1
						Engineering support	3.1.1.2
						CAD / Modelling	3.1.1.3
		Marine	3.2	Logistics	3.2.1	Freight services	3.2.1.1
				Construction, Installation & Site	3.2.2	Subsea Cable Contractors	3.2.2.1
						Offshore Scaffolding & rigging	3.2.2.2
		Construction	3.3	Fabrication of Key Equipment	3.3.1	Machine Assembly	3.3.1.1
						Welding	3.3.1.2
				Manufacturing	3.3.2	Machining, casting & moulding	3.3.2.1
						Component Quality checks	3.3.2.2
				Logistics	3.3.3	Long distance transport	3.3.3.1
						Cargo handling / heavy lifting	3.3.3.2
				Construction, Installation & Site Services	3.3.4	Installation of components (i.e pipeline)	3.3.4.1
						Connections and integration	3.3.4.2
						Site Stuides	3.3.4.3
						Plant housing	3.3.4.4
		Commissioning	3.4	Testing & Inspection	3.4.1	Electrical testing	3.4.1.1
						Quality testing / NDT	3.4.1.2
						Safety inspections	3.4.1.3
				Construction, Installation & Site Services	3.4.2	Security	3.4.2.1
						Waste Management	3.4.2.2
						Communications	3.4.2.3
		Operations & Maintenance	3.5	Testing & Inspection	3.5.1	Safety	3.5.1.1
						Quality	3.5.1.2
				Monitoring/Data Collection	3.5.2	Leakages	3.5.2.1
						Metering	3.5.2.2
						Predictive Maintenance	3.5.2.3
				Construction, Installation & Site Services	3.5.3	Security	3.5.3.1
						Waste Management	3.5.3.2
						Communications	3.5.3.3
				Operations	3.5.4	Shutdown/Turnaround Services	3.5.4.1
						Process Operators	3.5.4.2
				Maintenance	3.5.5	On-site Maintenance Services	3.5.5.1
		Decommissioning	3.6	Testing & Inspection	3.6.1	Quantity Surveying	3.6.1.1
						Safety	3.6.1.2
				Management	3.6.2	Project Management	3.6.2.1
						Project Planning	3.6.2.2

Loading/ Offloading	4	Initiation - Concept	4.1	Subsea, Wells & Exploration	4.1.1	Geotechnical services	4.1.1.1
						Well selection	4.1.1.2
						Drilling contractors	4.1.1.3
		Development	4.2	Engineering & Design	4.2.1	Engineering contractors (concept, pre-FEED/FEED)	4.2.1.1
						Pipeline Engineering support	4.2.1.2
						Pipeline CAD / Modelling	4.2.1.3
		Construction	4.3	Fabrication of Key Equipment	4.3.1	Machine Assembly	4.3.1.1
						Welding	4.3.1.2
				Manufacturing	4.3.2	Machining, casting & moulding	4.3.2.1
						Component Quality checks	4.3.2.2
				Logistics	4.3.3	Long distance transport	4.3.3.1
						Cargo handling / heavy lifting	4.3.3.2
				Construction, Installation & Site Services	4.3.4	Installation of components	4.3.4.1
						Connections and integration	4.3.4.2
						Subsea cable contractors	4.3.4.3
						Offshore Scaffolding & rigging	4.3.4.4
						Site Stuides	4.3.4.5
						Plant housing	4.3.4.6
		Commissioning	4.4	Testing & Inspection	4.4.1	Electrical testing	4.4.1.1
						Quality testing / NDT	4.4.1.2
						Safety inspections	4.4.1.3
				Construction, Installation & Site Services	4.4.2	Security	4.4.2.1
						Waste Management	4.4.2.2
						Communications	4.4.2.3
		Operations & Maintenance	4.5	Testing & Inspection	4.5.1	Safety	4.5.1.1
						Quality	4.5.1.2
				Monitoring/Data Collection	4.5.2	Leakages	4.5.2.1
						Metering	4.5.2.2
						Predictive Maintenance	4.5.2.3
				Construction, Installation & Site Services	4.5.3	Security	4.5.3.1
						Waste Management	4.5.3.2
						Communications	4.5.3.3
				Operations	4.5.4	Shutdown/Turnaround Services	4.5.4.1
						Process Operators	4.5.4.2
				Maintenance	4.5.5	On-site Maintenance Services	4.5.5.1
		Decommissioning	4.6	Testing & Inspection	4.6.1	Quantity Surveying	4.6.1.1
						Safety	4.6.1.2
				Management	4.6.2	Project Management	4.6.2.1
						Project Planning	4.6.2.2

Storage	5	Initiation - Concept	5.1	Subsea, Wells & Exploration	5.1.1	Geotechnical services	5.1.1.1
						Well selection	5.1.1.2
						Drilling contractors	5.1.1.3
						Seismic scanning contractors	5.1.1.4
				Engineering & Design	5.1.2	Feasiblity study	5.1.2.1
				Management	5.1.3	Project Management	5.1.3.1
						Project Planning	5.1.3.2
		Development - Pre-FID	5.2	Engineering & Design	5.2.1	pre-FEED	5.2.1.1
						FEED	5.2.1.2
				Management	5.2.2	Consenting	5.2.2.1
						Funding Acquisition	5.2.2.2
						Wider Stakeholder Engagement	5.2.2.3
						Project Management	5.2.2.4
		Development, post-FID	5.3	Engineering & Design	5.3.1	Detailed design	5.3.1.1
						Owners Engineer	5.3.1.2
						EPCm	5.3.1.3
				Management	5.3.2	Project Management	5.3.2.1
						Wider Stakeholder Engagement	5.3.2.2
						Land Acquisition	5.3.2.3
		Construction	5.4	Fabrication of Key Equipment	5.4.1	Machine Assembly	5.4.1.1
						Welding	5.4.1.2
				Manufacturing	5.4.2	Machining, casting & moulding	5.4.2.1
						Component Quality checks	5.4.2.2
				Shipping & Delivery	5.4.3	Long distance transport	5.4.3.1
						Cargo handling / heavy lifting	5.4.3.2
				Construction, Installation & Site Services	5.4.4	Site Stuides	5.4.4.1
						Plant housing	5.4.4.2
						Installation of components	5.4.4.3
						Connections and integration	5.4.4.4
						Offshore Scaffolding & rigging	5.4.4.5
						Subsea cable contractors	5.4.4.6
		Commissioning	5.5	Testing & Inspection	5.5.1	Electrical testing	5.5.1.1
						Quality testing / NDT	5.5.1.2
						Safety inspections	5.5.1.3
				Construction, Installation & Site Services	5.5.2	Security	5.5.2.1
						Waste Management	5.5.2.2
						Communications	5.5.2.3
		Operations & Maintenance	5.6	Testing & Inspection	5.6.1	Safety	5.6.1.1
						Quality	5.6.1.2
				Monitoring/Data Collection	5.6.2	Downhole Monitoring (Pressure/Temperature/Acoustic)	5.6.2.1
						Leakages	5.6.2.2
						Metering	5.6.2.3
						Subsea monitoring/inspection	5.6.2.4
						Predictive Maintenance	5.6.2.5
				Construction, Installation & Site Services	5.6.3	Security	5.6.3.1
						Waste Management	5.6.3.2
						Communications	5.6.3.3
				Operations	5.6.4	Shutdown/Turnaround Services	5.6.4.1
						Process Operators	5.6.4.2
				Maintenance	5.6.5	On-site Maintenance Services	5.6.5.1
						Subsea maintenance	5.6.5.2
		Decommissioning	5.7	Testing & Inspection	5.7.1	Quantity Surveying	5.7.1.1
						Safety	5.7.1.2
				Management	5.7.2	Project Management	5.7.2.1
						Project Planning	5.7.2.2

4.6 Equipment identified for high-value assessment

The above illustration shows a section of the taxonomy developed for carbon capture. Once major components are defined at Level 4, they are categorised by component type in the adjacent column. Categorising by component type (see Figure 7, below) provides insight as to the most common and critical components in CCS development. This step also facilitates high value analysis of the associated supply chain by component types (rather than a specific component in isolation).

Figure 7: Snapshot of taxonomy, post combustion capture plant

Level 1	Level 2	Level 3	Level 4	Component type
Capture	Post-Combustion - Solvent	Flue gas collection/pre-treatment	Skimmer	skimmer
			Catalytic Reduction Package	sub package
			Filter	Filter
			Cooler	Heat exchanger/fan
			Pump	Pump
			Fan	Fan
			Flue gas blower	Gas blower
			Nox Removal (SCR) package	sub package
			Desulfurisation package	sub package
		Capture	Direct Contact Cooler	Column vessel
			Absorber Column	Column vessel
			Water Wash	sub package
			Absorber wash Column	Column vessel
			Rich/lean heat exchanger	Heat Exchanger
			Stripper Column	Column vessel
			Reboiler	Heat Exchanger
			Condensor	Heat Exchanger
			Stripper wash column	Column vessel
			Solvent (MEA)	Chemical
			Solvent tank	Tank
			Pumps	Pump
		CO_2 conditioning (molecular sieve de-hydration assumed)	CO_2 compressor	Compressor
			Compressor KO drums	Tank
			Coolers	Heat exchanger/fan
			Lube oil unit	sub package
			Motor	sub package
			Knock out drum (de-hydration unit)	Column Vessel
			Coalescer Filter	Filter
			Adsorber Column	Column vessel
			Regeneration Column	Column vessel
			Regeneration Gas Steam Heater	Heater
			Regeneration Gas Electric Heater	Heater
			Regeneration Gas Cooler	Heat exchanger/fan
			Regeneration Gas Separator	Column vessel
			Dust Filters	filter
			Condensate Vessel	Tank
			Regeneration gas blower	Gas blower

Figure 7 above illustrates the selection of components that were carried forward for high-value assessment. Both components and engineering packages were assessed in the equipment high value assessment, as discussed in section 4.3. This represents the majority of infrastructure needed to facilitate CO_2 capture, transport, and storage in the UK. |Given further time and scope to complete this analysis, we would like to develop a more detailed breakdown of component parts of equipment including in particular offshore drilling rigs, topsides for potential CO_2 vessels and processing facilities (currently subject to R&D), and chemical solvents (also subject to R&D, and a potential opportunity area for the UK meriting further attention).

Table 4 - Equipment selected from taxonomy for high value assessment.

Item	Component or Package	Description and details
Column Vessels	Component	Pressurised Steel Cylinders, for the largest columns (Absorption Columns) concrete may be used.
Heat exchangers	Component	A range of heat exchanger types required. For the lean-rich heat exchanger a plate and frame are often recommended but reboiler and condensers are often shell and tube heat exchangers.
BPCS	Component	Monitoring and controls systems of linear infrastructure
Meters	Component	Various meters required across CCS chain to track CO_2 content of gas streams
Column Internals	Component	Packing inside columns used to improve mass transfer capabilities.
Pumps	Component	Centrifugal or progressive cavity pumps assumed

Pipelines	Component	Large-scale stainless-steel pipe assumed (>0.5m diameter)
Tanks	Component	A range of tanks required e.g. for solvent storage and CCS transportation. ISO (internal Standard Organisation) liquid-state tanks assumed for road and rail transport, CO_2 storage capacity 19.5 tons
Compressors	Component	Single shaft or integrally geared, multi-stage centrifugal compressors assumed. Reciprocating compressors may be an option for smaller plants.
Gas Blowers	Component	For flue gas entering the capture plant. Centrifugal gas blower often used for CO_2 capture plants.
Filters	Component	Bag filters and coalescer filters assumed for removing large particulates.
Offshore Jacket platforms	Component	Required for offshore long term CO_2 storage facilities, Scope to reuse existing jacket form oil and gas rigs
Post-combustion capture	Package	Amine based solvent, e.g., MEA (mono-ethyl-amine) – 1% to 5% CO_2 concentration in flue gas feed assumed
Pre-Combustion capture	Package	Amine based solvent, e.g., MDEA (mono-di-ethyl-amine), 15+% CO_2 concentration in flue gas feed assumed.
CO_2 conditioning	Package	Adsorption via molecular sieves or Silica gel and Absorption via TEG (Triethylene Glycol)
Liquefaction	Package	Cooling CO_2 down to liquid state for transportation.

Table 5 - Equipment selected from taxonomy for high value assessment.

4.7 Services identified for high value assessment

Table 7 summarises the services that were carried forward for high-value assessment. This represents the majority of services needed to facilitate CO_2 capture, transport, and storage in the UK. However, it is not an exhaustive list and other services could be considered in further work.

Table 6 Services selected from taxonomy for high value assessment.

Item	Description and details
HR & Recruitment Services	Business operation functions directly relating to the workforce such as Human Resources, Recruitment and Training.
Legal & IP Services	Services relating to the law & intellectual property which serve as a vital enabler to project execution.
Financial Services	Relating to investment and financial management for projects & organisations, including insurance.
Industry Organisations	Organisations that are involved with the development of standards and/or the production of supply chain action plans (SCAPs).
IT / Digital Services	All software-related services as well as IT infrastructure, consultancy, cyber security, and AI/ML services.
Engineering & Design	Engineering design through all project phases and contracting structures (i.e., pre-FEED, EPCm) including CAD / Modelling

Management	Project management and planning functions, including early-phase enabling activities such as consenting, stakeholder engagement etc.
Construction, Installation & Site Services	Services relating to building structures, including scaffolding and cabling. Also includes site services such as security and waste management.
Testing & Inspection	Commissioning services to ensure installed equipment is in working condition including electrical testing and safety.
Monitoring/Data Collection	Services relating to the instrumentation to verify the well integrity and enable predictive maintenance, metering etc.
Logistics	Commercial activities relating to the transportation & handling of goods
Subsea, Wells & Exploration	Specialist services in the offshore industry such as geotechnical surveys, well selection and drilling
Fabrication of key equipment	The assembly of equipment from semi-finished or raw materials, containing activities such as machine assembly or welding.
Hospitality & Accommodation	Essential functions relating to the housing of the project workforce
Operations & Maintenance	Activities relating to the regular process function of the plant including shutdown & turnaround services

Table 7 Services selected from taxonomy for high value assessment.

4.8 Comparison with other taxonomies

There are lots of ways in which to break down the UK CCUS Supply Chain for tracking of UK value and content in the emergence of the new UK CCUS infrastructure. Other taxonomies exist for the parts of the supply chain and have been developed previously for various industrial equipment and services. Discussions with industry have indicated that taxonomies would ideally be:

- **Cross-sector** - Can be applied to all other sectors in the energy transition, to enable multi-project aggregation of equipment vendor/manufacturer asks; and,
- **Granular -** Levels of a taxonomy reaching a granularity that can identify and define specific components to specific vendors or manufacturers.

For government, a common standardised taxonomy for CCUS in the UK is designed to:

- Enable tracking industry trends for equipment and service types procured for projects;
- Allow the monitoring of local content per equipment and service type; and,
- Allow mapping of international sourcing
- Enable industry-wide transparency of the strengths and weaknesses of the UK Supply chain for CCUS in order to support future shaping of policy and regulation to further maximise UK benefit

Merging desires of both industry and government will be crucial to ensuring accepted uptake of a standardised taxonomy.

In 2022 Wood and Optimat developed a taxonomy for the hydrogen sector for The Department for Business, Energy & Industrial Strategy (BEIS)[15]. The structure is similar to that proposed for CCS, breaking-down:

[15] Wood and Optimat, for The Department for Business, Energy & Industrial Strategy (BEIS), Supply Chains to Support a Hydrogen Economy, 2022 – Link

- Hydrogen production methods (green and blue);
- Hydrogen transport, storage, and fuel cells (end use) into different taxonomies,
- Separating materials (equipment and services).

The final level lists component types, as with the taxonomy in this work. See Figure 8: Snapshot of hydrogen taxonomy, developed by Wood and Optimat

Components	Equipment/Material Category	Area/Unit	Segment	Product
air coolers	Catalysts and Chemicals	Feed pre-treatment (water)	Materials	Green Hydrogen
Basins/Sumps	Civil/ Structural Materials	Electrolysis		
Buildings/shelters	Electrical Equipment/Materials	Hydrogen treatment & Compression		
Bus Systems	Fired Equipment	Hydrogen Liquefaction and Conditioning		
Cable Trays	Instrumentation and Control Equipment/Materials	Temporary Hydrogen Storage		
Cables	Piping Materials	Utilities and offsites		
catalyst	Rotating Equipment			
Cell Stack	Static Equipment			
Continuous Emissions Monitoring Systen	Thermal Equipment			
Chemicals	Packaged Equipment			
compressors				
control system				

Figure 9

Figure 8: Snapshot of hydrogen taxonomy, developed by Wood and Optimat

Components	Equipment/Material Category	Area/Unit	Segment	Product
air coolers	Catalysts and Chemicals	Feed pre-treatment (water)	Materials	Green Hydrogen
Basins/Sumps	Civil/ Structural Materials	Electrolysis		
Buildings/shelters	Electrical Equipment/Materials	Hydrogen treatment & Compression		
Bus Systems	Fired Equipment	Hydrogen Liquefaction and Conditioning		
Cable Trays	Instrumentation and Control Equipment/Materials	Temporary Hydrogen Storage		
Cables	Piping Materials	Utilities and offsites		
catalyst	Rotating Equipment			
Cell Stack	Static Equipment			
Continuous Emissions Monitoring Systen	Thermal Equipment			
Chemicals	Packaged Equipment			
compressors				
control system				

Figure 9: Snapshot of hydrogen taxonomy, developed by Wood and Optimat

Other international taxonomies exist primarily as procurement tools, such as the United Nations Standard Products and Services Code (UNSPSC)[16]), or EU Common Procurement Vocabulary (CPVs)[17]. These use numerical IDs to define and categorise items. This type of taxonomy is typically developed for the separate purpose of tracking procurement aligned to the purchasing organisation's internal accounting system as well as that of the vendor.

Further work be required to merge the desires of industry and government, to produce a taxonomy, with the detail level required for procurement, and to track UK content across the CCS chain. This would include:

- Engagement with EPCs, to:
  - Understand the current procurement coding systems EPCs use, and any recent industry trends with numerical IDs.
  - Understand the level of detail required at component specification that will enable cross-sector streamlining of procurement. Details required to define individual components will be unique to each component type.
  - Align typical packages across major energy infrastructure projects, to Level 3 of the proposed CCS taxonomy.
- Mapping component types identified in the CCS taxonomy to the level of detail required by industry, see Table 8 for some examples.
- Digitising of the taxonomy into a free to access, user-friendly platform.

[16] United Nations Standard Products and Services Code (UNSPSC) – Link

[17] EU Common Procurement Vocabulary (CPV) – Link

Table 8: Examples of potential details, to reach sufficinet granularity from this taxonomy for differnet component types

Component type identified at Level 4 CCS taxonomy	Example component additional details
Column Vessels	Material, dimension ranges (e.g. height/diameter),
Heat Exchangers	Type (e.g. plate/shell and tube etc.), operating temperatures
Compressors	Type (Centrifugal/reciprocating/rotary etc), operating pressures

5. High Value assessment

5.1 Summary and Comparison of Preceding Reports

5.1.1 The following sections provide a summary of four principle preceding reports in this field, and how the content has been utilised in this study. The reports are : OEUK – Carbon Capture and Storage and the opportunity for the oil and gas supply chain (2022), CCSA – Supply Chain Excellence for CCUS (2021), NAMRC – CCUS supply chain intervention strategy (2022), and WSP – Industrial CCUS UK Supply Chain Capability (2022).

Overall, the preceding reports provided only a partial view of the CCUS supply chain, with principle focus on the capture plant rather than full capture, transport and storage value chain as here. Further comparison is summarised here:

Figure 11a: Summary of high value analysis methods, consolidated from four principle preceding reports

Factors considered by previous reports	Scoring type	UK Supply chain coverage
Capability of providers	RAG	Partial (Capture only - equipment) + services (SIC-code based))
Experience of UK providers	RAG	Partial (Capture equipment only)
Readiness of providers	RAG	Partial (Capture process only)
Value impact (£)	High/Low	Partial (Capture only/ Equipment only)
CCS specificity	High/Low	Partial (Equipment only)

5.1.2 NAMRC – CCUS supply chain intervention strategy (2022)

NAMRC undertook work to assess the UK supply chain capability for CCUS projects. Work was focused on manufactured components required for carbon capture plants specifically. A summary of the method of assessment and results is given below in Figure 11.

Figure 10 - NAMRC scoring matrix (a) and results (b)

	Number of suitable manufacturers	Capability	Experience
Green	More than 5 manufacturers capable of producing the components needed.	Sufficient knowledge and equipment to create the components required. May not currently be active in the CCUS sector.	Fully experienced in delivering suitable components. May have been involved in CCUS projects.
Amber	3 to 5 manufacturers capable of producing appropriate components.	Some knowledge and equipment, but not capable of producing parts of the appropriate scale. Some investment is required.	Some experience producing components of a similar magnitude.
Red	Fewer than 3 manufacturers capable of producing appropriate components.	Significant investment is required to improve sector knowledge and improve equipment to manufacture to the required specification.	Significantly lacking appropriate experience with components of the required type and size.
Grey	Insufficient information gathered during the analysis, due to lack of publicly available information. Direct contact with likely companies will be required in future for proper analysis to be performed.		

Component	Number of suitable manufacturers	Capability	Experience	Supply chain readiness
CO_2 compressors				Amber
Absorption columns				Amber
Amine treatment				Green
CO_2 pipelines				Grey
Flue gas blower				Amber
Direct contact coolers				Amber
CO_2 stripper columns				Amber
Pumps				Green
Heat exchangers (general)				Green
Gas-gas exchangers				Green
Crossover exchangers				Green

Figure 11 - NAMRC scoring matrix (a) and results (b)

NAMRC give a clear RAG scoring framework for assessing UK CCS supply chain capabilities. Their analysis is focused on analysing the UK capabilities without contextualising with international offerings in their scoring shown above.

Overall, the analysis indicates great opportunity across many components, with pumps, amine treatment and heat exchangers specifically identified. The report identified 5+ suitable UK manufactures in nearly all instances (except compressors and Flue gas blowers). The report notes the limitations of this methodology, including the use of volume of companies, but without individual manufacturer engagement, and that further work would be required to establish capacity more accurately to fully establish gaps, which would include equipment supplier engagement.

To capitalise on the opportunities identified a series of steps, further work and recommendations is provided, including (non-exhaustive):

- Initial intervention is focused on database management, supply chain mapping and supply chain readiness assessment. Broadly this requires a structured approach to assess UK manufacturing and supply chain capabilities, and manufacturing and supply chain needs form the CCS industry to deliver the ambitious pipeline of projects.
- Develop and inventory of components for carbon capture project, and set unit sizes for key components, and particular focus on CO_2 pipeline specification.
- Further exploration of key areas such as other capture technologies (non-solvent based), the wider blue hydrogen plant (ATR and SMR), and CO_2 storage facility requirements.

These recommendations are responded to in the analysis and scope of this report.

5.1.3 WSP – Industrial CCUS UK Supply Chain Capability (2022)

WSP were commissioned in 2022 to provide an assessment of the equipment required for industrial CCUS and the UK capability to deliver .This builds on NAMRCs work, conducting supplier engagement, and numerically estimating component requirements for industrials CCS applications. (Note only industrial CCS was considered, CCUS-enabled hydrogen and power sector was not considered in estimations). One or two vendors were consulted for each component, and there was a mix of large international industrial process equipment companies, and smaller UK-based companies.

Equipment requirements for 2040 industrial CCUS ambitions were estimated, with the results illustrated in below extract (figure 13). The ability of the UK to deliver on these components was then assessed with results shown in Figure 14 below.

Figure 12: WSP equipment requirements in 2040 for carbon capture plants for industrial applications, for different CCUS uptake scenarios in industry

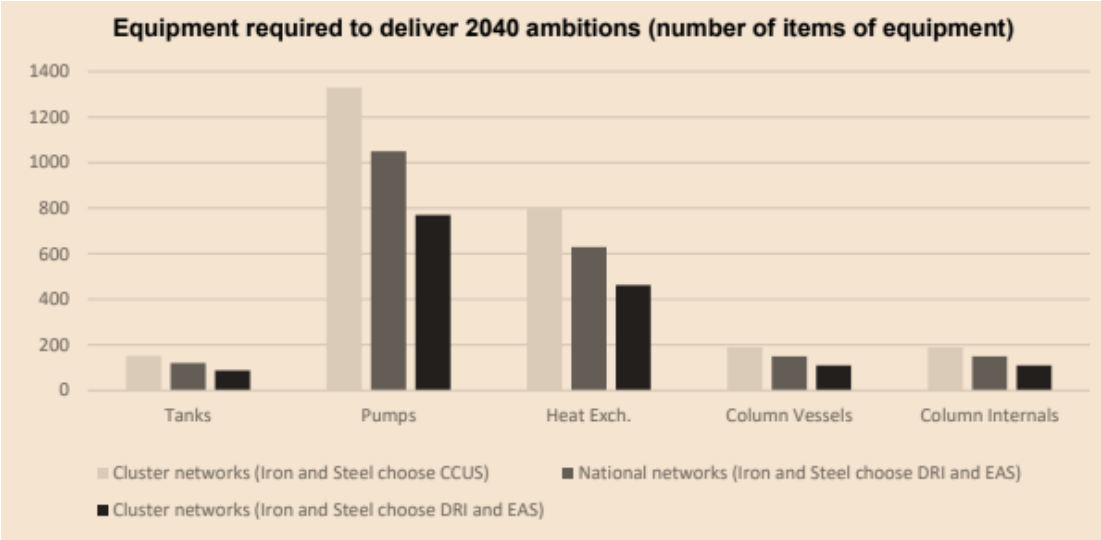


Figure 13: WSP equipment requirements in 2040 for carbon capture plants for industrial applications, for different CCUS uptake scenarios in industry

Equipment	WSP	NAMRC	Size	Other CCUS Markets	Other Markets
Column Vessels	High	Amber	41%	Yes	Yes
Column Internals	Medium	Green	8%	Yes	No
Pumps	Low	Green	1%	Yes	Yes
Heat Exchangers	Low	Green	4%	Yes	Yes
Tanks	High	-	3%	Yes	Yes
Flue Gas Blowers	Low	Amber	-	Yes	Yes

WSP analysis.

This resulting analysis gave a more targeted view of UK supply chain capabilities. This was done by contextualise what UK vendors could deliver in the required timeframe and a high-level overview of how they will likely compete with international offering.

The UK supply chain is highlighted as being best placed to deliver column vessels and tanks, with columns vessels identified as being the of the greatest value piece of equipment in the carbon capture plant. Column internals offer a possible additional opportunity but have been at risk of being less applicable to other markets.

This report backed up the analysis, by illustrating high-level trends in the UK manufacturing sector summarised below:

Generally, the manufacturing industry for process engineering can be categorised by small scale, which provides bespoke equipment for specific needs; and large scale, which provides high volumes of standardised equipment. Supplier and industry engagement indicates that the UK supply chain is primarily small-scale, bespoke manufacturing comprised of SMEs which focus on delivering high-quality, high-cost equipment. This is where the UK is believed to best placed to have a competitive advantage.

Therefore, if each industrial CCUS plant is different and there is limited opportunity for standardisation, then the UK supply chain is well placed. If there is standardisation, then it will be challenging for the small-scale operations in the UK to compete with large-scale manufacturers in Germany, Italy, and Poland. In addition, the smaller scale means that appetite for risk, access to finance and opportunities to develop a significant

pipeline to justify expansion are limited. However, a lot of the equipment can be manufactured by both small and large-scale manufacturers, and this is a common trend seen for much of the equipment required for the carbon capture plant.

On face value, market analysis found in the WSP report suggests that quantities of certain equipment such as columns and tanks, required to meet government industrial CCUS targets could be provided by a single UK supplier comfortably. However, it was noted that key dependencies such as status of current order books, and demand from other sectors was not accounted for.

The report highlights key barriers and opportunities for the UK to maximise supply chain content, covering:

- Ensuring visibility of project pipeline, so manufacturers can scale and adapt production capabilities as necessary.
- Improve access to industrial land, to mitigate the risk of land constraint causing bottlenecks.
- Support UK supply chain players, getting access to key project decision makers (EPCs).
- Promote installation of industrial CCUS to capitalise on UK expertise in this sector.
- Explore cross sector supply chain collaboration.
- Consider net zero procurement for future projects.

5.1.4 CCSA – Supply Chain Excellence for CCUS (2021)

Other previous UK CCS strategy work from the CCSA[18] has given a more pessimistic outlook for the UK supply chain, and emphasis the risks from overseas companies:

"*For post combustion CO_2 removal plant (fabricated vessels, exchangers etc) and machinery (pumps, compressors etc) much of the total required (about half by value) had a very weak UK supply chain – "less than 3" (feasibly zero) potential vendors were visible to the EPC, and the chain for those items was assessed as low on capacity, capability, and experience. Where the chain was strong, it still had to compete with foreign companies"* – CCSA, 2021 – Link

The CCSA report focuses on how to achieve long-term benefit to the UK and its domestic markets through CCUS, highlighting the importance of increased focus on improving our local content percentage to avoid half of UK project expenditure being spent outside of the UK. The below estimates were made to frame the size of the opportunity for CCUS (including hydrogen and greenhouse gas removals). A summary of the totals is shown in the table below.

Table 9 - CCSA Opportunity Scale

Capex and Opex of Technologies in CCUS/H2. Guidance from Net Zero Studies (CCC and ESC)	**Total CapEx spent by 2035**	**Total CapEx Spent by 2050**	**Fixed OpEx 2035**	**Fixed OpEx 2050**
Total £Bn	41	90	50	101
National H2 Transmission (Not in model)	Lifetime £30bn if fully deployed			

Table 10 - CCSA Opportunity Scale

This table uses estimated values for onshore & offshore technologies representative of the current suite of CCUS cluster projects in the UK, with around 85% of the spend being onshore.

CCSA concluded that modularisation could benefit the CCUS supply chain's ability to deliver whilst also providing economic and employment benefits for the UK, with export potential. Additionally, by focusing on

[18] CCSA, Supply Chain Excellence for CCUS, 2021 – Link

training operators now, we can ensure that these highly-skilled and long-term jobs are held by UK nationals and support the communities around our industrial clusters.

CCSA recommends a comprehensive supply chain strategy to identify early high potential opportunities that can deliver long-term benefit to the UK. Their key recommendations have a focus on industrial clusters having cross-industry communication to give transparency on the project pipeline, along with an assessment of our current capacity, to avoid future bottlenecks.

5.1.5 OEUK – Carbon Capture and Storage and the opportunity for the oil and gas supply chain (2022)

This report focuses on examining what aspects of the existing oil & gas supply chain can aid the UK's project delivery, support investment, and create jobs. The 4 main conclusions drawn from the research & analysis of this report were as follows:

- **The offshore oil and gas industry is agile -** Stakeholder engagement suggested that areas of the existing oil and gas supply chain aligns with the requirements for CCS and are in fact already making the transition between sectors;
- **Bottlenecks are likely in major areas of the CCS supply chain -** Due to the large number of energy and infrastructure projects in the pipeline in the UK, there will be competition between industries for key skills and materials. One of the key areas of bottleneck is construction & commissioning, due to the increase in nuclear, hydrogen and other renewable energy sectors, which will be coming at a time of upturn for other non-energy-related infrastructure projects;
- **Support is needed for UK competitiveness -** There is a lack of existing manufacturing supply chain for a significant number of the key technologies required for CCS. Intervention is required to address labour cost and productivity challenges that threaten major plant fabrication in the UK and in order to capitalise on some of the high-value opportunities; and,
- **Invest to gain early-mover advantage -** Due to the bottlenecks discussed above, it is important that investment is made to address these challenges to avoid delays or relying on imported skilled labour.

The OEUK report also made estimations of the size of the opportunity for each of the supply chain sections, using assumptions based on their experience and an approximated CCS investment value of £20bn, which is visible in Table 12 below.

Table 11 – OEUK Opportunity Estimates

	Carbon capture				Transport & storage	
	Design and engineering	Major plant fabrication	Equipment design & manufacture	Construction & commissioning	Pipework supply and installation	Storage – wells, subsurface and reservoir
Proportion of Capex	10%- 15%	15%- 25%	15%- 20%	25%-35%	10% - 15%	5% - 10%
Est. share of £20bn investment (£bn)	2.0-3.0	3.0-5.0	3.0-4.0	5.0-7.0	2.0-3.0	1.0-2.0

Table 12 – OEUK Opportunity Estimates

These values were also used as input into further analysis of the CCS supply chain sections, from which assessments were made to give a scoring to the "value and accessibility of opportunity", alongside the current UK capability in this area, as shown in the Figure 15 below (The key used to make distinction between these rankings is included below the data).

Figure 14 – OEUK value and accessibility of opportunity assessment

Supply chain activity		UK capability	Value and accessibility of opportunity
Capture	Plant design & engineering		
	Major plant fabrication		
	Equipment design & manufacture		
	Construction & commissioning		
Transport	Pipework onshore & offshore Supply & Installation		
	Marine transport of CO_2		
	Marine loading & offloading		
Storage	Wells, subsurface & reservoir design & engineering		
	Marine & subsea contractors		

	Capability	Value & accessibility of opportunity
	The UK can supply all the required capability.	There is a significant opportunity, readily accessible to the existing supply chain.
	The UK can supply most of the required capability.	There is a significant opportunity but some constraints or barriers to access.
	The UK has moderate coverage of the required capability.	There is a moderate opportunity with constraints or barriers to access.
	The UK has limited coverage of the required capability.	There is a limited opportunity with challenging constraints or barriers to access.
	The UK has minimal coverage of the required capability.	There are prohibitive constraints of access limiting the value of the opportunity.

Figure 15 – OEUK value and accessibility of opportunity assessment

5.2 Stakeholder response to Questionnaire

As part of the research for this study, a number of questions were issued to industry participants. These questions, a narrative summary of the responses, and the identified key components are captured Table 14. This information was used as a research input to the analysis within the high-value assessment.

Table 13 – Stakeholder questionaire response

Question	Response Summary	Key Items
1) "Which manufactured goods, chemicals or materials are most likely to represent the greatest constraints in the supply chain as CCS production ramps up in mid-2020s?"	One of the commonly raised issues to this question was the ability of the UK to meet the steel demand from CCS, partially due to a global shortage of feedstock. The capability in the UK for steel manufacturing is diminishing, meaning that the remaining domestic manufacturers are very busy. Increasing reliance on China for steel is exposing us to schedule risk, as there is currently a high Chinese internal product demand. Similarly, to steel, the number of UK fabrication yards has decreased over the past decade, meaning that our ability is limited to fabricate equipment such as large pressure vessels for CCS. Fabrication yards in the UK are very busy supporting other industries both in the UK and in Europe.	**Steel** Compressors Pipework Fabrication Transformers
2) Which manufactured goods, chemicals or materials could represent an opportunity for increased UK production (and where in the UK)?	One comment made was that CCS is very energy intensive, so the demand for energy optimisers will be high, which is a field we could build on UK IT expertise & industry. As in the previous question, it was noted that there is limited UK capability for producing pressure vessels. CO2 and hydrogen transports will require a lot of large bore pipework, which the UK does not currently have capability for. It was suggested that the UK should consider trying to ramp up production in this area as it may prove less difficult relative to some other key equipment with more complex requirements.	**Pipework**
3) Which parts of the UK service economy will be most critical to the CCS supply chain?	Electricity and water demand will greatly increase for blue and green hydrogen as well as post-combustion carbon capture plant. UK Utility providers are already struggling to meet the demand of the first projects alongside feeling the effects of climate change (increased drought risk in the summer months) and the dramatically increasing infrastructure requirements associated with electrification. Engineering companies are currently very busy with projects in other industries, such as the large amount of UK civil engineers working on HS2. A suggested way to help mitigate this, is by encouraging sponsorships of graduates for all engineering and construction disciplines and creating more apprenticeships. Another key issue raised is the lack of suitable accommodation and hotels around industrial clusters. This may result in it being harder to resource projects if there are no t places for the project workforce to live.	**Engineering** Accommodation
4) Which parts of the UK service economy would be instrumental to our growing CCS industry, and which services are most likely to be constrained?	UK construction is constrained generally in terms of human resources and specifically certain skills e.g., some classes of welding. For a range of reasons related to risk, major UK EPC companies have been reluctant to offer fixed price contracts for CCS construction elements, preferred for cost surety within Govt CfD frameworks. Similarly, to the previous questions, it was raised that there is the lack of UK capability to offer large modularisation potential due to lack of appropriately sized fabrication yards. Also, however much manufacture and plant fabrication are outsourced, civils and heavy lift capability is tied to construction site locations, so these sectors are critical to construction timelines. The huge global demand for Energy Transition projects is creating a very competitive market for design engineers. This is good for the UK which has significant well-respected	**Engineers** Construction

	engineering resource but the ability of international projects to pay better is causing shortages for UK projects.	
5) What are the major risks & constraints for the CCS supply chain in the UK?	Aside from answers raised in the previous question, general resourcing issues are likely to pose a major threat to CCS project execution. Suppliers are prioritizing projects in execution (e.g., O&G, wind) where the work is guaranteed. There is a wider belief that it is becoming difficult to encourage people to work in the energy industry as it is not seen as 'trendy', and the traditionally cyclical nature of the industries. It was suggested this could be counteracted by increasing government & industry support for apprentices & graduates. CCS projects are also subject to constraints caused by resourcing in regulatory authorities, which is contributing to the delay of investment decisions. This is also being impacted by the timelines to agree government contracts, which is stifling the industry's ability to deliver on target commissioning dates.	**Engineers** Resourcing
6) What do you believe the 3-5 highest value opportunities are for the UK & why?	A common theme amongst some answers was that in the value of investment in training and development within industrial clusters to support skilled resources required to deliver decarbonization targets. We must focus on solving the wider resourcing issue to ensure that there is the skills and labour available in key areas such as construction. Track 1 projects' procurement strategies are already set and delivery timescales are too short for changes to impact them through intervention now. For this reason, agreeing government contracts on these projects as well as Track 2 projects will increase the likelihood of these projects being able to deliver on target commissioning dates. This could also be aided by cluster sequencing for Track 2 & 3 projects. Encouraging and supporting first-of-a-kind technologies may increase the future export potential of the UK as the "go-to" nation for innovative Net Zero technologies. A forward-thinking attitude, such as by leveraging the UK IT capability to target a data-driven approach to project design, could also bring value.	**Training & Development**

5.3 Defining the 'High Value' Assessment

Approaching the 'high value' assessment task in this study, we have sought to establish a method which is wide-ranging, consultative and inclusive of a range of available datasets. Establishing which of the services and equipment in the UK CCUS value chain can be considered 'high value' to the UK is a challenging process and may attract critique and challenge. For that reason, as wide a range of sources and inputs for this analysis to be as objectives as possible, has been sought.

We have consulted on the definition of high value with members of the CCSA, and in particular the CCSA and CCS Council working groups associated with this report. Where metrics have not always been possible to assess across the full range of goods and services, and /or data has not been consistently available, we have used a combination of engineering judgement, research and analysis and expert advice to navigate through the uncertainty in the available data at this early point in the development of the UK's CCS sector.

The definition of 'high value' has been established to consider the potential benefit to the UK economy, and a reflection of the criticality and risk to the delivery of this new infrastructure sector. Following an industry workshop on 23rd March 2023, we invited participants to respond to a further questionnaire to inform the definitions used in this section of the report. The responses are captured and analysed in section 5.2. These were compiled alongside our desktop research on the UK capacity and capability, vacancy analysis, market analysis and research of companies advertising UK services.

On 18th April 2023 we presented to the CCS Council's working group the below summary of the 5 dimensions of our 'high value' analysis, which we agreed to apply to the items in the above-described taxonomy at Level 4. These 5 parameters accordingly form the structure of our detailed analysis summarised below.

Figure 16 - Arup High Value assessment tool: Main Criteria as shared with the CCS Council Supply Chain working group on 18th April

ARUP

High value assessment: tool is developed & in testing

Our tool combines full supply chain and full asset life cycle in single evaluation

Fig. 2: Preceding reports: Summary of scoring

Factors considered by previous reports	Scoring type	UK Supply chain analysis coverage in reports so far
Capability of providers	RAG	Partial (Capture only - equipment) + services (SIC-based))
Experience of UK providers	RAG	Partial (Capture equipment only)
Readiness of providers	RAG	Partial (Capture only)
Value impact (£)	High/Low	Partial (Capture only/ Equipment only)
CCS specificity	High/Low	Partial (Equipment only)

Fig. 3: Arup 'high value' tool: Main structure

	Arup "high value characteristics" for supply chain evaluation	Coverage
1	CCS or CCU criticality/ bottleneck /risk	▪ Core plant equipment & materials for capture, transport & storage ▪ Full asset life cycle services
2	UK Value impact (£/GVA/jobs)	
3	UK strengths (inc. legacy North Sea)	
4	Technology readiness / IP opportunity	
5	Market rating: UK capacity, capability	

Three overarching considerations for "high value"

- CCS acceleration: criticality and 'bottleneck' potential, sub-supply chain risk, scalability
- 'UK Plc': job creation opportunity, relevance to UK strengths or industrial strategy
- Market factors: price, availability, existing demand, logistics

Link to full HV scoring (WIP)
20230328 Taxonomy_V2.xlsx (sharepoint.com)

5.4 Criteria Definition

As a result of this initial engagement, five key groups of criteria were established for testing and development. The considerations within each assessment criteria are set out below:

- CCS or CCU criticality and bottleneck risk:
    - Estimated specificity to CCS versus relevance to other industries of a given item of equipment or service;

- Overall likelihood of an item of equipment or service posing a bottleneck risk to UK CCS to 2030, based on vacancies and recruitment analysis;
- Overall likelihood of an item of equipment or service posing a bottleneck risk to UK CCS to 2030, based on high value questionnaire and workshop responses.

- **UK value impact:**
  - Estimated overall potential opportunity for new job creation through the deployment of an item of equipment or service in support of the CCS industry.
  - Considerations re: market fluidity, market entry potential (excluded due to data availability)
- **UK strength:**
  - Synergies with UK North Sea industry jobs, skills and infrastructure;
  - Synergies with UK onshore industrial infrastructure hubs, including energy transition hubs;
  - Alignment to existing UK companies and supply chains;
- **Technology Readiness and innovation opportunity:**
  - This refers to the opportunity represented by the development of new intellectual property within the UK. It is assessed as a combination of the readiness and availability of the technology, and the level of UK capacity and capability to lead on the development and deployment of the new technology, where relevant.

In addition, an indicative view of a market rating for UK capacity and capability was undertaken considering market fluidity (accessibility for new entrants) and scale of UK companies, to the extent that data was available.

5.5 'High value' - detailed methodology and assessment criteria

1. **Potential UK economic opportunity**: Consideration of the existing UK capability and capacity in this area, the potential for development of new intellectual property, and for the likelihood of growth of new enterprise.
2. **Risk to delivery in the UK:** How well-positioned (or otherwise) the UK might be to deliver in the area. Considering the potential for a constraint to the UK CCS supply chain in relation to this service or equipment item, that causes a bottleneck or block to deployment of the full CCS chain in the UK. Identifying areas where action may be required to enhance or de-bottleneck the supply chain in the UK.

These factors have been assessed with the criteria as summarised in the below table 15 for both **equipment and services**:

Table 14: Summary of assessment criteria for high value assessment across equipment and services

	Factor	Equipment	Services	Rationale for inclusion as an assessment criteria	Rating method
Risk to delivery in the UK	Number of suitable UK manufacturers	X		More manufacturers implies (although does not guarantee) higher supply chain capacity, and more market competition to improve quality of products	No. of companies
	Use in other sectors	X		Components specific to CCs are unable to rely on other markets to stimulate growth which increases the risk of bottlenecks.	Yes/No
	Experience of manufacturers	X		High UK experience will improve chances of reliable delivery of equipment, on tie and on budget.	Low/Medium/High
	UK Bottleneck or Constraint for CCS		X	Bottlenecks will increase the risk to project delivery and UK being able to develop respective service sectors	Low/Medium/High
Potential value for UK economy	Job Creation		X	Higher job creation opportunities will be of greater opportunity for the UK.	No. of jobs
	Estimated CAPEX in 2030/Financial Value	X		Higher CAPEX will mean a greater economic opportunity.	Low/Medium/High
	Repurpose legacy infrastructure & skills (O&G)	X	X	Reusing existing infrastructure could reduce project budgets and timelines or reduce decommissioning costs	Yes/No
	UK IP opportunity	X	X	Can generate growth through R&D and IP can be exported internationally to offer value to the UK economy	Low/Medium/High

The criteria developed from previous CCS supply chains work, and feedback from industry questionnaires. Exact criteria differ between equipment and services, due to the nature of the two different industries, but the criteria consider both the risk and possible opportunity for components.

Data for each criterion has been compiled from a range of sources including:

- Previous government strategy work, references for which are identified within the analysis;
- Industry body engagement, including via questionnaires and via CCSA forums;
- Desk-based research on equipment suppliers; and,
- Early engineering design work, where available, for current CCS projects;

A common scoring matrix has been used across the equipment and services to enable consistent use and understanding across all supply chain components. This is summarised in the below Table 16.

Table 15: Equipment high value assessment scoring matrix *Equipment CAPEX, based on high-level literature estimates, the exact proportion will be unique to each different CO_2 capture, transport, and storage facility.

	Risk/Value	Low/no	Medium	High/yes
Number iof UK Manufacturers	**Risk**	2 or fewer companies identified in that manufacture in the UK	3 to 5 companies identified that manufacture in the UK	Over 5 companies identified that manufacture in the UK
Use in other sectors	**Risk**	Component is bespoke to CCS, and not used in many other industries/applications	Similar components are used in other industries/applications	Component is a standard piece of industrial equipment, that is used widely in other industries/applications
Experience of UK manufacturers	**Risk**	Fewer than 10 years experience from UK companies	10 to 20 years experience from UK companies	20+ years experience, from UK companies
Financial value (Proportion of supply chain CAPEX*)	**Value**	Estimated to be under 5% CAPEX of a CO_2 capture, transport or storage facility	Estimated to be 5 to 20% CAPEX of a CO_2 capture, transport or storage facility	Estimated to be over 20% of a CO_2, transport or storage facility
Repurpose legacy infrastructure (O&G)	**Value**	Exisiting installed infrastrucure has no scope to be repurposed for this component.	n/a	Exisiting installed infrastrucure has scope to be repurposed for this component.
IP	**Value**	No competing technology/component in development, or new technogloy opportuntiy identified that could be commercialised in the near future	Competing technology/component in development identified or new technogloy opportuntiy, estimated TRL 3 to 5 that could be commercialised in 10 years	Competing technology/component in development identified or new technogloy opportuntiy, estimated TRL 6 to 8 that could be commercialised in 5 years

Table 16: Services high value assessment scoring matrix

	Low/No	Medium	High/Yes
1. UK Bottleneck or Constraint Risk for UK 2030 CCS horizon	There are established companies which are likely to be able to have enough capacity to handle CCS projects	There is a chance of bottleneck which may come from relatively few companies being established, or CCS being in competition with other industries/projects	It is likely that this service will face a UK bottleneck, either due to no existing capacity, or a forecasted reduction in availability due to low uptake in young people
3. UK North Sea Industry Synergy	Is it not likely to be possible to repurpose infrastructure/skills from Oil & Gas, or other industries	Some alignment to historic UK strengths and synergies	It is possible to repurpose infrastructure/skills from historic energy industries
4. Technology readiness	The industry is stable & does not have significant change over time, and unlikely to hold any significant innovation opportunity	There is some potential for IP but there is uncertainty or significant barriers such as other countries being significantly ahead of the UK.	It is clear that, with investment or focus, there is an opportunity for the UK to establish exportable IP

These criteria aim to provide a relative assessment for each component. However, there will be uncertainties and limitations in the data, which would need to be considered in more depth if a quantified approach was required. In considering the number of companies, for example, consideration would also need to be given to the size of the company (and hence its capacity to supply), the proportion of UK operations (where international in nature) and the position of its order book.

5.6 Equipment Results

Table 18 and Table 20 set out the summary of the high value assessment completed on the equipment and packages respectively. Full detail of the analysis against each criteria is in Appendix 63A.1.

Table 17: High value assessment of equipment components

Component	HV summary	UK Capacity	UK Experience	Cross Sector	Financial Value	IP	Repurposing legacy infrastructure
Column Vessels	**High -** Column vessels are a significant opportunity for the UK due to the size & specificity of CCS columns. Retrofitting columns will require bespoke turnkey solutions, which is well suited to the UK manufacturing sector capabilities. However, large volume orders without advanced notice could create bottlenecks for the UK supply chain and existence of a limited number of UK fabrication yards with already constrained order books.						
Heat Exchangers	**High -** A variety of heat exchanger technologies are needed in carbon capture plants. Manufacturers note the optimal technology selection varies between plants (e.g. plate and frame for the lean/rich heat exchanger and shell and tube for the reboiler). The UK has a number of companies now designing, manufacturing and installing high quality products, again offering turnkey solutions. This could be well tailored to the retrofit of carbon capture technology to existing plants.						
Pumps	**Low -** it is hard for the UK to compete with well-established existing overseas supply chains. Pumps are required throughout the CCS supply chain but typically do not represent a significant proportion of project CAPEX.						
Column Internals	**Medium -** There is an opportunity to develop this supply chain in the UK, where procured alongside the column vessels. It is likely to be specific to the capture plant's location and process requirements. Exact internal requirements will vary with technology type and flue gas, which will be unique when retrofitting to existing plants. Column internals are a major CAPEX expenditure for a capture plant. UK has several manufacturers capable of producing internals, typically for distillation columns or reactor vessels.						
Compressors	**Low** - CO_2 compressors will need significant capital investment to enable a widespread connected CCS chain in the UK. However, given the UK's limited expertise and lack of established manufacturing facilities, prioritising UK centrifugal compressions manufactures would be high-risk. The international supply chain also faces a significant bottleneck given competition with other industries.						
Gas Blowers	**Low** - The UK has manufacturing capability but overall it will be challenging for the UK to compete with well-established European supply chains, who have established manufacturing facilities. If highly bespoke blowers are required for a less-typical process, then there could be a niche opportunity for the UK manufacturers that currently exist.						
Filters	**Medium** - The UK is well-positioned to manufacture filters for CCS applications and develop new filtration technology if existing testing and research facilities are maintained. However, filters are a relatively small component of project cost.						
Tanks	**Low** - Liquid CO_2 storage tanks could have use if rail and road transport CO_2 markets develop. Other tanks for temporary CO_2 storage and solvent storage are required, but overall these are often a relatively small expenditure across the CCS chain. UK has capability to produce tanks but many are currently imported from overseas						
Metering	**Medium -** Meters required across the CCS chain. The equipment is a relatively small CAPEX compared to other larger items. The value will come potential for integration with control systems, and software driven data collection and analysis from meter readings, across the chain.						
Basic Process Control System (BPCS)	**High -** A critical opportunity area due to 1) the central importance of monitoring across the capture, transport and storage value chain, 2) the importance of balancing the demands on the system and communication across the networked assets and 3) the sensitivity and variability across store types.						
Line Pipe	**Medium** - There is a large opportunity but also high risk to develop CO_2 pipeline production in the UK. A bulk scale CO_2 network will be needed to connect clusters to storage centres. Additionally R&D work is ongoing into corrosion resistance and detection to minimise leakage risks. Stainless steel is required for CO_2 pipes, and there are only two UK companies that manufacture steel pipe (Liberty Steel Group and Tata Steel). They will struggle to compete with overseas manufacturers as the energy price spike has increased their costs. There could be opportunities for CO_2 pipes fabrication.						

Jackets	Medium - Around 60% of jackets value is in steel and 40% in fabrication. It will be challenging for UK steel to compete with overseas, however UK fabrication yards have diversified into offshore wind in the last decade. While many facilities have faced difficulties from oil and gas demand slowing down this century, there have been very few closures in the last decade. This demonstrates resilience and adaptability of the UK fabrication industry, offshore CO_2 storage offers them a new opportunity, so if supported with order volumes, could be an opportunity for UK industry.						

Table 18: High value assessment of equipment components

Table 19: High Value assessment of packages

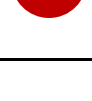
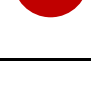
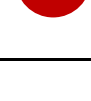
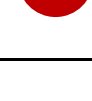
Package	HV summary	UK Capacity	UK Experience	Cross Sector	Financial Value	IP	Repurposing legacy infrastructure
Capture (post-combustion package)	**High** - There are several smaller newer-market entrants developing post-combustion capture. These face challenges from competing with more established companies with experience built up in enhanced oil recovery. However, there is great opportunity with new technologies getting closer to commercial readiness. Smaller companies may offer an advantage in the fast-paced UK CCS sector, being able to adapt and move more quickly, but they may need support. Initial evidence from Track 1 emitter capture technology providers shows more established players being selected for first projects, including newly formed Aker Carbon Capture UK ltd.						
Capture (pre-combustion package)	**High** - There are several smaller newer-market entrants developing pre-combustion capture. These face challenges from competing with more established companies with experience built up in enhanced oil recovery. However, there is great opportunity with new technologies getting closer to commercial readiness. Smaller companies may offer an advantage in the fast-paced UK CCS sector, being able to adapt and move more quickly, but they may need support. Initial evidence from Track 1 emitter capture technology providers shows more established players being selected for first projects, including Johnson Matthey-Basf partnership.						
CO_2 conditioning package (De-hydration unit)	**Low** - a limited number of UK-based technology providers was identified, and this assembly/skid is typically a smaller proportion of equipment costs than other assemblies such as capture (pre or post combustion)						
Liquefaction package (Refrigeration & compression system)	**Low** - A limited number of UK-based technology providers were identified. There is an IP opportunity to integrate this step with capture through cryogenic capture technology, but this expertise is being developed overseas.						

Table 20: High Value assessment of packages

5.7 Equipment Results Summary

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A number of key components in the end-to-end CCS process have a number of viable manufacturers in the UK such as, Column vessels, internals, filters and heat exchangers. Increasing the manufacturing capability for these key components will increase the UK's chances of being able to meet order requirements for rapid roll out of CCS.. However, most of these UK manufacturers are small scale, and single site. This could pose barriers to accessing the CCS market:

- Given their small-scale nature, these companies will not have dedicated personnel for monitoring government strategy to map project opportunities. (Larger international players will have this within their business).
- Procurement of large-scale CCS projects will typically be managed by large multi-national EPCs. These EPCs operate with pre-approved vendors that they procure equipment from. This pre-approval list can be an international list, and will typically contain, vendors with international operations, which could rule out several smaller UK manufacturers. UK manufacturers will need to become pre-approved vendors of EPCs to fully impact CCS deployment sin the UK.

CCS presents significant opportunities in R&D, for new capture technologies, and the UK has strong capability here. This has seen a number of UK SMEs that assemble, deliver and license capture packages expand to be able to supply capture packages for commercial scale plants. These represent a significant economic opportunity from both the ongoing R&D and technology improvements that can occur and the large capital investment required for carbon capture plants.

However as there is a limited number of companies in the UK, with the SME being less-proven for commercial operations that established players, there will be barriers and risks to fully capitalising on the opportunity:

- Components (heat exchangers, columns, compressors etc) to assemble packaged should also be UK-manufactured to fully realise benefits for the UK economy.
- SMEs need to compete with established players both UK-based and overseas for supply of packages to commercial plants to continue their growth.

Large-scale CO_2 transport and storage equipment has scope to use, installed legacy O&G infrastructure, which offers economic benefits such as reducing materials costs and decommissioning costs for old assets. These components carry significant value in both the materials used and the fabrication works required to manufacture these components.

Historically, UK fabrication yards saw large business form fabrication of this equipment but more recently have been losing out to overseas yards, who ship in jackets for deployment in the UK from abroad. Some yards have secured contracts to fabricate jackets for the offshore wind sector, but much offshore wind fabrication work occurs overseas.

Further engagement with yards is required to understand the role they can play for CCS in the UK and how this can be maximised; whether this is acting as logistics hubs for storage of imported equipment, fabricated and installed by overseas companies, conducting installation and maintenance works of overseas fabricated works or fabricating jackets for offshore CO_2 storage.

The below 'heat map' graphically illustrates the output of the assessment of Equipment based on UK capability and capacity only (excluding the dimension of criticality to the UK CCS Supply chain).

The basis of the heatmap is:

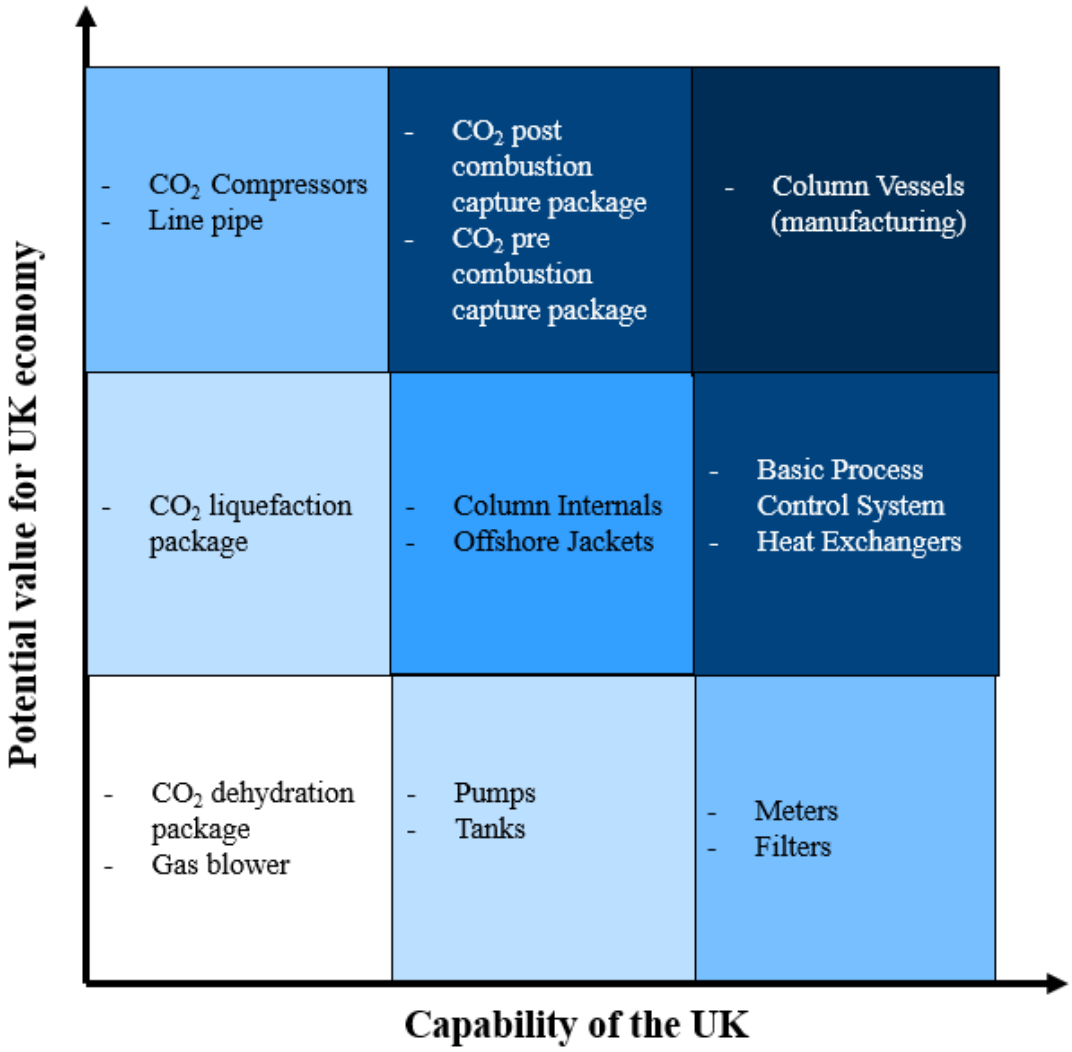
- **Capability of the UK** - Components where the UK has a higher number of manufacturers, higher levels of experience, and potential to leverage other markets through cross sector applications of components.
- **Potential Value for the UK Economy** - Where components have higher CAPEX, more potential to develop IP through R&D activities, and can re-use existing infrastructure.

The darker the colour (towards the top-right) indicates a greater value opportunity to the UK.

Figure 17: Heat map of high value equipment opportunities for CCS in the UK

5.7.1 Risks to Deployment

As well as presenting opportunities for the UK, some equipment present bottlenecks that pose risk to near-term CCS deployments. For equipment such as compressors and gas blowers, as well as CO_2 conditioning packages the UK has a lower number of manufacturers with less experience. These are critical across the CCS chain. The UK will not be able to develop new capabilities in these sectors for Track 1 projects and so steps must be taken to mitigate the risk of being exposed to overseas supply chains, that could delay roll out of first projects. Additionally further investigation is required to pinpoint gaps and barriers to the UK developing capabilities for these areas.



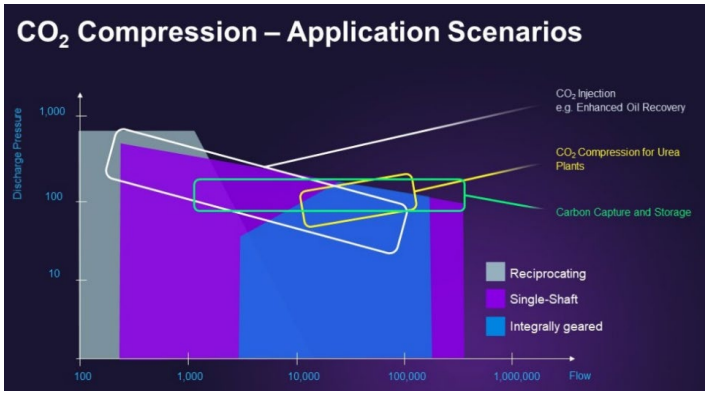
5.8 Case Studies

The following sections, present a series of case studies on components or packages assessed. The purpose of these is to provide further visibility into how the individual assessments were conducted, show the type of information examined and offer further insight into how the conclusions were made.

5.8.1 CO_2 Compressors

CO_2 compressors are required across the CCS chain. Captured CO_2 must be compressed when exiting a capture plant before it is exported via pipeline, tube trailer (via train/truck) or liquefied for shipping. Recompression stages can then be required during transport via pipeline depending on distance and compression is then required to inject CO_2 into underground storage facilities.

Figure 18: Siemens – CO_2 compression application & preferred technology



Given the large flow rates and pressure ratios required in these steps, most compressor suppliers recommend multi-stage centrifugal compressors, (single shaft or integrally geared) depending on the required pressure ratio and flow rate.

Table 21: CO_2 compressor high value assessment summary

Component	Compressors
Financial Value	High
IP Opportunity	High, Supersonic shockwave compression in development (estimated TRL 8)
Repurposing legacy infrastructure	No - limited possibility to retrofit installed, operating infrastructure
UK Company Count	Under 2 companies that manufacture centrifugal (integrally geared or single shaft) in the UK identified.
Use in other Sectors	Yes – centrifugal compressors used in many other industries, e.g., gas transmission network
UK Experience	CO_2 compressors have a weak UK supply chain with most expertise and products being sourced abroad

There will therefore need to be significant investment in centrifugal compressors to realise in the UK and connect multi-sector industrial cluster to long-term CO_2 storage sites. Compressors are required across the supply chain. The fast-moving mechanical parts e.g. (rotors), require precise high-skilled manufacturing, and specific steel types, that are designed for high-pressure operation and are resistant to CO_2 acidic effects. These factors make compressors a high CAPEX item.

The UK currently has a limited number of companies capable of manufacturing MW-scale centrifugal compressors[19]. There are many compressor suppliers in the UK that will source centrifugal compressors, deliver, and install and offer maintenance for new/existing compression facilities. However, the suppliers identified in this study all manufacture centrifugal compressors overseas, in locations including Germany[20]. This trend is common in other centrifugal compressor applications in the UK. Due to the complexity of this equipment developing UK manufacturing capacity that will be competitive with overseas manufacturers ahead of the 2030s will be challenging. For this reason, enabling the UK supply chain to manufacture CO2 compressors would require significant investment and present a risk, which is why compressors were not highlighted as a high-value opportunity.

Reliance on overseas supply chain increases UK's dependency on other countries to realise its decarbonisation goal and the UK will have reduced visibility of these supply chains. There are steps the UK can take mitigate associate risks with this:

- Ensuring there is warehouse space to stockpile required components, will provide supply chain redundancy. Conducting this for key equipment such as compressors and gas blowers mitigates the impacts of unforeseen international bottlenecks.
- Making early decisions on standardisation of equipment so correct equipment sizes and types can be imported to the UK. Equipment suppliers and manufacturers will therefore need early signals and visibility of what equipment is to be standardised.
- Understanding early what the demand for equipment will be (cross sector).

Undertaking these steps will enable the UK to optimise interactions with international suppliers. Ensuring correct equipment types and volumes and procured and available for UK projects from UK warehouses that match demand CCS project demands, on required timeframes. This will balance offering sufficient redundancy for UK CCS sector, without over procuring equipment for which there is not enough demand.

5.8.2 Column Vessels

Several column vessels are needed for solvent-based capture plants. The most crucial being the absorption and desorption/stripper columns. Additional column vessels are needed for the direct contact cooler and stripper and absorption wash columns. Cylindrical pressurised steel vessels are typically used for these columns. Each of these columns varies in size, with the absorption column being the largest required.

Table 22: Column Vessels high value assessment summary

Component	Column Vessels
Financial value	High
IP Opportunity	Low - no alternative lower TRL method for column vessels found (pressurised steel vessels)
Repurposing legacy infrastructure	Low
UK Company Count	5+ manufacturers with sites in the UK,
Use in other sectors	Yes- Columns used in many other existing industries, including chemicals, refining, conventional O&G

[19] Only Gas Compressors ltd, advertised having the capability to manufacture MW-scale centrifugal compressors – Link Other manufacturers such as Peter Bortherhood – Link, and Belliss & Morcom – Link were identified but manufacture reciprocating compressors, which are assumed to not be fit for the CO2 compression required for CCS plants.

[20] An example Utile Engineering supply compressors for CCUS, but partner with German-based compressor manufacturer Mehrer to do this – Link Utile Engineering will offer installation and maintenance services for the compressors

UK Experience	High, over 5 fabricators of steel column vessels with decades of experience

Several UK-based steel fabricators manufacture pressurised steel vessels. Solutions are often bespoke, and include complete turnkey services covering design, manufacture, fabrication, and installation. This offers both opportunity and risk for UK Industry:

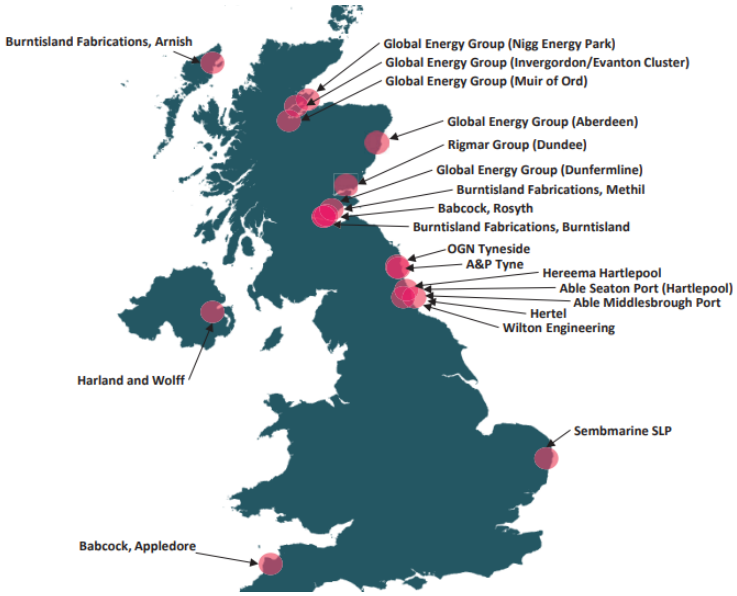
- Skilled labour, and large quantities of material make column vessels a significant proportion of the major equipment CAPEX for capture plants. However, for the UK to receive full economic benefit from this, steel would need to be sourced locally, and the UK steel industry currently faces considerable challenge from international competition.
- Retrofitting CCS to operational plants will need bespoke solutions with column sizes and operating pressures varying between the plants of different scale and from different sectors. This is suited to the bespoke turnkey solutions offered by UK fabricators, over bulk standardised production of columns offered overseas. Additionally, the absorption columns for the largest CCS plants could be over 100m in height rendering distribution via road unfeasible. This initially presents a challenge to the industry, with many manufacturers typically fabricating offsite and delivering via road. Larger columns will require onsite fabrication, using techniques such as slip forming or use of concrete vessels, or marine delivery via barge/ship. If fabrication techniques can be adapted this presents the UK opportunity as onsite fabrication must take place in the UK and will require a skilled workforce[21].

With the above factors in mind, it was determined that column vessels present a high value opportunity in CCS for the UK supply chain, as with careful intervention from government & industry to address bottlenecks, the UK may be able to be meet the domestic demand in CCS projects.

5.8.2.1 Fabrication Yards

Many fabrication yards have faced challenges and been closing with decline in demand from O&G sector. However, many have adapted to support the growing offshore wind industry in the last decade, and this has seen limited closures in the last decade with over 10 years still open, despite this the expertise in the UK and could be leveraged for CCS projects.

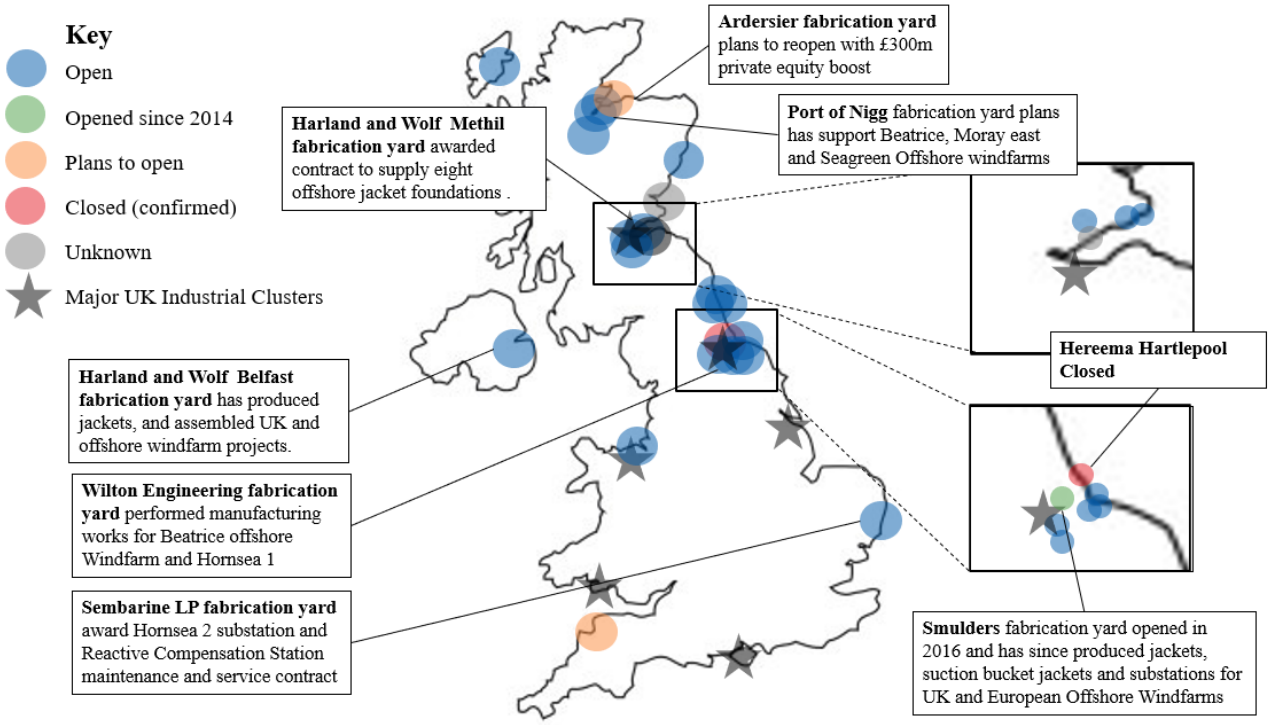
Figure 19: UK fabrication yards locations, 2014 – Atkins for Oil and Gas UK – Link



Updated map (Arup) showing UK fabrication yards 2023 highlighting key contract awards and updates in the last decade.

[21] NAMRC- Catapult CCUS supply chain intervention strategy, 2022 – Link

Figure 20:, Sources: Atkins for Oil and Gas UK,2014 & The Capability & Capacity of the UK Offshore Oil & Gas Fabrication sector, Department of Energy and Climate Change, 2011 – Press releases for, Ardersier, Port of Nigg, Hereema Hartlepool , Smulders, Sebmarine Maritime, Wilton Engineering, Harland And Wolf Belfast, Harland and Wolf Methil



Fabrication works are required for the largest components and have yards have historically developed infrastructure for offshore oil and gas rigs, typically steel. Fabrication of key components will be required for the CCS supply chain. Firstly, for the largest columns in capture plants (absorption and desorption columns), but additionally much of the offshore storage infrastructure including jackets and topsides. Fabrication works for these large components, can make up a significant proportion of the equipment cost. The CCSA report estimates approximately 60% of jackets and 25% topsides equipment cost will be fabrication works and the remainder materials, for an offshore CO_2 store. While these numbers will vary between specific projects this demonstrates the value for UK fabrication.

The UK fabrication yards are reported to have faced significant challenges over the last decade form a decline in traditional oil and gas work, and competition from overseas fabricators[22]. This has led to some facing closure. Despite this many have remained open, and in some instances have seen foreign investment to transition towards the offshore wind sector, such as Ardersier fabrication yard[23]. This along with successful contract wins for supply of offshore jackets for windfarms demonstrates the UK's capability to deliver.

However, despite this much fabrication works for offshore wind occurs overseas and is subsequently delivered via ship to the UK, e.g. Lamprell delivery for Moray East and Seagreen 1 offshore windfarms[24]. Some jackets for the same Moray East offshore windfarm have been fabricated in Smulders fabrication yard in the Northeast of UK which opened in 2016.

[22] CCSA, Supply Chain Excellence for CCUS, 2021 – Link

[23] Press Article OGV Energy, 2023 – Ardersier fabrication yard – Link

[24] Press Articles, (a) – OffshoreWind.biz, 2020 Link, (b) – OffshoreWind.biz. 2022 Link, (c) – Smulders 2022 Link

A range of works will be required from fabrication yards the growing offshore wind sector and emerging CCS sector (Both onshore and offshore facilities), including:

- Fabrication of major structures
- Storage and logistics management of major equipment.
- Installation of fabricated equipment
- Maintenance of operational offshore assets.

Further engagement with industry and yard managers is required to understand, the role fabrication yards can play in the CCS sector, covering:

- **Requirements for CCS:** The exact fabrication works will be required for CO_2, capture, transport and storage plants, both for onshore and offshore structures.
- **Fabrication yard competitiveness:** Understand in instances where major jackets contracts have been awarded to UK fabrication yards, how they were able to compete with overseas yards and if steps can be taken to replicate this success for new projects.
- **Space constraints:** Yards, require large areas to store equipment available yard space and cross-sector space requirements to mitigate the chance of bottlenecks.
- **Logistics constraints:** Yards are most concentrated in the Humber, Teesside and Grangemouth regions. These areas have good alignment with industrial cluster situated there, but Merseyside, South Wales and Southampton clusters see a lower concentration of fabrication yards. Further investigation would be required to assess whether this would lead to bottlenecks that would delay the rollout of CCS..

Understanding these factors will illustrate and inform the role UK fabrication yards, can play in the CCS supply chain. Whether new equipment (absorption columns, jackets etc) is fabricated at UK yards and steps that can be taken to avoid a scenario where fabricate yards are limited to works that are geographically constrained to the UK such as storage and logistics hubs, for import and installation of equipment form overseas companies.

5.8.2.2 Standardisation & Modularisation of Equipment

The UK is well paced to offer bespoke turnkey solutions for column vessels (and other pieces of equipment) but less well suited) for supplying larger volume orders of man pieces of equipment[25].

Below gives a high-level comparison of the potential to modularise system for two carbon capture projects selected to enter contract negotiations with government. Both projects will use carbon capture technology to reduce the emissions of hydrogen production.

[25] WSP, Industrial CCUS UK Supply Chain Capabilities, 2023 (UNPUBLISHED)

1. HyNET low carbon hydrogen production – newbuild ATR with GHR

Figure 22: HyNET proposed site layout and planned build out rate

Plant	Target deployment year	H_2 Production capacity
1	2025	350 MW_{th}
2	2026	700 MW_{th}
3	2028	1,400 MW_{th}
4	2030	1,400 MW_{th}

Figure 21: BOC's steam methane reforming facility in Teesside (Teeside Gazette)

The HyNET hydrogen production facility is targeting a first deployment in 2025, with an initial output of 350 MW of hydrogen. HyNET has significant expansion plants, aiming for an installed CCUS-enabled hydrogen production capacity of 3.8 GW by 2030. This will be phased across four plants. The selected size of each plant enables modularisation of the 350 MW reformer deployed in Plant 1. highlights a site layout where Plant 2 consists of two 350 MW modules installed adjacent to Plant 1 (Shown in pink). In total by 2030 HyNET production would be comprised of 11 350 MW modules if modular deployments are selected. The carbon capture technology required for the site could be installed as modules, each attached to a 350 MW reformer module.

Whether scale-up is modularised or not will be an engineering decision unique to each project, that optimises costs and risks, with modularisation having the ability to reduce risk. In an earlier stage feasibility report, HyNET highlight partial modularisation as an approach to achieve a fivefold scaleup CCUS-enabled hydrogen production. (4 GHRs and 2 ATRs)[26]. This demonstrates how carbon capture technology can be modularised with consideration in the design stages for new build projects.

2. Teesside Hydrogen CO_2 capture – retrofit SMR

Teesside hydrogen CO_2 capture will retrofit carbon capture technology to BOC's existing steam methane reforming facility in Teesside. The facility has two twin cell reformers but a common feed gas pre-treatment and syngas cooling train[27]. This project could therefore use a single, carbon capture system with a flue gas

[26] HyNET low carbon hydrogen plant Phase 1 Report or BEIS, 2020 – Link

[27] H21 Leeds City gate Report, Northern Gas Network, 2017 – Link

pre-treatment system that collects flue from both reformers and syngas shift facilities. This would be a bespoke retrofit with the design adapted for the SMR flue gas composition and scale of facility.

Overall, this shows that there will likely be scope for both bespoke project design and modularisation in the CCS industry. New build facilities can be design with modularisation in mind to reduce project risks and costs, whereas retrofit designs will be determined by the nature of existing facilities, presenting less design flexibility to modularise.

This has considered modularisation at the system level (carbon capture), the same principles can be applied at a component level e.g., columns, heat exchangers and compressors.

Detailed engagement with column vessel manufactures will be required to:

- Understand the breakdown of material, manufacturing and fabrication costs in column to understand how the UK can fully capitalise on the opportunity CCS presents.
- Logistics constraints for large scale columns, and the balance of offsite and onsite works that will be required for the largest absorption columns.
- The role standardisation of size will play. Standardisation reduce lead times and costs, but will increase the competition UK column manufacturers will face with overseas suppliers. Ensuring collaborations between manufacturers, EPCs and project developers will be required to ensure standardisation of equipment benefits UK manufacturers.
- The exposure UK manufacturers have to major multi-national EPCs, which are often contracted to manage procurement of CCS projects. Thes companies operate with pre-approved equipment manufacturer/vendor lists to speed up procurement. However pre-approved vendors of these EPCs are often large multi-national equipment vendors. This would rule out UK manufacturers under many CCS project structures from being able to supply equipment to projects. Engagement with EPCs and UK manufacturers is required to understand, processes for getting onto EPC pre-approved vendor lists and opportunity for UK manufacturers to be pre-approved[28]. Measures such as commitment by project developers to 30 day payment terms, and streamlining of pre-approval and compliance procedures targeting smaller and emerging UK companies would assist to ensure revenue secured for UK companies.

5.8.3 Filters

Table 23: Filter high value assessment summary

Component	Filters
Financial Value	Low
IP Opportunity	Medium - filters made of materials in R&D such as graphene may offer novel CCS solutions
Repurposing legacy infrastructure	Low
UK Company Count	5+ manufacturers with sites in the UK
Use in other sectors	Yes, all of the filtration solutions offered are used in other application
UK Experience	There is a large amount of experienced filtration companies in ranging capacity based in the UK.

[28] Discussion with Worley – 05/05/2023

Filters are required to remove impurities from gas streams across the CCS chain. Flue gas entering a capture plant must first be filtered. Filtration solutions are then also used in the dehydration unit, following capture, and can also be needed during liquefaction and regasification during transport. A number of filtration technologies can be used including particulate filters and liquid/gas coalescers. The required filtration will depend on the flue-gas entering the capture plant (which will be application specific), and operating requirements of other pieces of equipment, such as technology choice of dehydration unit (e.g., molecular sieve vs. triethylene glycol), as different technologies will tolerate different levels of impurities. Exact filters type, number and size will therefore be bespoke to each CCS plant.

Figure 23: UK filter manufacturer locations

Many companies operate in the UK, advertising manufacturing facilities on their website, including GFSA which recently doubled UK-manufacturing capacity, demonstration UK based manufacturing growth[29]. Many of these UK manufacturers advertise designing and testing expertise, enabling them to produce bespoke solutions tailored to a CCS project requirement.

Filters do not make up as high a proportion of major equipment CAPEX on CCS plants than other components. Despite requiring complex, intricate engineering in some instances, bulk material-requirements are relatively small. However due to their bespoke nature, and new applications in CCS-fitted to multi-sector industrial clusters (e.g., cement/steel plants or refineries instead of solely enhanced oil recovery), there could be R&D for UK industry if design, testing and research capabilities can be maintained.

Filters represent an area of equipment where the UK currently, has expertise and capacity to manufacture, but there will still be action needed to fully capitalise on opportunities the CCS sector offers. For this reason, filters were ranked as a medium-level high value opportunity, which can be realised with the following intervention:

[29] GFSA, UK Filter Manufacturer - Link

- Manufacturers will need early visibility on orders and likely order sizes. Early signalling of project pipeline, such as the track 1 and 2 cluster program can help this.
- Existing design and testing facility should be maintained. This enables equipment suppliers to offer bespoke turnkey solutions, which is where they typically have a competitive edge of international manufacturers[30].
- Exploring if standardisation of components could help procurement and manufacturing. If production lines can be scaled up through automation and standardisation of component types and sizes which in turn reduce production costs and lead times. However, standardisation and scale up, must be done with manufacturers, EPCs and project developers aligned else these risks losing competitive edge international suppliers, with already standardised manufacturing capabilities.

5.8.4 Capture packages

Table 24: Pre & post-combustion capture high value assessment summary.

Component	Capture (pre and post combustion combined)
Financial Value	High
IP Opportunity	High - Several alternative technologies, with TRL 6 to 8 in development that could be commercialised in 5 years - cryogenic, sold adsorbents, polymeric membranes
Repurposing legacy infrastructure	Low
UK Company Size/Count	3 or 4 UK-based companies identified (different scales, each for post and pre combustion)
Use in other sectors	No supply of these capture packages/skids is unique to the carbon capture industry.
UK Experience	Low – most companies identified either found or developed technology this century with a relatively low number of commercial deployments to date.

Several UK companies offer capture plants as packages of assembled components on modules/skids. These companies cover many different capture technologies, including, pre-, post- and oxyfuel combustion and vary in size with some new small-medium-enterprises (SMEs) and other, larger, established engineering companies offering technologies.

Figure 24: Carbon Capture technology, providers with involvement in Track-1 emitter projects

Initial announcements of carbon capture technology providers for the Track 1 emitter projects have been dominated by larger companies. The Track 1 cluster projects have ambitious targeted deployment dates, and

[30] Industrial CCUS UK Supply Chain Capabilities, WSP for Department for Business Energy and Industrial Strategy, 2023 - UNPUBLISHED

selecting technology from a larger company may be seen as less risky. (Approved vendor lists are a common method for pre-qualification in tendering processes for large scale projects). Some smaller UK-based carbon capture technologies have secured roles in shortlisted emitter projects, e.g., Origen in Zerocal250[31], and Carbon Clean in Acorn[32], but these projects were not selected to enter negotiations in March 2023. Announcements due for Track 2 cluster represents a significant opportunity for these companies.

The first UK CO_2 capture projects are confirmed, for the Track 1 cluster HyNET and East Coast Cluster, but the final size of the market remains uncertain with significant competition from other decarbonisation pathways for all leads CCS sectors:

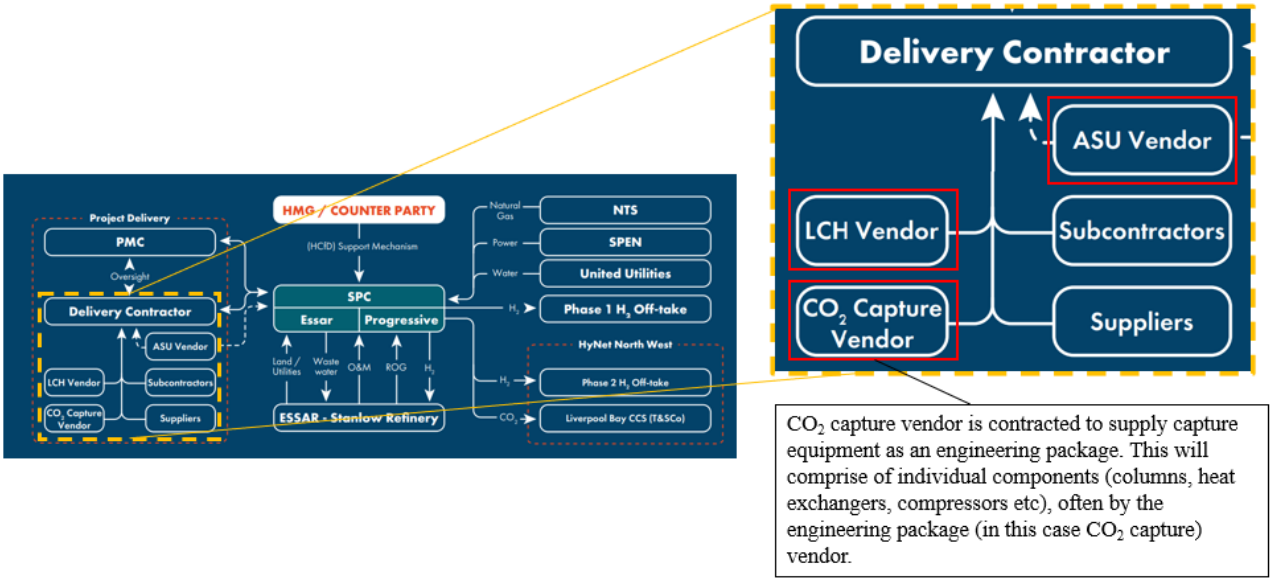
- Low carbon H_2: electrolytic-green H_2 has received much government attention and costs are predicted to fall up until 2050.
- Industry: Wider electrification may be the preferred option in some instances, e.g., electric arc furnace technology for steel, rather than CCS. Power: Other mechanisms of providing dispatchable power and system flexibility, such as nuclear Hydrogen (electrolytic-green) gas turbines, and short duration utility battery storage.

All these factors create uncertainty in the final market size for CCUS technology in the UK and increases the risk to CCS technology developers.

Carbon Capture technology providers will play a major role in carbon capture project developments. The UK government has recognised this on previous occasions awarding grant funding to UK carbon capture SMEs, C-Capture[33] and Carbon Clean[34]. This has helped the UK to be a leader in R&D developments for carbon capture R&D, with UK companies now amin got commercials their new technologies.

Some projects have stated to name a single carbon capture vendor, see Figure 25 as an example. (Exact delivery and procurement structures will vary between projects).

Figure 25: HyNET CCUS-enabled blue hydrogen production, Delivery Structure (HyNET Project)



[31] Origen Carbon Solutions, Press release – Link

[32] Carbon Clean, Press release – Link

[33] C-Capture, press release, 2019 – Link

[34] Carbon Clean, Press release, 2018– Link

This would give the carbon capture vendor ownership of procurement of major manufactured components such as column vessels, heat exchangers, pumps etc. Assembly of components and either onsite (with delivery on skid) or offsite to deliver a carbon capture package is then significant additional work.

Selection of a non-UK carbon capture technology vendor may have knock-on supply chain impacts. For example, technology providers that offer standardised packages will have pre-arranged agreements with component manufacturers (heat exchangers) which if not fully understood could limit manufacturers for components of these packages to overseas manufacturers.

This makes selection of carbon capture technology providers for CCS projects pivotal for maximising benefits to the UK economy. The UK has a number of companies, large and SME. SME companies have a high growth opportunity within the nascent UK CCS sector.

These and several other UK manufacturers will need to secure a commercial market foothold soon, or risk competing with established overseas companies becoming more challenging.

5.9 Services Results

Service	HV Summary	UK IP Opportunity	Legacy UK Industry Synergy	UK Bottleneck Risk for Track 2 CCS Projects
Engineering & Design	**High -** We have vast experience in executing engineering projects in the UK. We have an established workforce, with the opportunity to create exportable IP through rolling out successful CCS projects. The biggest challenge to realising the value opportunity of Engineering & Design will be the anticipated constraint in the available workforce. The UK government and industry leaders are already working to encourage students to choose STEM subjects, making apprenticeships more accessible and to ensure that education is affordable and available to all, and this work must continue, (as set out in the parallel Opergy report). There is potential for government and industry associations further to help mitigate this bottleneck further through facilitating coordination of demands on the EPC sector across UK sectors ranging from Water and Nuclear through to Hydrogen and CCS.			
Management	**High -** Alongside Engineering & Design, there is opportunity to export our project expertise internationally, as well as to continue to grow and upskill our national engineering management and project and programme management workforces, as the CCS and related energy transition industries continue rapidly to develop across the UK.			
Construction, Installation & Site Services	**High -** As advised in the WSP report, and raised in several industry engagements undertaken as part of this study, open communication and collaboration with industry and ensuring consistency across government departments will ensure the value of installation and specialist construction jobs as part of the CCUS supply chain[35]. This will help to ease expected bottlenecks in this part of our engineering workforce As construction is one of the key constraints to CCS, its value lies in being an enabler to CCS projects. A significant portion of the capital expenditure for CCS projects will be in construction, so it is important that this money goes to UK companies where possible.			

[35] (WSP 2022)

Service	HV Summary	UK IP Opportunity	Legacy UK Industry Synergy	UK Bottleneck Risk for Track 2 CCS Projects
Testing & Inspection	**Medium –** This category of services is closely related to Construction, Installation & Site Services, and includes many of the same members of the workforce, and will be subject to similar constraints. However, Commissioning, Testing & Inspection accounts for a lower overall proportion of CCUS capital costs according to our analysis.[36]			
Monitoring & Data Collection	**High -** Subsurface and reservoir management services have been carried out extensively for oil and gas, and the capability is well established in the UK and capable of pivoting to CCS[37]. There is significant potential for growth of UK capability in this area in response to the demand from the CCS market[38].			
Logistics	**Med-** Equipment and storage constraints will be addressed and mitigated through the development of logistics services in critical energy transition hubs. Though the services provided may not represent high value services in themselves, the development of logistics services in critical energy transition hubs will be a major strategic enabler of the energy transition and of CCS.			
Subsea, Wells & Exploration	**High -** A percentage of the existing workforce from Oil & Gas projects may be ideally positioned to work on new CCS projects, as OEUK and other studies have emphasised. Opergy estimations for CCS job creation highlighted that, other than in Engineering & Design, there would be more jobs created in Subsea, Wells & Exploration than in any other job area[39]. This may lead to a developed service model specific to CCS in these industry areas that has scope for global export, bringing in additional revenue to the UK.			

[36] (WSP 2022)

[37] (OEUK 2022)

[38] (OEUK 2022)

[39] Opergy CCUS Employment Data (Unpublished)

Service	HV Summary	UK IP Opportunity	Legacy UK Industry Synergy	UK Bottleneck Risk for Track 2 CCS Projects
Fabrication of Key Equipment	**High –** In several parts of the UK supply chain for critical equipment there is a focus on small scale, bespoke manufacturing. The supply chain comprises SMEs, rather than large scale manufacturing, and the focus is on high quality, high-cost equipment. Since large amounts of manufacturing will take place in East Asia, if we reopen fabrication yards and focus on them being available for CCS projects, this will allow us to ensure that more of the money can be put back into the UK economy.			
Hospitality & Accommodation	**Medium -** Ensuring that industrial clusters have suitable accommodation is vital to ensure the workforce has somewhere to live. This has been highlighted as being a key challenge for the industry in our questionnaire feedback, however it is unlikely to hold a large revenue opportunity in comparison to other service categories.			
Operations & Maintenance	**Medium** – Operations & Maintenance for CCS projects presents the greatest longevity of any of the service categories, given that the carbon will remain stored permanently. However, given the timescales of these projects and existing capability, this category of services will not yield a high value return in the short term.			
HR & Recruitment Services	**Low –** Whilst there may be bottlenecks which can be addressed and mitigated, according to our research within the scope of this study, these services do not yet represent a high value opportunity that is specific to the CCS supply chain.			
Legal & IP Services	**Medium -** Significant legal barriers have been addressed during the execution of the Northern Lights project in Norway[40], such as the amendment to Article 6 of the London Protocol which prohibited exporting CO2 for the purpose of storage. Given that these are well-established services less likely to experience major bottleneck, they are not highlighted as being a high value CCS opportunity. However, UK strength in this area is a key resource for the emergence of the CCS regulation and business models, the subsequent deployment of commercial arrangements under the proposed regulatory model, and for the development of new assets.			

[40] (OEUK 2022)

Service	HV Summary	UK IP Opportunity	Legacy UK Industry Synergy	UK Bottleneck Risk for Track 2 CCS Projects
Financial Services	**Medium -** The financial services industry, specifically the insurance industry, will benefit from the growth of the CCS industry as the technology becomes proven in the field[41]. For this reason, the financial services industry is not identified as being a high value opportunity in the context of the near-to-mid-term for the CCS supply chain. However, the need to insure and reinsure complex new assets which will form part of the UK's critical infrastructure network presents an exciting set of challenges for our world-leading insurance and reinsurance sector. The CCS sector will benefit from the depth of experience in innovative and large-scale asset insurance which is currently held in the City of London and wider UK finance sector.			
Industry Organisations	**Low –** The UK has a history in the UK of producing standards for quality, environment, and health & safety. The development of standards is beneficial to industries by driving innovation and increasing quality, however, many of these organisations are non-profit and while UK leadership on standard-setting continues to improve global standards, associated direct revenue streams are limited.			
IT & Digital Services	**Medium –** These service industries are showing huge growth in revenue with a rising UK capability, however considerable uncertainty remains as to the extent to which UK companies will secure the benefit of IT & Digital opportunities unique to the CCS supply chain. With growth in the development of controls and monitoring technologies, along with the UK's existing strength in monitoring and controls for linear infrastructure assets, opportunity remains there to secure. This may include the use of machine learning in monitoring and operational controls, and in risk-based maintenance forecasting, logistics and asset management.			

[41] (DNV GL Energy 2020)

6. Conclusions & Recommendations

This study set out to establish a shared view of the UK CCS Supply Chain and to identify within that taxonomy, the high value opportunities, key risks and constraints for UK businesses in the development of the UK's critical new CCS system.

This work was commissioned in order to ensure that as we develop this 'remarkable new infrastructure system' (Lord John Hutton, Chair of the UK CCS Council's Supply Chain Working Group, May 2023) we secure UK jobs and UK growth.

In building the Taxonomy, we have established a core structure for the monitoring of UK benefit across the value chain for services and goods, from capture, through treatment, transport, and storage. We have developed a system of classification which can be further refined, and/or used for classification, value-tracking, and policy development at its current level of detail.

Establishing a definition for 'high value' which reflects both criticality to this new industry and capacity of the UK to achieve competitive returns has been the most challenging part of this process for the team. We have tested a wide range of assessments across the goods and services taxonomy, drawing on data sources ranging from tax codes to procurement plans, supply chain interview data, workshops, and specialist expert inputs. We are confident that the resulting analysis combines the wide range of available information types to provide as clear as possible a summary of the current range of critical opportunities and risks for the UK.

Following this assessment, we offer the following summary of our conclusions and recommendations.

Recommendation 1: Mitigate risk of EPC & engineering design constraints (Industry and Policy Makers)

- Construction & construction management services are identified by this study as 'high value' to the UK and to the CCS supply chain. Engineering design is a major economic opportunity for the UK, playing to a nationwide strength in high-value technical design, building on our active domestic on and offshore energy industries and drawing on the skills of the estimated 5.6 million people employed in the UK engineering sector. Further, these services are anticipated to present a potentially major constraint due to availability of workforce, to the UK CCS sector and wider UK Energy Transition. Increased coordination across UK sectors, the construction (and wider EPC) sector is recommended in order to mitigate this risk and to ensure that demand can be met ahead of 2030. This unprecedented cross-sector effort must be coordinated by policy makers and industry associations in order to improve demand forecasts and potentially even to prioritise projects in order to achieve legally-binding Net Zero commitments.

- It is important to increase communication and collaboration between developers, enabled and supported by industry and industry associations, when commissioning services from the construction sector. This is in order to de-bottleneck this critical service group and enable the achievement of national CCS targets, as well as securing jobs and growth opportunities for UK companies. Industry associations and regulatory bodies who are well-positioned to improve communication, transparency and shared planning across this new infrastructure sector may include Offshore Energies UK (OEUK), the North Sea Decommissioning Authority (NSTA), the Infrastructure Projects Authority (IPA), the Institute for Civil Engineers (ICE), The Crown Estate (TCE), Crown Estate Scotland (CES) and the Carbon Capture and Storage Association (CCSA).

Recommendation 2: Develop UK column assembly & heat exchanger supply chains (Industry and Policy Makers)

- Column vessel manufacture, assembly and internals are identified as 'high value' items identified in this study and represent the major single source of opportunity for UK companies of the equipment needed to serve the UK CCS sector. Column vessels are typically the largest item in a capture plant by both physical size and capital expenditure. This presents both an opportunity and a constraint in terms of UK fabrication yard capacity and leads us to recommend an early and wide-ranging consultation with existing UK fabrication yards in order to establish the possibilities for their expansion in strategic locations.

- There is significant UK capability and capacity in heat exchanger manufacture and assembly in the UK. Given the range of sizes of heat exchangers required across industrial carbon capture, processing, compression and transport, we consider that heat exchanger production also presents a significant potential growth area for the UK and one in which the UK could gain competitive advantage in the light of the emergence of new UK CCS infrastructure. We recommend that policy makers engage with a wide range of UK fabrication yards and heat exchanger manufacturers at different levels of maturity in order to establish best available means of expanding capacity for assembly and storage of columns.
- Industry and policy makers should pro-actively evaluate the possibility of increased fabrication and equipment storage at port facilities. This will help to ensure that UK yards benefit from the capital expenditure on the largest single equipment item in a capture plant, as well as potentially enabling increased use of UK steel and manufacturing in the production of column vessels and internals.
- Regulators and policy makers should ensure that UK heat exchanger suppliers and manufacturers have access to procurement opportunities and supplier pre-qualification for UK CCS
- In conjunction with targeted entities, policy makers should further evaluate options for targeted financial support, tax relief and/or other incentives to further develop both UK fabrication yard and heat exchanger capability and capacity

Recommendation 3: Ensure procurement opportunities are accessible and transparent to UK companies, including SMEs (Industry, Regulators and Policy makers)

- Perform follow up taxonomy work outlined in Section **Error! Reference source not found.** to result in a digital taxonomy tool that can track local content across the CCS value chain for policy makers, as well as integrating with industry efforts to streamline procurement, overseen by a cross-industry steering committee.
- Developers should advertise UK procurement opportunities for the full CCS value chain in a central site similar to the NSTA's Pathfinder tool for North Sea opportunities. Ensure the tool is free to access and easily searchable, well indexed, and easily provides alerts to relevant providers of upcoming opportunities.
- Developers should set payment terms for cascade down the supply chain which enable smaller market participants to compete, such as short (30-day) guaranteed payment terms, as well as facilitating streamlined pre-qualification procedures for UK SMEs where feasible.
- Process controls, including controls interfaces and dashboards, as well as connected infrastructure control system monitoring technologies present a UK opportunity area due to the importance of balancing demands across the emerging CCS infrastructure system and communication across the networked assets, as well as the sensitivity and variability across store types. Policy makers should engage companies in this industry to establish means of facilitating UK advantage in this space.

Recommendation 4: Development of monitoring & controls system capabilities for CCS (Industry and Policy makers), identified as 'high value' and an area of UK capability as well as presenting strategic opportunity for the new infrastructure system.

- Encourage UK providers of monitoring and controls for linear infrastructure to support the development of CCS infrastructure monitoring technologies through the provision of demand forecasts envisaging the monitoring and system operation needs of the connected new infrastructure service.
- Enable IP (intellectual property) development in this area where possible through support to universities, colleges, and research centres. Facilitate research and development of associated software capabilities for infrastructure monitoring and control including artificial intelligence (AI) and machine learning techniques for risk-based maintenance, as well as advanced communication protocols.

Recommendation 5: Planning represents a constraint in the UK system which can be mitigated via coordination across industry (Industry with Policy maker enablement and support)

- Project developers can seek to establish planning coordination including consenting corridors for combined infrastructure development in industrial hubs and along pipeline corridors. Coordination

between industry and power emitters and CCS infrastructure providers on planning must be industry-led and is essential to needed to make the regional and national case for joint planning facilitation. Government can further facilitate and encourage this effort.

- Regulators may decide to support and accelerate efforts using more accelerated infrastructure development packages such as the one announced by Ofgem for Accelerated Strategic Transmission Investments (ASTI) in December 2022 (in support of the infrastructure construction programme now described by National Grid Plc as 'The Great Grid Upgrade').
- Developers and fabricators may combine efforts and seek further assistance to secure land and development rights for CO2 capture plant at major emitter hubs for both 2030 and beyond (The UK's major emitter hubs are Humber, North West, South Wales, Scotland, Teesside, Solent, Black Country in order of cluster emissions in mtCO2pa).

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A.1 High-value assessment – equipment results

Table 25 Equipment assessment results

Equipment Category	IP Opportunity	Repurposing legacy infrastructure	UK Company Count/Size	Financial Value	Use in other sectors	UK Experience vs Competitor Markets	High Value Assessment Summary
Column Vessels	**Low -** No alternative lower TRL method for manufacturers column vessels, currently under development identified	**No -** existing operational units cannot be used in deploying new CCUS projects	Over 5 manufacturers	**High**	**Yes -** Columns used in many other existing industries, including chemicals, refining, conventional oil and gas, though new design and scale will be required for CCS columns	**High** - UK has a number of experienced manufacturers of steel column vessels. Challenges could be faced from the quantity required if all CCUS projects are developed at the same time, and for larger columns. The largest columns may not be transportable and could potentially increase the case for UK fabrication. Additionally, concrete columns could be an option.	**High -** Column vessels are a significant opportunity for the UK due to the size & specificity, of CCS columns. Retrofitting columns will require bespoke turnkey solutions, which is well suited to the UK manufacturing sector capabilities. There will be challenges in the logistics or the largest columns (which can be over 100m), but this could be an upskilling and growth opportunity for UK industry, subject to capacity. However, large volume orders without advanced notice could create bottlenecks for the UK supply chain and existence of a limited number of UK fabrication yards with already constrained order books. UK fabrication yards have demonstrated adaptability in the last decade transitioning operations away from oil and gas work to the rapidly growing offshore wind industry. This adaptability could be valuable for the UK CCS sector.

Basic Process Control System (BPCS)	Pressure, heat, gas monitoring for capture and transport of CO_2, plus instrumentation for surface level and subsurface level monitoring of stored CO2 are a key area of opportunity for research and development and a UK opportunity.	**No -** existing operational units cannot be used in deploying new CCUS projects	Over 5 manufacturers	**Low**	**Yes**	**Medium**	A critical opportunity area due to 1) the central importance of monitoring across the Capture, Transport and Storage value chain, 2) the importance of balancing the demands on the system and communication across the networked assets and 3) the sensitivity and variability across store types.
Metering	Insufficient data currently	**No -** existing operational units cannot be used in deploying new CCUS projects	Over 5 manufacturers	**Low**	**Yes**	**High –** Many manufacturers in the UK with decades experience in other industries, such as chemical manufacturing and oil and gas	**Medium** – Meters required across the CCS chain. The equipment is a relatively small CAPEX compared to other larger items. The value will come potential for integration with control systems, and software driven data collection and analysis from meter readings, across the chain.
Heat Exchangers	**Medium -** alternative heat exchanger configurations at TRL 3 to 5 are in development, which could be commercialised within 10 years. Cross-Heat Exchanger for Sorbent-Based CO2 Capture is also a technology in development and ceramic membrane heat	**No -** existing operational units cannot be used in deploying new CCUS projects	Over 5 manufacturers	**Medium**	**Yes -** Heat Exchangers are used in many other existing industries, including chemicals, refining, conventional oil, and gas	**High -** over 5 manufacturers exist in the UK with decades of experience, although few have experience in CCS applications specifically. Some do not currently supply the required scale or type of components for all CCS applications but given many of the heat exchanger manufacturers identified conduct	**High -** A variety of heat exchanger technologies are needed in carbon capture plants. Manufacturers note the optimal technology selection varies between plants (e.g., plate and frame for the lean/rich heat exchanger and shell and tube for the reboiler). The UK has a number of companies now designing manufacturing and installing high quality products, again offering turnkey solutions. This could be well tailored to the retrofit of Carbon capture technology to existing plants.

	exchanger research ongoing.					bespoke design and manufacture, it is assumed they can adapt.	
Column Internals	**Low -** no alternative lower TRL method for column internals were found, however, research is ongoing to make the process more efficient with less degradation over time.	**No -** existing operational column internals cannot be used in deploying new CCUS projects.	Over 5 manufacturers	**Medium**	**Yes** - Column internals are used in many other existing industries including chemicals, refining and conventional oil and gas..	**Medium -** The UK have some experience producing components of a similar magnitude. The UK is well placed for an expansion in column internals manufacturing given the current capability, readiness, and size of market but they are not as applicable to other markets. In terms of capability, the column internals are likely to be supplied from outside of the UK. Skilled labour within the UK will be required for installation and this will be the main challenge to the supply chain.	**Medium –** There is an opportunity to develop this supply chain in the UK, where procured alongside the column vessels. Likely to be specific to the capture plant's owner site and process requirements. Exact internal requirements will vary with technology type and flue gas, which will be unique when retrofitting to existing plants. Column internals are a major CAPEX expenditure for a capture plant. UK has several manufacturers capable of producing internals, typically for distillation columns or reactor vessels. Advanced warning of orders will help avoid bottlenecks.
Pumps	**Low -** no alternative lower TRL method for pumps were found.	**No -** existing operational pumps cannot be used in deploying new CCUS projects	Over 5 manufacturers	**Low**	**Yes -** the pumps used in CCS tend to be Low NPSHr Centrifugal pumps, used	**High -** UK companies are experienced in delivering suitable components for CCUS projects, especially for projects that	**Low –** UK has capacity but will have steep competition form international supply chains. Pumps are required throughout the CCS supply chain but typically do not represent as much CAPEX as other major equipment pieces

					in many other processes	require more bespoke/ niche design is required.	
Line pipe	**Insufficient data**	**Yes -** there is the potential to reuse existing pipelines from legacy offshore projects for CCS New pipelines may be needed on and offshore, especially where there is not a suitable onshore pipework connecting emitter sites to offshore storage.	2 - assumed only Liberty steel group and tata steel UK manufacturer carbon-steel pipe at sufficient diameter, for CO2 transportation in the UK. Many other pipeline suppliers from overseas	**High**	**Yes -** as long as the pipeline is suitable to store CO2 (due to corrosion potential), then the pipe can be generic. Some CCS specifics such as anti-corrosion measures. Steel pipeline itself is not a unique opportunity to the CCS supply chain.	**High -** High - historical ally the UK has decades experience producing and fabricating steel pipe even if local UK steel pipe production has been losing out internationally more recently.	**Medium -** There is a large opportunity but also high risk to develop CO2 pipeline production in the UK. A bulk scale CO2 network will be needed to connect clusters to storage centres. Additionally, R&D work is ongoing into corrosion resistance and detection to minimise leakage risks. Stainless steel is required for CO_2 pipes, and there are only two UK companies that manufacture steel pipe (Liberty Steel Group and Tata Steel). They will struggle to compete with overseas manufacturers as the energy price spike has increased their costs. There could be opportunities for CO2 pipes fabrication.
Compressors	**High -** High TRL alternative technologies such as Supersonic shockwave compression in development (estimated TRL 8) are under development, which may represent exportable IP opportunity	**No -** existing operational units cannot be used in deploying new CCUS projects	Under 2 companies that manufacture centrifugal (single or multistage) in the UK found. Several UK compressor suppliers found, but manufacturing partners are overseas (e.g., German)	**High**	**No - Centrifugal** compressors used in many other applications	**Low -** CO2 compressors have a weak UK supply chain with most expertise and products being sourced abroad	**Low -** CO2 compressors will need significant capital investment to enable a widespread connected CCS chain in the UK. However, given the UK's limited expertise and lack of established manufacturing facilities, prioritising UK centrifugal compressions manufactures would be high-risk.

Tanks	**Low –** no other technologies identified	**No -** existing operational units cannot be used in deploying new CCUS projects	3 to 5 manufacturers identified	**Low**	**No –** tanks used in many other applications	**Medium -** Capability currently exists in the UK to produce tanks and vessels for amine treatment, and for temporary CO2 storage, with a variety of different alloys available.	**Low** - Liquid CO2 storage Tanks could have use if rail and road transport CO2 markets develop. Other tanks for temporary CO2 storage and solvent storage, but overall these are often a small relatively small expenditure across the CCS chain. UK has capability to produce tanks but many are currently imported from
Gas Blowers	**Low –** no other technologies identified	**No -** existing operational units cannot be used in deploying new CCUS projects	3 to 5 manufacturers identified	**Low**	**No –** gas blowers used in many other applications	**Medium -** UK has domestic experience of delivering suitable components, potentially in CCUS projects. Many industrial fan manufacturers in the UK are capable of producing flue gas blowers, with a wide range of sizes available. This provides a good opportunity for the development of smaller plants. Manufacturers producing components of the required size for large carbon capture plants are currently lacking.	**Low -** The UK has manufacturing capability but overall it will be challenging for the UK to compete with well-established European supply chains, who have established manufacturing facilities. If highly bespoke blowers are required for a less-typical process, then there could be a niche opportunity for the UK manufacturers that currently exist.
Filters	**Medium -** filters made of materials in R&D such as graphene may offer novel CCS solutions	**No -** existing operational units cannot be used in deploying new CCUS projects	Over 5 manufacturers identified	**Low**	**No –** filters used in many other applications	**High -** There is a large amount of experienced filtration companies in ranging capacity based in the UK. Companies such as Pall offer filtration solutions tailored for CCS	**Medium -** The UK is well-positioned to manufacture filters for CCS applications and develop new filtration technology if existing testing and research facilities are maintained. However, filters are a relatively small component of project cost.

Jackets	**Low -** Jackets are structural steel supports to hold up a platform from the seabed, which, relative to other areas in the CCS supply chain, is less technology-focused. No R&D activity for new technology identified	**Yes-** Scope to repurpose parts of oil and gas jackets for offshore CO2 storage	Over 5 manufacturers identified	**Medium**	**No –** jackets used heavily in offshore wind and O&G industry	**High -** High, historical ally the UK has decades experience producing and fabricating jackets even if recently the UK has been losing out internationally more recently.	**Medium -** Around 40% of jackets value is in steel and 60% in fabrication. It will be challenging for UK steel to compete with overseas, however UK fabrication yards have diversified into offshore wind in the last decade.
Capture – Pre-combustion package	**High -** Several alternative technologies are under development such as cryogenic, sold adsorbents, polymeric membranes. These technologies have TRL 6 to 8, which could be commercialised in 5 years.	**No -** new capture equipment will be required	3 to 5 UK manufacturers identified	**High**	**Yes –** specific to CCS	**Low –** Manufacturers identified were founded this century and have limited commercial deployments to date	**High** - There are several smaller newer-market entrants developing post-combustion capture. These face challenges from competing with more established companies with experience built up in enhanced oil recovery. However, there is great opportunity with new technologies getting closer to commercial readiness. Smaller companies may offer an advantage in the fast-paced UK CCS sector, being able to adapt and move more quickly, but they may need support. Initial evidence from Track 1 emitter capture technology providers shows more established players being selected for first projects, including newly formed Aker Carbon Capture UK ltd.
Capture post combustion package	**High -** Several alternative technologies are under development such as cryogenic, sold adsorbents, polymeric membranes. These technologies have TRL 6 to 8,	**No -** new capture equipment will be required	3 to 5 UK manufacturers identified	**High**	**Yes –** specific to CCS	**Low -** Manufacturers identified were founded this century and have limited commercial deployments to date	**High** - There are several smaller newer-market entrants developing pre-combustion capture. These face challenges from competing with more established companies with experience built up in enhanced oil recovery. However, there is great opportunity with new technologies getting closer to commercial readiness. Smaller companies may offer an advantage in the fast-paced UK CCS sector, being able to adapt and move more quickly, but they may need support. Initial evidence from Track 1 emitter capture technology providers shows more established

	which could be commercialised in 5 years.						players being selected for first projects, including Johnson Matthey and Basf.
CO_2 conditioning package (De-hydration unit)	**No R&D activity identified**	**No –** new dehydration equipment will be required	Fewer than 2 UK manufacturers identified	**Low**	**Yes –** specific to CCS	**Low** – as limited UK manufacturing presence	**Low -** a limited number of UK-based technology providers was identified, and this assembly/skid is typically a smaller proportion of equipment costs than other assemblies such as capture (pre or post combustion)
Liquefaction package (Refrigerant & compression system)	**High** - There is scope to incorporate the package with cryogenic separation technology, which is TRL 6 to 8	**No –** new liquefaction equipment will be required	Fewer than 2 UK manufacturers identified	**Medium**	**Yes –** specific to CCS	**Low** – as limited UK manufacturing presence	**Low -** A limited number of UK-based technology providers was identified. There is an IP opportunity to integrate this step with capture through cryogenic capture technology, but this expertise is being developed overseas.

A.2 High-value assessment - services results

Table 26 Service assessment result

Service Category	UK IP Opportunity	Legacy UK Industry Synergy	UK Bottleneck Risk for Track 2 CCS Projects	High Value Assessment
HR & Recruitment Services	**Low** - As these services operate relatively independently of the industry they serve; it is unlikely that the CCS supply chain will have a unique IP opportunity in these areas. Some of the challenges faced by the HR industry is the adjustment to a higher percentage in remote working and flexible working hours, however these challenges are not specific to CCS. Whilst some practices are adopted internationally, it is not common for there to be services that can be exported internationally.	**Yes -** Whilst these functions operate in a manner that is relatively independent of the industry they are serving; we already have an existing workforce serving various industrial technology industries which will be suitable to work in the CCS industry when the projects begin.	**Medium -** 26% of employers struggled to filled HR roles in the past year (theHRdirector 2022), however, there is no reason to suggest that there will not be a continued uptake of HR roles as there is in other areas of the supply chain.	**Low –** Whilst there may be bottlenecks which can be addressed and mitigated, according to our research within the scope of this study, these services do not yet represent a high value opportunity that is specific to the CCS supply chain.
Legal & IP Services	**Low -** Given that these services are often very country-specific, it is unlikely that there will be many instances of IP that is specific to CCS. We will face multi-country legal issues, especially as we begin to offer CCS as a service down the line, but these are not likely to create a service product that can draw a large amount of income from outside of the UK.	**Yes -** Legal & IP services are well-established industries in the UK where we have experience working on offshore projects from oil & gas.	**Low -** Opergy research suggests that a moderate number of jobs will be created by the CCS industry in legal & other professional services, relatively to other areas. Additionally, there is no evidence from job vacancy data or industry feedback that these industries will experience a bottleneck for CCS projects in the near future (Statista 2023).	**Medium -** Significant legal barriers have been addressed during the execution of the Northern Lights project in Norway , such as the amendment to Article 6 of the London Protocol which prohibited exporting CO2 for the purpose of storage. Given that these are well-established services less likely to experience major bottleneck, they are not highlighted as being a high value CCS opportunity. However, UK strength in this area is a key resource for the emergence of the CCS regulation and business models, the subsequent deployment of commercial arrangements under the proposed regulatory model, and for the development of new assets.

Service Category	UK IP Opportunity	Legacy UK Industry Synergy	UK Bottleneck Risk for Track 2 CCS Projects	High Value Assessment
Financial Services	**Low -** Insurance represents one of the most interesting financial services for CCS, where we will have to explore the challenges related to novel technology (Swiss Re Institute 2021). However, given that these services are often very country-specific, it is unlikely that there will be many instances of reportable IP that is specific to CCS.	**Yes -** Financial services are well-established in the UK.	**Low -** There is no evidence from job vacancy data or industry feedback that these industries will experience a bottleneck for CCS projects in the near future (Statista 2023).	**Medium -** The financial services industry, specifically the insurance industry, will benefit from the growth of the CCS industry as the technology becomes proven in the field (DNV GL Energy 2020). For this reason, the financial services industry is not identified as being a high value opportunity in the context of the near-to-mid-term for the CCS supply chain.
Industry Organisations	**High -** The BSI[ACRONYM] has continually expanded over the last 20 years with a huge global presence. We are well positioned to be able to export carbon capture standards to the global market.	**Yes –** We have a history in the UK of producing standards which lead to being adopted worldwide - the BSI produced the three most widely adopted standards for quality, environment, and health & safety.	**Low -** There are 11 CCS standards currently in progress by BSI and 10 already published, which would suggest that the industry bodies are already mobilised on this. Additional information relating to their capacity is difficult to obtain.	**Low -** The UK has a history in the UK of producing standards for quality, environment, and health & safety. The development of standards is beneficial to industries by driving innovation and increasing quality, however, many of these organisations are non-profit and while UK leadership on standard-setting continues to improve global standards, associated direct revenue streams are limited.
IT & Digital Services	**Medium -** Emerging IT services such as cyber security, software engineer and AI / ML services are well-paid, highly skilled, and sought-after jobs (Department for Science, Innovation & Technology 2022). Research does not suggest that CCS presents unique opportunities in this area for exportable IP, due to the fact that these roles operate in many industries.	**Yes -** Whilst there will be unique challenges presented by CCS, we already have an existing workforce serving various industrial technology industries including offshore, which makes us well positioned to transfer this knowledge across to CCS.	**Medium -** Software engineer & information security analyst are two of the hardest to fill jobs in the current UK market (Indeed 2022). These roles have application in most industries, meaning that there will likely be competition against other industries to recruit, which is backed up by recruitment & job vacancy statistics (Statista 2023).	**Medium -** These service industries are showing huge growth in revenue with a rising UK capability, however considerable uncertainty remains as to the extent to which UK companies will secure the benefit of IT & Digital opportunities unique to the CCS supply chain. With growth in the development of controls and monitoring technologies, along with the UK's existing strength in monitoring and controls for linear infrastructure assets, opportunity remains there to secure. This may include the use of machine learning in monitoring and operational controls, and in risk-based maintenance forecasting, logistics and asset management.

Service Category	UK IP Opportunity	Legacy UK Industry Synergy	UK Bottleneck Risk for Track 2 CCS Projects	High Value Assessment
Engineering & Design	**High -** For more CCS projects to go ahead, we need cost-effective and energy efficient designs to ensure that these projects are worth the investment, and to address commercial scepticism (OEUK 2022). Purchase orders for Track 1 projects are likely to be placed within the next 12 months, which indicates how quickly the industry is likely to move.	**Yes -** Using the UK's upstream engineering experience from legacy hydrocarbon projects will benefit companies in their execution and support of CCS projects. Most of the large UK engineering consultancies have worked on CCS projects from feasibility to pre-Feed/Feed and moving towards implementation (OEUK 2022).	**High -** Skilled personnel are highlighted as being one of the key areas where we will face bottleneck, due to competition with other industries. In addition to this, there is a view that younger people are not as interested in being engineers due to the cyclical nature of the industry (Global CCS Institute 2020).	**High -** We have vast experience in executing engineering projects in the UK. We have an established workforce, with the opportunity to create exportable IP through rolling out successful CCS projects. The biggest challenge to realising the value opportunity of Engineering & Design will be the anticipated constraint in the available workforce. The UK government and industry leaders are already working to encourage students to choose STEM subjects, making apprenticeships more accessible and to ensure that education is affordable and available to all, and this work must continue. There is potential for government and industry associations further to help mitigate this bottleneck further through facilitating coordination of demands on the EPC sector across UK sectors ranging from Water and Nuclear through to Hydrogen and CCS.
Management	**High -** The UK will be one of the first nations in western Europe to roll out CCS at scale, which will give us an advantage in the emerging market. Proven successful execution of CCS projects will create a market for exportable project/programme management services (OEUK 2022).	**Yes -** Companies with experience in project management of oil & gas upstream projects are now being selected to offer these services for CCS, such as Wood group for the Humber Zero Project (Wood plc 2023). This shows the overlap in competency between industries.	**High -** Skilled personnel are highlighted as being one of the key areas where we will face bottleneck, due to competition with other industries. In addition to this, there is a view that younger people are not as interested in being engineers due to the cyclical nature of the industry (Global CCS Institute 2020).	**High -** Alongside Engineering & Design, there is opportunity to export our project expertise internationally, as well as to continue to grow and upskill our national engineering management and project and programme management workforces, as the CCS and related energy transition industries continue rapidly to develop across the UK.

Service Category	UK IP Opportunity	Legacy UK Industry Synergy	UK Bottleneck Risk for Track 2 CCS Projects	High Value Assessment
Construction, Installation & Site Services	**Low -** The construction industry in the UK features a highly skilled workforce that is mainly focused on executing projects domestically. Given the expected upturn in industry over the next 10 years, with many construction projects tipped to take place across a wide range of industries, it is unlikely that we will be able to export this as a service.	**Yes -** Much of the required skills, expertise and industrial capabilities already exist within the UK's oil, gas, petrochemical and other sectors. For its bioenergy plus CCS project, Drax intends to source 80% of the construction materials and services from the UK, indicating confidence in UK capability (Drax 2021).	**High -** CCS projects will be coming at a busy time for the infrastructure market (OEUK 2022). Cross-industry project planning and scheduling will be vital to ensure we have the capability to execute CCS projects, which can only come from transparent communication between government and industry.	**High -** As advised in the WSP report, and raised in several industry engagements undertaken as part of this study, open communication and collaboration with industry and ensuring consistency across government departments will ensure the value of installation and specialist construction jobs as part of the CCUS supply chain . This will help to ease expected bottlenecks in this part of our engineering workforce As construction is one of the key constraints to CCS, its value lies in being an enabler to CCS projects. A significant portion of the capital expenditure for CCS projects will be in construction, so it is important that this money goes to UK companies where possible.
Testing & Inspection	**Low -** As part of the wider construction industry, construction, testing & inspection is well-established in the UK. A literature review did not appear to show any pending innovations in this area that are likely to result in exportable IP for the CCS supply chain, given the domestic demand these service industries face.	**Yes -** Much of the required skills, expertise and industrial capabilities already exist within the UK's oil, gas, petrochemical and other sectors. For its bioenergy CCS project, Drax intends to source 80% of the construction materials and services from the UK, indicating confidence in UK capability (Drax 2021).	**Medium -** Whilst a literature review did not highlight any constraints specific to commissioning, testing & inspection, the challenges that infrastructure projects face overall are likely to create complications for these service industries.	**Medium -** This category of services is closely related to Construction, Installation & Site Services, and includes many of the same members of the workforce, and will be subject to similar constraints. However, Commissioning, Testing & Inspection accounts for a lower overall proportion of CCUS capital costs according to our analysis.

Service Category	UK IP Opportunity	Legacy UK Industry Synergy	UK Bottleneck Risk for Track 2 CCS Projects	High Value Assessment
Monitoring & Data Collection	**High -** Monitoring of CCS storage is one of the key challenges. There is no doubt to be technological advancement in this field with export value, based on the amount of monitoring techniques currently available and the requirement of constant monitoring for the entire lifetime of a storage well. Additionally, financial metering will be essential to the success of the CCS industry, in order for customers to validate the storage of their CO2.	**Yes -** There is a wealth of experience in well monitoring and reservoir management services due to our extensive portfolio of oil & gas projects, which have created a well-established capability in the UK, with a skillset transferable to CCS (OEUK 2022).	**Low -** There are 40 monitoring techniques available to monitor a CO2 storage project during all stages from site characterisation through to post-injection in various scenarios of well conditions (IEAGHG 2023). Similarly, to Subsea, Wells & Exploration, there is going to be a part of the oil & gas workforce that become available to work in CCS as we naturally transition away from new oil & gas capital projects as a part of the wider energy transition strategy.	**High -** Subsurface and reservoir management services have been carried out extensively for oil and gas, and the capability is well established in the UK and capable of pivoting to CCS . There is significant potential for growth of UK capability in this area in response to the demand from the CCS market .
Logistics	**Med-** Logistics and supply of goods and materials is a critical enabler of the CCS supply chain. In the context of the potential constraint in the supply of e.g. pipeline to the growing markets for H2 and CO2 transport, it could become more critical to manage equipment storage to prevent delays. Ports and logistics hubs will play a key role in enabling the rapid development of this new sector.	**Yes -** There is no legacy industry for bulk CO2 transport - all the CO2 pipelines in the East Coast cluster are new, although some repurposing of pipelines has been considered for future projects. The UK has a mature gas shipping, marine design, gas pipeline and wider gas services logistics and supply industry. Further, we have a well-developed and connected infrastructure sector serving our ports and industrial centres which will underpin and enable the growth of CCS in the UK.	**High -** In addition to the lack of domestic pipeline capabilities, there has been an 127.7% increase in job vacancies in the transport & storage sector in the past year. Intervention is likely required to be able to address these bottlenecks.	M**ed** - Whilst there may be bottlenecks which can be addressed and mitigated through the development of logistics services in critical energy transition hubs, these services do not represent a high value opportunity that is specific to the CCS supply chain. The development of logistics services in critical energy transition hubs will be a major strategic enabler of the energy transition and of CCS.

Service Category	UK IP Opportunity	Legacy UK Industry Synergy	UK Bottleneck Risk for Track 2 CCS Projects	High Value Assessment
Subsea, Wells & Exploration	**High -** The UK has proven expertise in Subsea technology and its accompanying services, which are some of our flagship exports suitable for the CCS industry (CCSA 2021).	**Yes -** Marine and subsea engineering have been vital to our execution of offshore oil and gas projects, from which we have a developed UK competency (OEUK 2022).	**Low -** It is believed that there is enough of an established workforce in Subsea, Wells & Exploration to address the demand from CCS. If there is the desire to do so from contracting companies, CCS can become their priority to utilise existing capability (CCSA 2021).	**High -** A percentage of the existing workforce from Oil & Gas projects may be ideally positioned to work on new CCS projects, as OEUK and other studies have emphasised. Opergy estimations for CCS job creation highlighted that, other than in Engineering & Design, there would be more jobs created in Subsea, Wells & Exploration than in any other job area . This may lead to a developed service model specific to CCS in these industry areas that has scope for global export, bringing in additional revenue to the UK.
Fabrication of Key Equipment	**Medium -** If we created a successful fabrication capability in the UK, it would be possible to export this service across the European market, for similar North Sea CCS projects. However, as existing capacity is limited, it will take investment for us to meet domestic demand before we are able to offer our fabrication yards as an exportable service.	**Yes -** Carbon capture facilities use similar technology as petrochemical and refining processes, as well as equipment such as absorption and pressure vessels.	**High -** The CCSA Supply Chain Excellence report states that fabrication yards have closed due to lack of work(CCSA 2021). Our analysis shows that there is significant and diverse UK fabrication yard capacity which can be deployed in support of CCS. [See p**].	**High -** UK Fabrication yards can operate effectively alongside the development of international supply chains for CCS, by providing assembly hubs close to UK capture and storage plants..
Hospitality & Accommodation	**Low -** The industry will be developed to serve our domestic workforce, where there is little scope for export.	**Yes -** Hospitality is a well-established industry in the UK, and whilst these functions operate in a manner that is relatively independent of the industry they are serving, we already have an existing workforce serving various industrial technology industries.	**High -** There has been a 296.5% increase in job vacancies in accommodation & food service activities (The Diversity Dashboard 2022).	**Medium -** Ensuring that industrial clusters have suitable accommodation is vital to ensure the workforce has somewhere to live. This has been highlighted as being a key challenge for the industry in our questionnaire feedback, however it is unlikely to hold a large revenue opportunity in comparison to other service categories.

Service Category	UK IP Opportunity	Legacy UK Industry Synergy	UK Bottleneck Risk for Track 2 CCS Projects	High Value Assessment
Operations & Maintenance	**Medium -** Since O&M for CCS will not be at the forefront of the industry until projects are nearing completion, the UK is well positioned to ensure that there is the available personnel to be a part of the first wave of CCS projects. With sufficient investment, we could become industry leaders.	**Yes -** There are strong synergies in O&M between CCS and oil and gas production, meaning that many jobs and infrastructures are interchangeable.	**Low -** Given the fact that Track-1 CCS projects will not be operational in the UK for a number of years, it is difficult to predict exactly what market constraints or bottlenecks will be. However, the evidence suggests that the supply chain is well placed to meet the demand given the UK's skillset in these areas.	**Medium** – Operations & Maintenance for CCS projects presents the greatest longevity of any of the service categories, given that the carbon will remain stored permanently. However, given the timescales of these projects and existing capability, this category of services will not yield a high value return in the short term.

UK Equipment Manufacturers sample data

Equipment Category	Potential UK Manufacturers identified
Column Vessels	Richard Alan Engineering Vessco Wefco WEC fabrication CPE Pressure Vessels Limited Hartwell Manufacturing Pressvess Spirotech group ltd Glacier Energy
Basic Process Control System (BPCS)	Saftronics BP systems SimKiss Core Control Solutions Industrial Control Systems ltd iac ltd BIJC Scada Systems ltd Phoenix Controls Telent
Metering	Nixon Flow meters MPB Industries Titan Enterprise Gas Sensing Solutions UK Flowtechnik Ltd GM Flow Measurement Allison Engineering

Heat Exchangers	Sterling Thermal Technology SAPHEX heat exchangers Specialist Heat exchangers ltd AKS Heat Transfer Turnbull and Scott group Therco-Serck Xchanger services ltd Vescco Engineering Heatric
Column Internals	Dtec fabs Langfields Mersen Pall rings Glacier Energy Plastichem ltd
Pumps	Taflo Pumps Apex Pumps North Ridge Pumps HMD Kontro Sealless Pumps Crest Pumps March May
Line pipe	Tata Steel Liberty steel group British Steel
Compressors	Gas Compressors ltd
Tanks	Richard Alan Engineering Vessco Wessington Cryogenics Pressure Design Tiverton Fabrications Pressvess
Gas Blowers	Fans & Blowers HR Blowers Halifax Fan ltd MODU Flow Woodcock & Wilson
Filters	Pall Parker Walker Filtration Barton Firtop Engineering Company ltd Amazon Filters GFSA Microtech Filters
Jackets	Harland & Wolf Global energy Group Babcock BiFab Wilton Engineering Smulders

	Sembmarine SLP Able UK
Capture Pre-combustion package	Johnson Matthey C capture Aker Carbon Capture UK Shell
Capture post combustion package	Carbon Clean C capture Aker Carbon Capture UK Shell
CO_2 conditioning package (De-hydration unit)	Pall
Liquefaction package (Refrigerant & compression system)	None identified

Equipment analysis: UK Supply chain sample data

Item	Observation	Source
Column Vessels	Column vessels are steel or concrete in Carbon capture plants	https://www.osti.gov/servlets/purl/1352138
Column vessels	Companies that state on website column vessels; are UK located; mention MF and/or fabrication or steel pressure vessels	
Column Vessels	Example potential Manufacturer	https://www.richardalan.co.uk/services/pressure-vessels?gclid=CjwKCAjw3POhBhBQEiwAqTCuBi7c1CYKccMgFyhE5wgfMca55nIFOjUVdxrfi0nf7aRcDEW6_DDItxoCldoQAvD_BwE
Column Vessels	Example potential Manufacturer	Columns - Vessco Engineering
Column Vessels	Example potential Manufacturer	Pressure Vessels and General Fabrication Gainsborough | Wefco Gainsborough
Column Vessels	Example potential Manufacturer	https://www.welding-eng.com/pressure-vessel-fabrication?gclid=CjwKCAjw3POhBhBQEiwAqTCuBt4l5xbPgrNvwshsb1QKuu1PKfXuFjsaj1JHUvu0hsKlMEiHpBylDRoCG58QAvD_BwE
Column Vessels	Example potential Manufacturer	https://www.pressure-vessels.co.uk/products/
Column Vessels	Example potential Manufacturer	https://hartwellmanufacturing.co.uk/pressure-vessels/
Column Vessels	Example potential Manufacturer	https://www.pressvess.co.uk/
Column Vessels	Example potential Manufacturer	https://www.spirotechgroup.co.uk/products/pressure-vessel-manufacturers/
Column Vessels	Example potential Manufacturer	https://www.glacierenergy.com/products-services/pressure-vessel-design-manufacture
Column Vessels	Absorption tower is tallest component - up to 100 m tall	https://www.padeswoodccs.co.uk/en
Heat Exchangers	Example potential Manufacturer	http://www.nelsonheattransfer.co.uk/index.html

Heat Exchangers	Number of heat exchangers needed in a carbon capture plant	https://www.researchgate.net/publication/319194129_Potential_for_Hybrid-Cooling_System_for_the_CO_2_Post-Combustion_Capture_Technology#pf4
Heat Exchangers	Plate and frame heat exchangers are used in deployed CCS/CCU plants	https://www.alfalaval.co.uk/industries/energy-and-utilities/sustainablesolutions/cleantech/clean-energy/carbon-capture-utilization-and-storage/
Heat Exchangers	Plate and frame/Shell and plate are preferred	https://www.tranter.com/heat-exchangers-for-carbon-dioxide-capture/
Compressors	Centrifugal compressors are preferred type of compressor CCS applications	https://www.siemens-energy.com/global/en/offerings/industrial-applications/compression/co2-compression.html
Compressors	Centrifugal compressors are preferred type of compressor CCS applications	https://solutions.mhi.com/ccus/co2-compressor/
Compressors	Centrifugal compressors are preferred type of compressor CCS applications	https://www.yumpu.com/en/document/read/3274269/forward-thinking-advanced-co2-compression-solutions
Heat exchanger	reboiler is normally a shell and tube heat exchanger	NAMRC - Catapult
Heat exchanger	Example of a new method being researched	https://pubs.acs.org/doi/10.1021/acs.iecr.0c06171
Heat exchanger	Example of a new method being researched	https://www.sciencedirect.com/science/article/abs/pii/S0376738818334203
Heat exchanger	Cross-Heat Exchanger for Sorbent-Based CO2 Capture - a new carbon capture method involving a heat exchanger in development	https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1079540/aecom-next-gen-carbon-capture-technology-technology-review-annex-1.pdf
Heat exchanger	Compact fin heat exchanger used for condensers	https://www.sterlingtt.com/products-services/compact-fin-heat-exchangers/condensers/
Heat exchanger	TRL 3 - secondary heat exchanger	https://inldigitallibrary.inl.gov/sites/sti/sti/5554590.pdf
Heat exchanger	Heat exchangers are key for other Carbon capture technologies including cryogenic	https://www.mdpi.com/2311-5629/7/3/58
Heat Exchanger	WCRUK supply heat exchangers in the UK - unclear if they manufacture or just supply	https://wcruk.com/?psafe_param=1&gclid=CjwKCAjw0ZiiBhBKEiwA4PT9z8o6PR1dlHe56vE-2L94xgoXg0JD-C1bzey4cEBUm4sduGJ9-wBCdRoCLx8QAvD_BwE
Heat Exchanger	Thermex manufacture shell and tube heat exchangers for power sector - however small scale, up to 200 kW	http://www.thermex.co.uk/industries/power-generation
Heat Exchanger	Sterling TT supply heat exchangers - manufacture in Aylesbury UK	https://www.sterlingtt.com/about-us/heat-exchanger-manufacturing/
Heat exchanger	heat exchanger manufacturer, but assumed typical equipment sizes assumed to be too small	https://www.uk-exchangers.com/applications/refrigeration/

Heat exchanger	Heat exchange manufacturer in UK, Wakefield and Prudhoe - equipment sizes potentially too small from website (but have some costs)	https://heatexchangegroup.co.uk/
Heat exchanger	SAPHEX - UK Manufacturer, Sheffield - based has some pros/cons for different types of heat exchanger on website	https://www.saphex.co.uk/products-and-services/shell-and-tube-heat-exchangers/
Heat exchanger	AKS Heat transfer - UK manufacturers, Sheffield	https://aksheattransfer.com/manufacturing/
Heat exchanger	HDT Specialist Heat Exchangers, Lincoln	https://specialistheatexchangers.com/Home/About
Heat exchanger	Turnbull & Scott Group, manufacture in Hawick assumed	https://www.turnbull-scott.co.uk/heat-exchangers/
Heat exchanger	Therco - Serck design and manufacture heat exchangers in the UK	https://www.thercoserckhtx.com/
Heat exchanger	Xchanger services, UK manufacturer in Leicester	https://www.xchangerservices.co.uk/heat-exchanger-manufacturing/
Heat Exchanger	Vessco engineering can manufacture heat exchangers, based in South Wales	https://vesscoengineering.co.uk/about-us/
Heat Exchanger	Heatrick, Head office Manchester - but do not manufacture in the UK	
Carbon capture (skid)		https://www.concawe.eu/wp-content/uploads/Rpt_20-18.pdf
Carbon capture (skid)	Carbon clean offer carbon capture technology (amine-based)	https://www.carbonclean.com/
Carbon capture (skid)	Origen have Carbon capture technology	https://origencarbonsolutions.com/
Carbon capture (skid)	C capture offer carbon capture technology	https://c-capture.co.uk/
Carbon capture (skid)	OCO technology - UK based and do accelerated carbonation technology, not quite carbon capture - the U in CCS	https://oco.co.uk/
Carbon capture pre-combustion (skid)	JM have pre-combustion carbon capture technology	https://matthey.com/products-and-markets/energy/hydrogen/ccs-enabled-blue-hydrogen
Carbon capture pre-combustion (skid)	Kew technology are working on a blue H2 pre-combustion module - gasifacation tech involved too so not sure if it counts	https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1075298/kew-dacs-ggr-programme-cch2.pdf
Carbon capture General	PMW technology have carbon capture technology - cryogenic	https://www.pmwtechnology.co.uk/technology/

Carbon capture (general)	Carbon capture Scotland - are a company that own and operate carbon capture plants	http://dryicescotland.co.uk/
Pumps	HMD manufacture centrifugal pumps in Eastbourne, UK	https://www.kinder-janes.co.uk/products/pumps/centrifugal/hmd-sealless-pumps/
Compressors	List of air compressors for the UK - none currently offer centrifugal according to website	https://www.aircompressor1.com/industrial-air-compressor-uk/
Compressors	Utile manufacturer some compressors in the UK range - but CO2 range comes through a partnership with a German company	https://utileengineering.co.uk/mehrer-scalable-compressor-systems/
Pumps	Based of ESI manufacturer for a Discflo Disc Pump a type of Low NSPH centrifugal pump	https://esitechgroup.com/products/pumps-vacuum/discflo-disc-pump/
Pumps	Only searched for manufacturers of Low NPSHr Centrifugal pumps in the UK	
Pumps	Progression in the improvement of pump efficiency via AI to create a service based industry rather than the discovery of new technologies	https://www.jeepumps.com/8-innovations-expected-in-the-pump-industry-in-2022/ https://store.frost.com/2025-vision-future-of-pumps-in-a-connected-world.html https://www.pumpindustry.com.au/the-new-norm-ai-enabled-pumps-extending-equipment-life/
Flue Gas Blowers	Flue Gas blowers are widely used, as this website is for biofuels	http://biofuelsacademy.org/index.html%3Fp=243.html#:~:text=A%20flue%20gas%20blower%20is,and%20directs%20these%20fumes%20outside.
Flue Gas Blowers	Manufacturer of industrial fans & blowers	https://fansandblowers.com/
Flue Gas Blowers	Worldwide company that sells at Chelmsford location so assuming they are also manufactured here	https://www.ebmpapst.com/de/en/support/contact/locations.html
Flue Gas Blowers	Worldwide company that sells at Bradford location so assuming they are also manufactured here	https://www.gardnerdenver.com/en-gb/officelocator
Cryogenic storage tank	the UK is researching novel cryogenic storage solutions	https://www.birmingham.ac.uk/research/energy/research/centre-energy-storage/cryogenic-energy-storage/research.aspx
Cryogenic storage tank	the UK is researching novel cryogenic storage solutions	https://www.brighton.ac.uk/business-services/consultancy/cryogenics/cryogenic-energy-storage.aspx
Cryogenic storage tank	Wessington, UK manufacturers ~100 employees	https://wessingtoncryogenics.co.uk/what-we-do/about-us/

Cryogenic storage tank	UK manufacturers 2-10 employees	https://www.pgmcryogenics.co.uk/cryogenic-liquid-storage-vessel
Cryogenic storage tank	UK manufacturers 2-10 employees	https://labmode.co.uk/product-category/liquid-cylinders/
Storage tanks		https://www.richardalan.co.uk/services/pressure-vessels
Filters	UK manufacturers	https://kccontrols.co.uk/about/
Filters	UK manufacturers - assume supplier	https://www.airprotekt.co.uk/profile/
Filters	UK manufacturers - Stourbridge	https://www.gfsa.co.uk/manufacturing/
Filters	UK manufacturers - pinxton	https://www.microtechfilters.co.uk/products/gas-filters/
Filters	UK manufacturers - midlands	http://www.bartonfirtop.co.uk/index1.htm
Filters	UK - assume supplier	https://www.filtration-ltd.co.uk/
Filters	UK manufacturers - assumed to still manufacture in Washington north east England - defo still design and test	https://www.walkerfiltration.com/en-gb/our-history/
Filters	UK manufacturers - Gateshead	https://www.chemeurope.com/en/companies/126/domnick-hunter-ltd.html
Filters	UK manufacturers, small scale non-industrial assumed	3M Cuno
Filters	UK manufacturers - manufacture in Camberley	https://www.amazonfilters.com/about-us
Filters	Specificity to CCS - based on solutions offered by Pall	https://www.pall.co.uk/uk/en/industrial-manufacturing/primary-metals/ccus.html
Filters	Graphene membranes offer IP potential	https://www.graphene.manchester.ac.uk/learn/applications/membranes/
column internals	progression in research for more efficient packing and materials to reduce degradation over time	https://www.ddpsinc.com/blog/distillation-columns-and-internals-for-todays-process-challenges
Dehydration unit	UK manufacturers	https://www.pall.co.uk/uk/en/oil-gas/midstream/midstream-glycol-filtration.html
Dehydration unit	there is limit research going on in UK currently to improve dehydration process	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8771981/ https://www.sciencedirect.com/science/article/abs/pii/S1875510018302567 https://www.researchgate.net/publication/281264585_Investigation_on_New_Innovation_in_Natural_Gas_Dehydration_Based_on_Supersonic_Nozzle_Technology
Offshore Platform jackets	UK manufacturers	https://www.smulders.com/en/smulders-projects-uk
Offshore Platform jackets	UK manufacturers	https://renews.biz/64773/bifab-believes-nng-jackets-contract-will-be-lost/
Offshore Platform jackets	UK manufacturers	https://www.harland-wolff.com/portfolio/humber-gateway-msf-jacket/
Offshore Platform jackets	UK manufacturers	https://www.4coffshore.com/news/lamprell-progresses-seagreen-jacket-fabrication-nid24950.html

Offshore Platform jackets	UK manufacturers	https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/48183/3164-the-capability-and-cap-of-uk-offshore.pdf
Offshore Platform jackets	jackets cannot be reused	https://www.mrw.co.uk/news/steel-recycling-to-revive-oil-port-in-scotland-03-12-2021/
General (EPC)	EPC very promising avenue for UK local content	https://infrastructure.planninginspectorate.gov.uk/projects/north-east/the-net-zero-teesside-project/?ipcsection=docs
Compressor	Gas compressors manufacturer centrifugal in UK	Gas Compressors Ltd - Independent Compressor Packaging
UK Fabrication yards		Fabricators Report 2014 v11.indd (publishing.service.gov.uk)
UK yards closing		Struggling Heerema Fabrication to sell two yards amid insufficient project volume - Offshore Energy (offshore-energy.biz)
Liquefaction plant in UK	Linde gave BOC a CO2 liquefaction plant in the UK	https://www.linde-engineering.com/en/process-plants/co2-plants/references/index.html
CO2 liquefaction plants	A lot of mainland European-headquartered companies e.g. Germany/Netherlands/Denmark	
CO2 liquefaction plants	Cryogenic separation is an IP opportunity for CO2 storage	
column internals	Dtec fabs, Stoke on Trent	https://dtecfabs.com/our-services/
column internals	Lang fields	https://www.langfields.com/products/distillation-columns/
column internals	Mersen - Teesside	https://www.mersen.co.uk/products/anticorrosion-equipment/columns-reactors-and-pressure-vessels/columns-internals-and
column internals	Pall rings - Norfolk	https://www.pallrings.co.uk/products/liquid-distribution-systems/
column internals	Definitely supply, could manufacture in the UK	http://www.plastichem.co.uk/default.asp
column internals	Have manufacturing facilities in UK (Glasgow) and a case study where they have manufactured column vessels	https://www.glacierenergy.com/products-services/pressure-vessel-design-manufacture
Metering	UK Manufacturer - Cheltenham	https://www.nixonflowmeters.co.uk/
Metering	UK Manufacturer - Dorset	https://flowmeters.co.uk/company-profile/
CO2 capture	BOC - Teesside plant two reformers but single flue gas collection	https://www.northerngasnetworks.co.uk/wp-content/uploads/2017/04/H21-Report-Interactive-PDF-July-2016.compressed.pdf
Overseas flow line manufacturer	Used to manufacture in UK but moved to US after UK acquisition (PE and steel pipe solution for CO2)	https://flexsteelpipe.com/history.html
UK-based steel tube manufacturer	3Mt per year capacity up to 0.1m diameter	https://marcegaglia.co.uk/carbon-steel-welded-tubes/

HyNET onshore pipe diameter	1 Mt per year CO2 needs ~ 0.9m diameter	https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1079835/HyNet_CCUS_Pre-FEED_KKD_WP4_-_Onshore_CO2_Pipeline_Design_Study_Report.pdf
Neos Engineering fabricate/manufacture steel pipe	Fabricate pipes	https://www.neosengineering.co.uk/about-us/history/
Finetubes Uk manufacturing	Manufacture some pipe items in the UK	https://www.finetubes.co.uk/aboutus/ametek-specialty-metal-products
UK steel pipe fabricator	Fabricate - not sure manufacture	https://varlowe.co.uk/about-us/
Liberty Steel group - UK pipe manufacturer	Manufacturer steel pipe in UK	https://libertysteelgroup.com/uk/products/line-pipe/
Tata Steel manufacture in the Uk	Manufacturer steel pipe in UK	https://www.tatasteeleurope.com/sites/default/files/Tata%20Steel%20UK%20Factsheet%202020%20%281%29.pdf
British Steel - Steel manufacturer, make steel but not steel pipes		https://britishsteel.co.uk/
Celsa Steel- Steel manufacturer, make steel but not steel pipes		https://www.celsauk.com/Products.mvc/Channels
CO2 dehydration skid	No Co2 dehydration unit UK manufacturers identified by Wood in 2022 (lines up with our analysis)	https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1092371/supply-chains-to-support-uk-hydrogen-economy-wood-template.pdf
Ratio of material and fabrication costs for jackets and topsides	Jackets about 50:50, Topsides 75:25 (materials higher)	https://www.ccsassociation.org/all-news/ccsa-news/ccus-supply-chain-report-showcases-major-uk-opportunity/
Low TRL of some corrosion protection and measuring for pipes		https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1079819/NS051-EN-PLN-000-00007-Technology_Plan.pdf
Tanks/Column Vessels	2 companies that manufacture column vessels in the UK	https://vesscoengineering.co.uk/ https://pressuredesign.co.uk/
CO2 meters	GSS design and manufacturer Co2 meters	https://www.gassensing.co.uk/company/about-us
Co2 meters	Report stating technology developments are required to develop CO2 meters	https://pure.hw.ac.uk/ws/portalfiles/portal/15583932/3_Revised_Manuscript_withoutHighlights.pdf
Blowers	HR blowers manufacture gas blowers	https://hrblowers.co.uk/hr-blowers-uk-ltd-howden-group-further-strengthen-relationship/
Tanks	Example UK manufacturer	https://www.richardalan.co.uk/services/storage-tanks
Fans/gas blowers	Example UK supplier	https://halifax-fan.co.uk/
Fans/gas blowers	Example UK supplier	https://moduflow.co.uk/
	Example UK supplier	https://www.fanmanufacturers.com/about-us/
	Example UK supplier	https://secomak.com/products/fans-blowers/

Authors

Jemima Bruin-Bland
Energy Market Leader – Strategy & Insights
Arup

t: +44 7977 631 365
e: Jemima.Bruin-Bland@arup.com
w: www.arup.com
a: 13 Fitzroy Street, London W1T 4BQ, United Kingdom

Henry Williams
Energy Engineer

t: +44 20 7755 0092
e: henry.williams@arup.com
w: www.arup.com
a: 13 Fitzroy Street, London W1T 4BQ. United Kingdom

Tom Phillips
Energy Engineer

t: +44 20 7755 0243
e: Tom.Phillips@arup.com
w: www.arup.com
a: 13 Fitzroy Street, London W1T 4BQ, United Kingdom

Ove Arup & Partners Limited
8 Fitzroy Street
London
W1T 4BJ
United Kingdom
arup.com