Department for Business, Energy and Industrial Strategy

INDUSTRIAL CCUS UK SUPPLY CHAIN CAPABILITIES

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CONFIDENTIAL

Department for Business, Energy and Industrial Strategy

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FINAL REPORT

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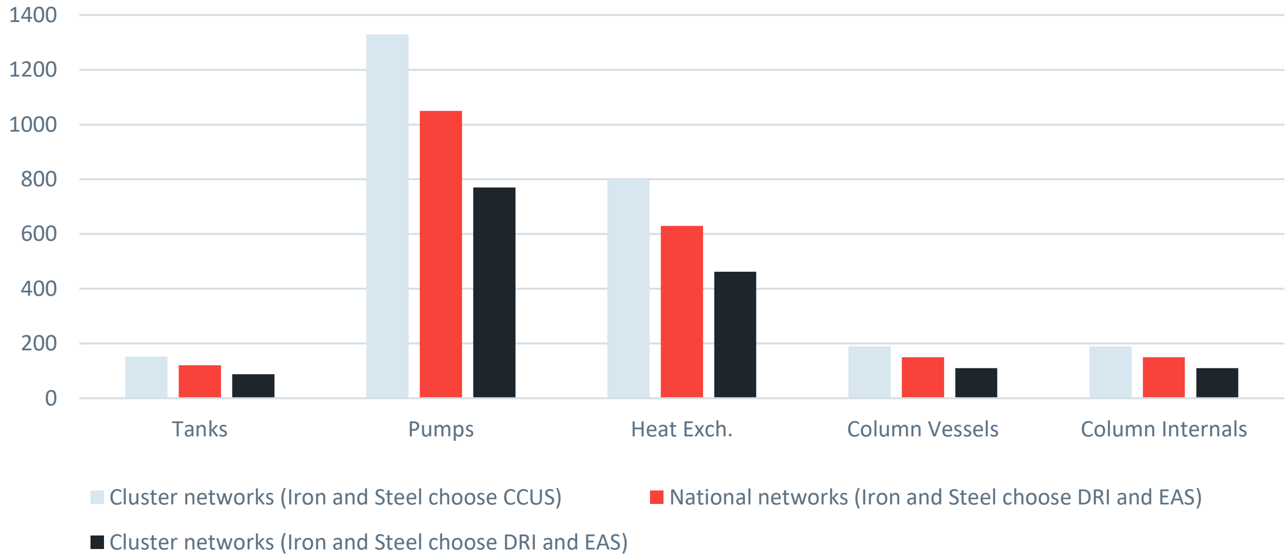
EXECUTIVE SUMMARY

The Government has put forward ambitions of capturing 6 million tonnes of CO_2 per annum from industrial emitters by 2030. This target is extended to 9 million tonnes per annum by 2035. This will require enormous investment in the manufacture and installation of equipment, creating a potentially significant market for the UK supply chain.

We have developed archetypes of Industrial Carbon Capture and Storage (ICCUS) plants to understand the equipment requirements to deliver these ambitions. The chart below shows the volume of equipment required to deliver 2040 ambitions under government scenarios.

Equipment required to deliver 2040 ambitions (number of items of equipment)



Our assessment of the current capabilities of the UK supply chain, total market size and applicability to other markets suggests that column vessels and column internals to be key potential markets to target.

Whist the number of pumps and heat exchangers is much higher, column vessels and column internals are significantly higher in value and have a simpler value chain, and therefore present a bigger market. We estimate that the equipment cost of column vessels could be around £20m for a 500MT per annum capture plant, compared to around £0.5m for pumps and £2m for heat exchangers.

We also note the significant overlap between the ICCUS supply chain, these other industrial CCUS applications, CCUS for power and more general process engineering applications. Government policy objectives at a sectoral level must be co-ordinated to maximise benefits across applications.

KEY FINDINGS

CCUS is innovative because of the novel way it uses existing technology. Equipment used in ICCUS has a long history in other markets, such as oil and gas, and the UK supply chain for this equipment is well established. However, the UK supply chain is largely SMEs focussing on small scale, bespoke manufacturing. This has implications for the types of intervention that can best support the UK supply chain. It also means the potential for the UK's strong SME focussed supply chain to serve the ICCUS market depends on the nature of equipment demand. A diverse market in which each ICCUS project is different may suit the existing UK supply chain better, but bigger, standardised operations may suit large-scale manufacturers overseas.

We also understand that market visibility is a particular issue for CCUS. It was clear from our stakeholder engagement that the UK supply chain does not consider CCUS to be a significant market. Conventional orders remain the focus, and hydrogen projects appear to be more visible and a higher priority as things stand. This lack of visibility could limit opportunities for the existing UK supply chain to engage in ICCUS activities and potentially expand their activities. It also could be a barrier to new entrants or inward investment into the UK from overseas manufacturers.

Our supply chain engagement has suggested that UK companies face significant international competition, including from "low cost, low quality" providers. One way to guarantee the UK supply chain a share of the ICCUS market is by imposing a local content requirement (LCR). However, we understand that an LCR would not be implementable in the UK. Instead, we have developed a set of recommendations that could help the UK supply chain to capitalise on these opportunities without an LCR. We consider collaboration between industry and government to be key in delivering all of these recommendations. We have provided further detail on specific roles in Section 6 of this report.

- Improve visibility of the market pipeline to allow existing and new companies to invest in manufacturing facilities in the UK;
- Highlight all appropriate industrial land to potential investors;
- Support the UK supply chain in accessing decision makers for ICCUS procurements;
- Ensure the UK supply chain is aware of all potential funding schemes to support future investment;
- Promote installation as a key part of the UK ICCUS supply chain;
- Capitalise on the wider applications of ICCUS equipment, in other CCUS and process engineering sectors; and
- Consider opportunities to take account of Net Zero considerations in procurement.

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1 STUDY CONTEXT

Carbon Capture, Usage and Storage (CCUS) is essential to meeting UK's net-zero ambitions including the decarbonisation of regional industry clusters across the UK. Decarbonising the UK's industrial sector will require application of Industrial CCUS (ICCUS).

Deploying ICCUS will create a large market for ICCUS equipment, bringing opportunities for the domestic supply chain. To maximise the opportunities, it is important to understand the capabilities of the supply chain and the barriers to successfully accessing the new market for CCUS equipment.

1.1 SCOPE

This study assesses the equipment required to deliver ICCUS aspirations. We consider industrial sites, rather than the broader ICCUS landscape of Energy from Waste (EfW), blue hydrogen and Combined Heat and Power (CHP). We assess the following:

- Typical components of a CCUS plant;
- Equipment requirements for two archetype plants for cement and pulp and paper;
- Analysis of the current UK supply chain capability to deliver this equipment;
- Consideration of the total future pipeline in the UK; and
- A scoping study of findings and recommendations to improve the UK's supply chain capability.

We also note the significant overlap between the ICCUS supply chain, these other industrial CCUS applications, CCUS for power and more general process engineering applications. Geographically, this report is primarily concerned with evaluating the potential for capturing the UK market, but we note the significant export market.

1.2 METHODOLOGY

The assumptions, evidence base and recommendations in this report have been developed through a combination of literature review, research and focused industry engagement (interviews with suppliers, industry and trade bodies). We also leveraged WSP extensive in-house knowledge to test and refine the conclusions of the literature and interviews.

1.3 INDUSTRIAL CCUS

Industrial Carbon Capture, Use and Storage (ICCUS) is the process of capturing carbon dioxide (CO_2) emissions from power generation for industrial purposes and industrial processes for storage deep underground or re-use.

The BEIS CCUS Cluster Sequencing guidance defines four types of industrial CCUS as summarised below. Our focus in this report is on industrial sites. However, given the similarity in much of the equipment manufactured by the supply chain relevant to industrial facilities will be relevant to the other types of industrial CCUS.

- **Industrial sites** – CCUS equipment installed at industrial facilities with high carbon dioxide outputs, usually linked to either manufacturing or processing activities. Key sectors are listed below;
- **Blue hydrogen** – Retrofitting CCUS to existing "grey" hydrogen facilities, converting it to "blue" hydrogen;

- **Energy from Waste (EfW)** – Installing CCUS to waste incineration facilities; and
- **Combined Heat and Power (CHP)** – Installing CCUS to CHP facilities where the majority of energy is used for industrial processes.

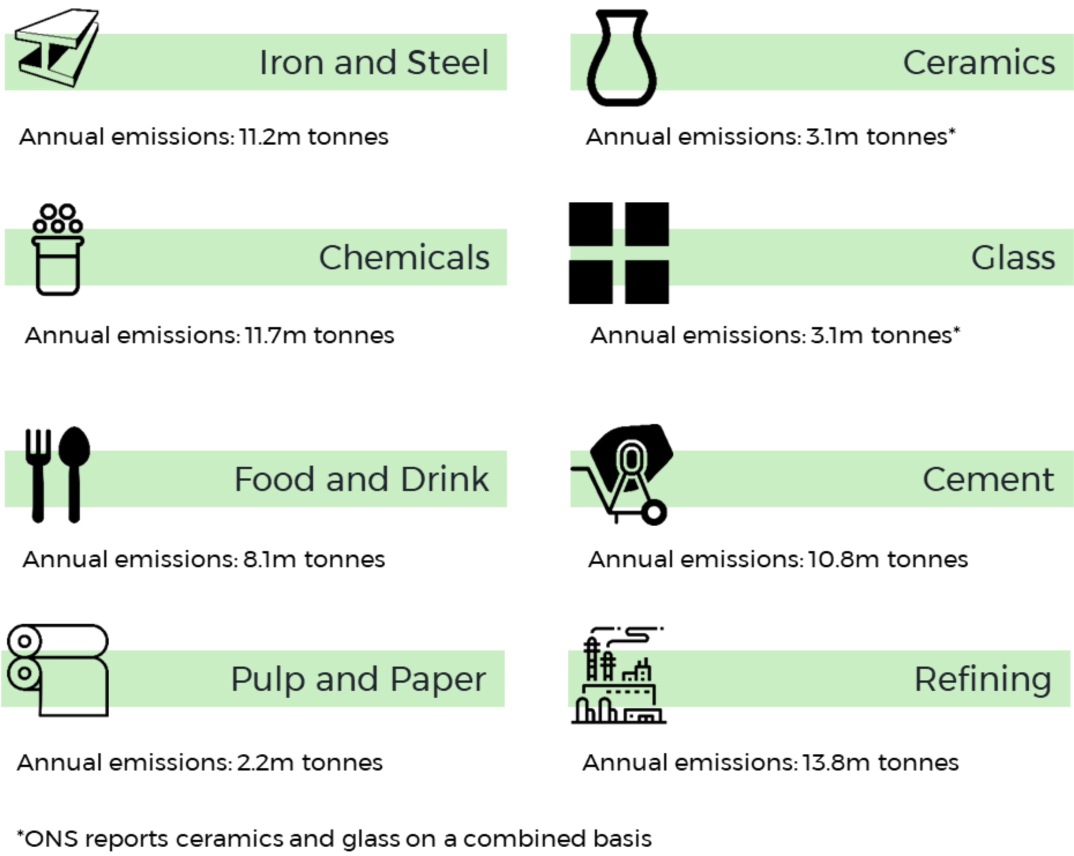
1.4 FOCUS INDUSTRIES

Our scope focusses on the highest CO_2 emitting industries, listed in the graphic below, along with their current annual emissions.

Section 6 below provides full details on each of the industries, information on current production, information on decarbonisation plans and high-level forecasts of future production. This information is used to estimate total potential for ICCUS, including consideration of industry strategies to achieve Net Zero.

Most of these industries are highly carbon intensive due to the significant on-site energy use. Energy efficiency is one of the key opportunities for these industries in reducing carbon output. However, some form of CCUS is likely to be required as even the most efficient equipment and operations will include significant Tier 1 carbon emissions. Food and drink is an outlier, in that most emissions are from Tier 2 and Tier 3 large scale logistics and transport operations, as well as emissions from agriculture. Therefore food and drink is of lower interest to this report.

Figure 1 - Focus Industries for CCUS



1.5 UK CONTEXT

The Climate Change Committee has stated that the UK's climate goals have been substantially reset, with the focus shifting to delivery and implementation. Developing CCUS is now seen as a necessity to reach Net Zero. According to BEIS, investment in CCUS could generate savings of around 40 million tonnes of CO_2 between 2023 and 2032, or 9% of all 2018 UK emissions. Without CCUS, emissions from current industrial processes cannot be reduced to levels consistent with Net Zero.

In recognition of this need for CCUS deployment at pace, the Government has put forward ambitions of capturing 20-30 million tonnes of CO_2 per annum by 2030, of which 6 million tonnes would be from ICCUS. This target is extended to 9 million tonnes per annum by 2035.

This is being supported by up to £1 billion of investment to support the deployment of CCUS in four industrial clusters via the Carbon Capture Storage Infrastructure Fund. BEIS is also developing business models to support the deployment of CCUS infrastructure.

The Ten Point Plan for a Green Industrial Revolution highlights that a new carbon capture industry could support up to 50,000 jobs in the UK, including a sizeable export potential. Achieving this will require strong involvement of the UK CCUS supply chain.

CCUS does not necessarily involve the development of new equipment. Rather, it involves the deployment of well understood equipment in new ways through the adaptation of existing industrial processes to CO_2 capture.

This equipment is typically used in existing process engineering activities, such as oil and gas. The UK has an existing process engineering supply chain that is well placed to input into these developments. However, with a market of up to 6 million tonnes of ICCUS capacity by 2030, it is important to understand the barriers and opportunities to UK supply chain involvement. Identifying actions now to resolve these barriers and maximise these opportunities will give the UK supply chain its best chances of capitalising on these markets.

As ICCUS uses equipment often used elsewhere in process engineering, there are strong synergies with other developments. Similar equipment will be required for the remaining 14 - 24m tonnes of the CCUS targets. In addition, the Ten Point Plan for a Green Industrial Revolution has targets of 10 GW of hydrogen production by 2030, which could leverage similar technologies and provide an additional market to the ICCUS supply chain.

1.6 INTERNATIONAL CONTEXT

Development of CCUS is not limited to the UK. There is significant activity globally, as presented in data from the Clean Air Taskforce project maps below. Table 1 below summarises the number of proposed and operating projects identified by the CATF database across Europe. The IEA's scenario of Net Zero transition by 2050 shows 8.6 GT of CO_2 capture in 2050, indicating the increasing importance of CCUS for global climate ambition. This confirms the sizeable export potential as highlighted in the Ten Point Plan for a Green Industrial Revolution.

The UK has an advantage in that it has more projects at Front-End Engineering Design (FEED) stage, whereas most international projects are at pre-feasibility or feasibility stage. This means projects in the UK are likely to be developed more quickly than those overseas. Therefore, if the UK supply chain can successfully capitalise on the UK market, it could develop the learning and scale to be competitive internationally.

Table 1 - Proposed and Operating CCUS Projects

Region	Number of Projects
Europe	59
MENA	11
United States	89

Clean Air Task Force project maps (accessed April 2022).

2 CCUS SUPPLY CHAIN ELEMENTS

We have used our prior experience to develop a material list for a typical carbon capture plant. This is the basis of our development of two archetypes.

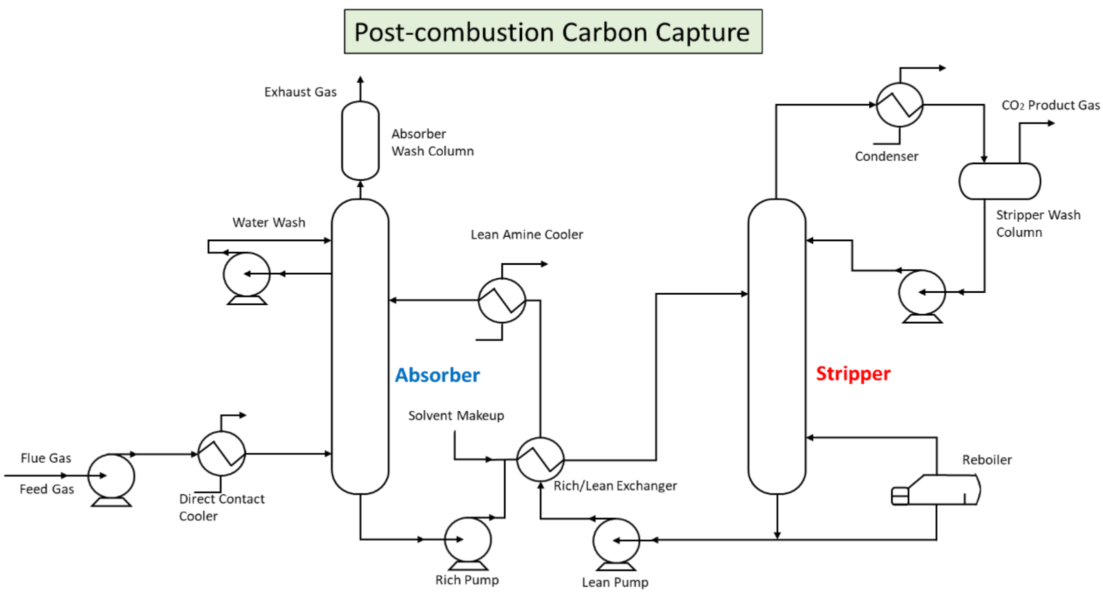
The material list is based on a generic carbon capture technology. It is not an exhaustive list of all equipment typically used by different carbon capture technologies available in the market, but it is representative of a typical process.

The equipment required for the carbon capture plant is similar for both archetypes. Any equipment and support services required to serve the carbon capture plant and to process the captured CO_2 is considered outside the battery limits of the carbon capture plant. These equipment types have been considered in the subsequent sections on Balance of Plant (BOP) and CO_2 Processing Equipment.

2.1 CARBON CAPTURE PLANT

The diagram below shows the equipment that is required for the carbon capture plant for both archetypes. We have provided below a high-level explanation of each of these equipment types.

Figure 2 - Typical Post-combustion Capture Process



WSP analysis.

COLUMN VESSELS

For a typical carbon capture technology, the column vessels required include a direct contact cooler, absorber, absorber wash column, stripper, and stripper wash column:

- Direct Contact Cooler – required to reduce the temperature of the incoming flue gas and remove excess water;
- Absorber – the solvent removes the CO_2 from the flue gas;
- Absorber Wash Column – removes contaminants from flue gas before it is returned to the existing facility;

- Stripper – the CO_2 is separated from the solvent through flashing. The incoming solvent is heated with steam before entry to the stripper to start the process of separation; and
- Stripper Wash Column – removes contaminants from the CO_2 stream before being transported to the CO_2 processing unit.

COLUMN INTERNALS

Column internals are required for all the column vessels. A column internal is a type of packing installed within a column vessel which optimises performance by increasing mass transfer and the surface area available for the processes taking place within the column vessel.

PUMPS

Various pumps (centrifugal, progressive cavity, etc) are required throughout the process to move the fluid throughout the process and provide the process parameters such as pressure and flowrate.

HEAT EXCHANGERS

Various heat exchangers are required throughout the process to cool or heat various streams. The process requires rotary plate, plate, and shell & tube type heat exchangers. Many of the heat exchangers use cooling water as a medium to cool or heat the various process streams.

TANKS

Tanks are required to store the solvent required for the CCUS process.

FLUE GAS BLOWER

A flue gas blower is required to achieve the flue gas supply pressure required for the carbon capture plant. A flue gas blower may not be required if the flue gas supply parameters of the existing facility meet the process requirements of the carbon capture plant. However, the likelihood of this scenario is small, and a flue gas blower will generally be required for both archetypes.

2.2 BALANCE OF PLANT AND CO_2 PROCESSING EQUIPMENT

To operate a post-combustion carbon capture plant and successfully deliver CO_2 to a pipeline or other transport system, additional equipment and support services outside of the battery limits of the carbon capture plant will be required.

Carbon capture technologies may vary in terms of the equipment and services they require, however, there are key equipment and services which will be universal to all technologies. To define this list of possible equipment and services required, we have used our in-house knowledge and previous experience.

As the requirement for support services can change based on capture technology selected, it is noted that the list provided below is not an exhaustive list of equipment and services, and different technologies may possibly require additional equipment and services to support the technology selected.

A list of equipment and services required for a typical post-combustion carbon capture plant has been outlined below. The list provided also indicates the likelihood of equipment and services required and whether they can be provided by the existing facility where carbon capture is being deployed.

DEMINERALISED WATER SUPPLY

A typical carbon capture plant will require supply of demineralised water. In some cases, mains water may be acceptable, however, demineralised water may be the preferred option for many carbon capture technology providers.

The demineralised water can be supplied to the carbon capture plant from the existing facility. However, this is only possible if the existing facility has a demineralised water plant and if it has the additional capacity to supply the existing facility as well as the new carbon capture plant. Alternatively, a new demineralised water plant may be required to support the carbon capture plant.

WASTE-WATER TREATMENT

As highlighted above, water will be used within the carbon capture process and therefore will leave the process "dirty". Therefore, for the carbon capture plant to comply with regulations it is likely that the waste-water will have to be treated before disposal.

The waste-water can be treated using the existing facility waste-water treatment plant. However, this is only possible if the existing facility process has a waste-water treatment plant and if it has the additional capacity and capability to support the existing facility as well as the carbon capture plant. Alternatively, a new waste-water treatment plant may be required to support the carbon capture plant.

Waste-water could potentially be treated offsite; however, this is more of a short-term solution, and it would be more practical and economical for the site to either use existing waste-water treatment facilities or install a new waste treatment facility to serve the carbon capture plant.

FLUE GAS PRE-TREATMENT

Dependent upon the industry, the flue gas may require treatment before the CO_2 can be captured. The need for this equipment will depend on the quality of the flue gas and whether the flue gas is treated within the battery limits of the existing facility.

COOLING WATER SUPPLY

Cooling water will typically be required for the carbon capture process. Cooling water is required for the heat exchangers to cool various process streams within the carbon capture plant.

Defining the equipment that will be included within the cooling water is difficult as this will depend on the selected capture technology. Typically, a cooling tower along with chillers and fin-fan coolers are required as a constant cooling water temperature required cannot be guaranteed all year round by cooling towers.

The cooling water required for the carbon capture plant could be provided from the existing facility. However, this is only possible if the existing facility has a cooling water system and if it has spare capacity and capability to serve the carbon capture plant. It may be a possibility that an existing facility can supply cooling water from their cooling tower, but a chiller or fin-fan cooler is required within the carbon capture BOP battery limits to supply the desired cooling water temperature during the summer months. Alternatively, the carbon capture plant BOP may have to supply the cooling water using a new cooling water system specifically erected for the carbon capture plant.

STEAM SUPPLY

For a typical carbon capture plant steam will be required. Steam within the carbon capture process is used for extraction of CO_2 from CO_2 rich solvent.

Steam can be provided for the carbon capture plant by the existing facility. However, this will be dependent on the existing facility using or producing steam as part of their process and the impact on revenue if steam is used for electricity generation. If the existing facility cannot supply the steam required, the carbon capture plant BOP can include multiple configurations to produce steam. A steam boiler can be installed to supply steam required for the carbon capture plant. The fuel used to power the steam boiler (electricity, natural gas, diesel, etc) will depend on capture technology requirements, site location and operational costs. A waste heat steam generator could also be included within the BOP to utilise thermal energy from the high temperature flue gas exiting the existing facility. This again will be project specific and depend on the process conditions of the flue gas.

CO2 POST CAPTURE PROCESSING

All carbon capture plants will require the captured CO_2 to be processed before it can be transported, utilised, or stored. The temperature, pressure and other characteristics of the CO_2 will depend on the pipeline or transport system that the CO_2 is using. For example, the pipeline conditions for HyNet and the East Coast Cluster are different and require the CO_2 to be transported in different phases.

Even with the difference in CO_2 characteristics, there will be key pieces of equipment required for CO_2 processing. Firstly, a CO_2 compressor and/or CO_2 pump will be required to achieve the desired pressure. Next, CO_2 cooling will be required (typically using heat exchangers) to remove water and achieve the desired delivery temperature. Finally, a CO_2 dehydration unit will be required to reduce water content down to ppm levels before transport. This process will typically employ triethylene glycol (TEG) absorption or molecular sieve adsorption technology. The final configuration and extent of CO_2 stream conditioning will be determined by the final entry specification for the specific transportation method. The current focus is on transport by pipeline, but road, rail and marine shipping are also expected to be part of a mature CCUS industry.

3 ARCHETYPES

Based on the equipment identified above, WSP has undertaken research into the supply chain requirements for retrofitting a carbon capture plant to two archetypes of industrial carbon capture plants in the UK. These archetypes were developed using post-combustion carbon capture technology, as pre-combustion carbon capture is typically a more niche endeavour and not easily deployable to existing facilities. We developed the following two archetypes:

- A Paper Mill with CHP retrofitted with post-combustion capture: This represents a small emitter with circa 50kt captured per annum; and
- A Cement Plant with post-combustion capture: This represents a medium to large emitter with circa 1000kt captured per annum.

To investigate the supply chain requirements for the two archetypes, we reviewed existing literature to develop preliminary designs and outline the equipment that is typically required for a post-combustion carbon capture plant. Thereafter, we analysed balance of plant (BOP) and CO_2 processing units that are typically required to support these carbon capture plants.

We conducted further research to identify the plant equipment that is installed at a typical Cement Plant and Paper Mill. The scale of the capture plant and the type of industrial process played an important role in defining the BOP equipment and support services required to serve the carbon capture plants.

This was then used to develop block flow diagrams for deploying carbon capture at the two archetypes. We used these block flow diagrams, our previous project experience and market knowledge to develop the material lists for the two archetypes.

Finally, we used the block flow diagram and materials list to assess the UK's supply chain capabilities in our supply chain analysis.

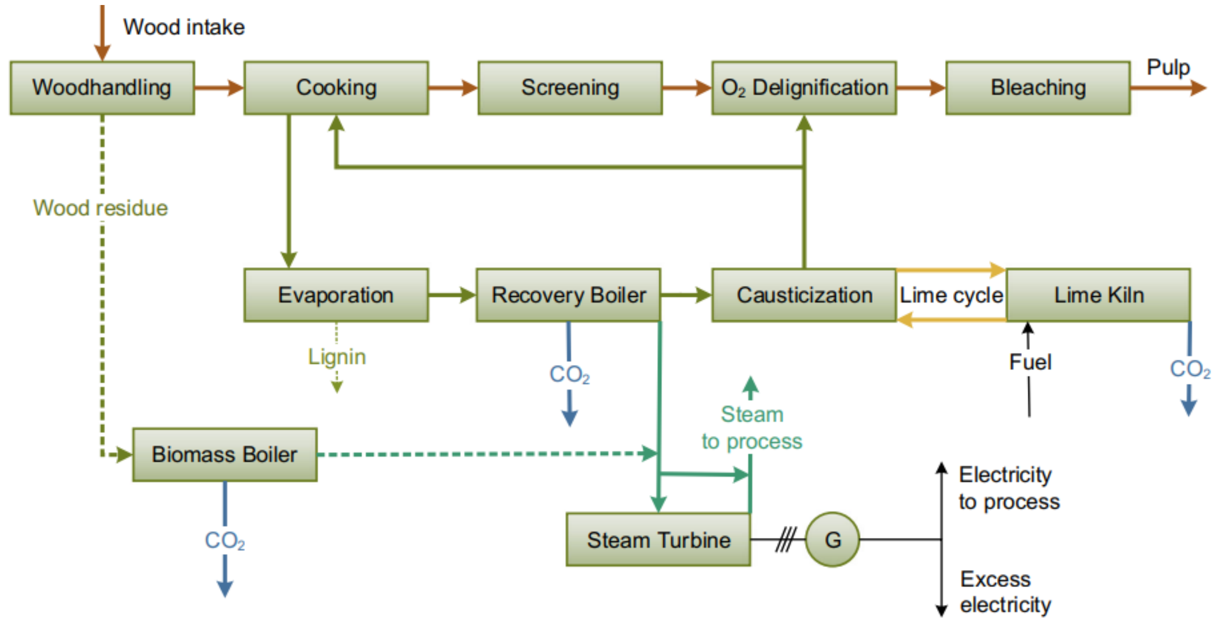
We conducted our analysis through literature review and engagement with vendors for the key equipment required for the carbon capture plant, BOP and CO_2 processing plants.

3.1 PAPER MILL WITH CHP

Typically, two main production pathways are used for paper production: mechanical mills and integrated Kraft mills. Kraft mills comprise the vast majority and have on-site emissions greater than 0.5 Mt CO_2 per annum. Kraft mills account for 73% of European pulp and paper industry emissions, and thus hold the largest potential for capture of CO_2.

Kraft pulp and paper mills produce CO_2 mainly from combustion processes. The largest sources are the recovery boiler, the biomass boiler, and the lime kiln. Due to utilising mostly biomass-based fuels, the CO_2 produced is largely biogenic. This offers a further opportunity to provide negative emission paper production. The block flow diagram for a typical paper mill is shown below.

Figure 3 - Block Diagram for a Typical Paper Mill with CHP



WSP analysis.

The first archetype that was analysed was a typical Paper Mill with CHP retrofitted with post-combustion capture. This archetype represented a small emitter with a capture rate of circa 50kt per annum.

The detailed block flow diagram for the capture plant is provided in Appendix A.

Using the block flow diagram, the following material list has been developed for a typical Paper Mill with CHP retrofitted with post-combustion capture, capturing circa 50kt CO_2 per annum. It must be noted that the equipment specified for each BOP and CO_2 processing package are typical requirements and may vary depending on technology selected and process requirements. Furthermore, the equipment within the carbon capture plant is based on typical carbon capture process and may vary depending on selected technology.

Our prior experience and market knowledge suggests that due to small scale of this archetype one "train" will be required to capture CO_2 from the facility.

A "train" refers to a package of capture technology from a technology licensor that can capture a certain amount of CO_2. From our interactions with technology licensors, we understand there to be a limit on the capacity of a single package of equipment. There will be a certain point where the design of the equipment will not be able to be meet capacity. For example, there will be limitations on column height and diameter and pump flow rates.

This means that a lesser demand will be placed on the supply chain to source the equipment and materials required to deploy carbon capture. Typical equipment required for this archetype is outlined in the Table 2. For equipment within CO_2 Capture Plant Battery Limits, we have highlighted the item type as green where we consider the UK supply chain as having high capability, amber where there is medium capability and red where we consider there to be low capability. This analysis only covers equipment within the CO_2 capture plant battery limits, as this is the equipment we have considered in detail under our supply chain analysis.

This is explained in full in Table 8.

Table 2 - Paper Mill Equipment Requirements

Item area	System	Description	Item Type
CO_2 Capture Plant Battery Limits	Post Combustion Carbon Capture Plant	Column Vessels	Vessel
		Column Internals	Packaging
		Pumps	Pump
		Heat Exchangers	Heat Exchangers
		Tanks	Tanks
		Flue Gas Blower / Compressor	Blower / Compressor
Paper Mill with CHP Battery Limits	Wastewater Treatment	Wastewater Equalisation Tank	Tank
		Equalisation Tank Discharge Pump	Pump
		Co-precipitation Tank	Tank
		Co-precipitation Chemical Dosing Pump	Pump
		Coagulation Tank	Tank
		Coagulation Chemical Dosing Pump	Pump
		Flocculation Tank	Tank
		Flocculation Chemical Dosing Pump	Pump
		Clarifier/Setting Tank	Tank
		FSR filter	Filter
		Filter Press	Filter
	Demineralised Water Treatment	Raw Water Pump Set	Pump
		Intermediate/recirculation Tank	Tank
		Pre RO 5 micron Filter	Filter
		Continuous Electro-deionisation module	Package
		Mixed Bed Polisher	Polisher
		Demin Boost Pumps	Pump
	Cooling Water System	Wet-Dry Cooling Tower	Cooling Tower
		Electric Chiller	Chiller
		Fin-Fan Cooler	Cooler

Item area	System	Description	Item Type
		Cooling Water Supply Pump	Pump
		CO_2 Pump	Pump
		Coolant Pump	Pump
CO_2 Compression & Dehydration Battery Limits	CO_2 Compression and Cooling	CO_2 Compressor	Compressor
		Compressor KO drum	Compressor
		Motor (note: sometimes driven by steam)	Motor
		Gearbox	Gearbox
		Lube Oil System	Package
		Dry Gas Seal System	Package
		CO_2 Pump	Pump
		CO_2 HP Aftercooler	Heat Exchanger
		CO_2 LP Intercooler	Heat Exchanger
		CO_2 Condenser	Heat Exchanger
	CO_2 Dehydration (Molecular Sieve)[1]	Dehydration Vessels	Vessel
		Desiccant Fines Filter	Filter
		Regeneration Gas Compressor	Compressor
		Regeneration Gas / Electric Heater	Heater
		Regeneration Gas Cooler	Cooler
		Regeneration Gas Separator	Separator

Key:

High UK supply chain capability

Medium UK supply chain capability

Low UK supply chain capability

WSP analysis.

Due to the small scale of the capture plant, the demands for utilities and support services will be much lower and we estimate that a circa 50kt CO_2 post-combustion capture plant will largely be able to use existing site utilities and support services to support the capture plant.

[1] There are two main types of CO2 dehydration, adsorption (molecular sieve) and triethylene glycol (TEG). For the archetypes, we choose to use the equipment of a typical molecular sieve option due to our previous research and experience. The TEG process uses similar equipment such as column vessels, filters and heat exchangers, therefore repeating the equipment list for TEG dehydration may not add much benefit. A typical TEG equipment list would include: Scrubber, Absorber, Cooler, Flash Tank, Reboiler, Still Column, Filter, Heat Exchangers and Pumps.

The equipment and materials required for a typical post-combustion capture plant retrofitted to a Paper Mill with CHP emitting circa 50kt CO_2 per annum has been listed below.

Also listed below is the typical equipment required to support this capture plant. As highlighted, due to the small scale of the capture plant, most of the existing utilities and support services available at the Paper Mill will be utilised. A description of how these services will be supplied to a post-combustion capture plant is provided below.

DEMINERALISED WATER SUPPLY

Paper Mills use a very large amount of water, with estimates of about 100 litres of fresh water needed to produce 1kg of paper.

Process water is used for cooking wood chips to make pulp, as a medium for heat transfer, and for washing the pulpwood, the wood pulp, and the machines that handle the pulp. The quality of water is not important when it comes to heat transfer as that water is not in direct contact with the product. However, water quality is important when making the pulp and washing the pulpwood, wood pulp, and machines that handle the pulp. The quality of the water used in the pulp mix may affect the quality of the final product, such as the strength, durability, and colour of the paper.

Therefore, from the above and further research, it appears the consensus is that a typical Paper Mill will have a demineralised water treatment plant installed to ensure the quality of the water for the paper production process.

For the small-scale capture plant, we have concluded that the existing demineralised water plant will have sufficient capacity and therefore will be able to supply demineralised water required by the carbon capture plant via a pipeline.

WASTE-WATER TREATMENT

A waste-water treatment plant and closed water circulation system on a typical Paper Mill allows over 90% of used water to be recycled. A typical pulp mill waste-water treatment plant includes primary treatment (neutralisation, screening, or sedimentation), principally to remove suspended solids, and biological/secondary treatment.

For the small-scale capture plant, we have concluded that the existing waste-water treatment plant will have sufficient capacity and therefore will be able to treat waste-water generated by the capture plant. This waste-water will be supplied to the existing plant via a pipeline.

COOLING WATER SUPPLY

As previously mentioned, water is used for heat transfer. A considerable volume of cooling water is normally required for the many cooling and condensing duties in pulp and paper plants. Cooling equipment is also required to cool hot water coming from the paper mill, cooling to then be re-used within the cycle.

Therefore, we have concluded that the existing cooling water system will have sufficient capacity to meet the cooling water demand for the capture plant and its support systems.

It must be noted that the temperature of this cooling water is unknown, as this is not readily available in the public domain. Furthermore, each capture plant technology may have varying cooling temperature requirements. Therefore, further cooling equipment (such as chillers) may be required to meet the capture plant process requirements.

STEAM SUPPLY

Paper mills generally contain two types of boilers.

- **Biomass Boilers:** Biomass residue is generated in the wood handling processes of the pulp mill, and, in addition to bark, the biomass residues contain other particles such as fines and wood lost during mill debarking. Almost all pulp mills burn this residue at site in the biomass boiler. Biomass boiler uses fossil fuels during start-up and shutdown. In many mills, additional auxiliary steam is generated with fossil fuels especially if the mill is an integrated mill. Integrated mill combines the pulp mill and the paper machine. For pulp mill, the fossil fuel usage produces at least 20 kilograms (kg) CO_2 per air-dry pulp ton (ADt), but this can be significantly larger.
- **Recovery Boilers:** Weak black liquor from brown stock washers after pulping is concentrated in multi-effect evaporator. Most of the water is removed, and concentrated black liquor, at 10–35% water content, is burned in a recovery boiler. The role of the recovery boiler is to burn organic residue from pulping and recover used sodium-based pulping chemicals in the black liquor.

The recovery boiler and a separate biomass boiler produce steam for electricity generation in a steam turbine (CHP Plant). Therefore, for this small-scale capture plant, we have concluded that the steam demand can be met by taking steam from the existing CHP Plant.

Steam is essential in numerous stages of the pulp and paper process therefore a study into the impact of removing steam from the paper mill will generally be required. Furthermore, the impact of diverting steam from the CHP Plant will also need consideration.

FLUE GAS PRE-TREATMENT

Depending on the quality of the fuel, flue gas pre-treatment may be required. It is important to note that this may not be the case for all projects as different carbon capture technologies will require different flue gas quality.

CO2 POST-CAPTURE PROCESSING

A CO_2 compression and dehydration plant will be required to export captured CO_2 from the site. This is required to compress the CO_2 to the required pipeline or transport pressure and then remove any excess water which could be harmful to the pipeline.

Oxygen removal may be required in some cases. This will be dependent on the quality of CO_2 leaving the capture process, as well as the limits set by the carbon network or other transportation methods. Therefore, not only could oxygen removal be required but further downstream processing to meet the final CO_2 specification at the battery limits may be required. For the archetypes, we have developed a generic rather than project specific equipment list. This specifies the main processes such as compression and dehydration, but other processes may also be required.

3.2 CEMENT PLANT

The cement industry is in desperate need of technologies that will reduce its CO_2 output. The industry is responsible for about 7-8% of global CO_2 emissions, the equivalent of more than any individual country except China and the US. Cutting emissions from cement production is difficult because the chemical processes used to make it and concrete release CO_2. The cement industry has pledged to become Net Zero by 2050 without the use of offsetting. The industry's roadmap for 2030 to 2050 would require about one-third of the reductions to come from the use of carbon capture and storage technology. Therefore, collaboration with carbon capture technology providers is crucial for the cement industry and its targets for 2050.

The second archetype that was analysed was a typical Cement Plant retrofitted with post-combustion capture. This archetype represented a medium or large emitter with a capture rate of circa 1000kt per annum.

Our prior experience and market knowledge suggests that due to scale of this archetype multiple trains of carbon capture units (two or more) will be required to capture CO_2 from the facility. This means that a much greater demand will be placed on the supply chain to source the equipment and materials required to deploy carbon capture. Typical equipment required for this archetype is outlined in Table 2.

Due to large scale of the capture plant, the demands for utilities and support services will be significantly higher than Archetype 1 and we estimate that a circa 1000kt CO_2 post-combustion capture plant will require newly installed BOP equipment. This conclusion would be independent of any industry looking to deploy large scale carbon capture. However, a typical smaller scale Cement Plant will have BOP equipment which could be used to support the capture plant. Furthermore, a post-combustion capture plant implemented at a Cement Plant would require BOP equipment which other industries may not require.

The detailed block flow diagram for the capture plant is provided in Appendix A.

Using this block flow diagram, the following material list has been developed for a typical Cement Plant retrofitted with post-combustion capture, capturing circa 1000kt CO_2 per annum. It must be noted that the equipment specified for each BOP and CO_2 processing package are typical requirements and may vary depending on technology selected and process requirements. Furthermore, the equipment within the carbon capture plant is based on typical carbon capture process and may vary depending on selected technology.

As per the paper mill example, for equipment within CO_2 Capture Plant Battery Limits, we have highlighted the item type as green where we consider the UK supply chain as having high capability, amber where there is medium capability and red where we consider there to be low capability. This analysis only covers equipment within the CO_2 capture plant battery limits, as this is the equipment we have considered in detail under our supply chain analysis.

This is explained in full in Table 8.

Table 3 - Cement Plant Equipment Requirements

Item Area	System	Description	Item Type
CO_2 Capture Plant Battery Limits	Post Combustion Carbon Capture Plant	Column Vessels	Vessel
		Column Internals	Packaging
		Pumps	Pump
		Heat Exchangers	Heat Exchangers
		Tanks	Tanks
		Flue Gas Blower / Compressor	Blower / Compressor
CO_2 Capture Plant BOP Battery Limits	Flue Gas Pre-Treatment	Skimmer	Skimmer
		Evaporative Cooler	Cooler
		Reactor	Vessel
		Filter	Filter
		Selective Catalytic Reduction	Package
		Additive and Ash Storage	Tanks
		ID Fan	Fan
	Waste Heat Steam Generation	Evaporator	Heat Exchanger
		Economiser	Heat Exchanger
		Steam Drum	Vessel
		Steam Accumulators	Vessel
		Deaerator	Vessel
		Feed Water Pump	Pump
		Condenser	Heat Exchanger
		Regenerator	Heat Exchanger
		Pump	Pump
		Steam Turbine	Turbine
	Steam Boiler	Steam Generator	Package
		Combustion Air Fan	Fan

Item Area	System	Description	Item Type
		Economiser	Heat Exchanger
		Separator	Vessel
		Gas Burner	Burner
		Feed Water Pump	Pump
		Thermal Deaerator	Vessel
		Chemical Dosing System	Package
		Blowdown Tank	Tank
	Wastewater Treatment	Wastewater Equalisation Tank	Tank
		Equalisation Tank Discharge Pump	Pump
		Co-precipitation Tank	Tank
		Co-precipitation Chemical Dosing Pump	Pump
		Coagulation Tank	Tank
		Coagulation Chemical Dosing Pump	Pump
		Flocculation Tank	Tank
		Flocculation Chemical Dosing Pump	Pump
		Clarifier/Setting Tank	Tank
		FSR filter	Filter
		Filter Press	Filter
	Demineralised Water Treatment	Raw Water Pump Set	Pump
		Intermediate/recirculation Tank	Tank
		Pre RO 5 micron Filter	Filter
		Continuous Electro-deionisation module	Package
		Mixed Bed Polisher	Polisher
		Demin Boost Pumps	Pump

Item Area	System	Description	Item Type
	Cooling Water System	Wet-Dry Cooling Tower	Cooling Tower
		Electric Chiller	Chiller
		Fin-Fan Cooler	Cooler
		Cooling Water Supply Pump	Pump
		CO_2 Pump	Pump
		Coolant Pump	Pump
CO_2 Compression & Dehydration Battery Limits	CO_2 Compression and Cooling	CO_2 Compressor	Compressor
		Motor	Motor
		Gearbox	Gearbox
		Lube Oil System	Package
		Dry Gas Seal System	Package
		CO_2 Pump	Pump
		CO_2 HP Aftercooler	Heat Exchanger
		CO_2 LP Intercooler	Heat Exchanger
		CO_2 Condenser	Heat Exchanger
	CO_2 Dehydration (Molecular Sieve)	Dehydration Vessels	Vessel
		Desiccant Fines Filter	Filter
		Regeneration Gas Compressor	Compressor
		Regeneration Gas Heater	Heater
		Regeneration Gas Cooler	Cooler
		Regeneration Gas Separator	Separator

Key:

High UK supply chain capability

Medium UK supply chain capability

Low UK supply chain capability

WSP analysis.

The equipment and materials required for a typical post-combustion capture plant retrofitted to a Cement Plant emitting circa 1000kt CO_2 per annum will be generally the same as Archetype 1. Below is listed the typical equipment required to support this capture plant. As highlighted, due to the large scale none of the existing facilities of the Cement Plant will be utilised, however, a description of these possible tie-ins has been provided for context.

DEMINERALISED WATER SUPPLY

For cement production, water is a key component.

For the water used in cement production, the quality of the water will have more of an impact as this can affect the strength and durability of the cement produced. Water of potable water (or even non-potable) standard may be used if the quality of the water does not negatively impact the quality of the cement.

From research, it appears the consensus is that Cement Plants will have a demineralised water treatment plant to ensure the quality of water used for cement production. However, as stated previously, for the large-scale capture plant, the quantity of demineralised water required will necessitate installation of a new demineralised water treatment plant.

WASTE-WATER TREATMENT

The Cement Plant will require waste-water treatment before the water is disposed from the site. The waste-water is produced at various stages and by different plant components throughout the cement manufacturing process.

Therefore, a waste-water treatment plant is generally installed on a Cement Plant site. As previously stated, for the large-scale capture plant, the quantity of waste-water generated from the capture plant will necessitate installation of a new waste-water treatment plant.

COOLING WATER SUPPLY

A Cement Plant typically will have multiple cooling systems. A cooling system will be required to cool the cement that leaves the kiln. This is important to maintain the quality of the concrete by preventing gypsum dehydration and the formation of lumps. Typical equipment used in the cement industry, such as cylindrical tube or heat exchangers, will require cooling water to be used. Therefore, a cooling water system is generally installed on a Cement Plant site.

As previously stated, for the large-scale capture plant, the quantity of cooling water required for the capture plant and support systems will necessitate installation of a new cooling water system.

Furthermore, the new equipment required would be dependent upon the temperature of the cooling water required for the carbon capture process. Higher cooling water temperatures would possibly only require a cooling tower whilst lower temperatures (below site ambient temperature) may require the use of chiller or fin-fan coolers.

STEAM SUPPLY

Typically, a Cement Plant has a low steam requirement, therefore a capture plant will require a stand-alone steam generating plant to produce low pressure steam (regardless of capture scale) required for the carbon capture process.

Therefore, it is concluded that a steam boiler will be installed to support the capture plant. The type of boiler (electric, diesel, natural gas, etc) will depend on scale of the Cement Plant and external factors such as site location, capital, and operating expenditure, etc.

As the flue gas leaves the facility at high temperatures, there is possibility for a waste recovery plant to be implemented to provide a portion of the steam required. The flue gas directly leaving the kiln can be at temperatures of around 370°C which is then cooled to 85-180°C before it is vented through the stack. The implementation of this solution will vary from site to site and subject to independent studies.

FLUE GAS PRE-TREATMENT

The flue gas produced from a typical cement production process generally contains high levels of contaminants such as NOx, SOx, HCl and dust. Therefore, a flue gas pre-treatment unit will be required to ensure that the flue gas is of the quality specified by the carbon capture technology provider. The flue gas pre-treatment will likely be made up of several stages with the appropriate technology used for each contaminant to be removed.

The flue gas from a typical Cement Plant will leave the plant at temperatures in the region of 85-180°C (dependent upon the process). Therefore, additional flue gas cooling will most likely be required before the capture plant.

CO2 POST-CAPTURE PROCESSING

A CO_2 compression and dehydration plant will be required to export captured CO_2 from the site. This is required to compress the CO_2 to the required pipeline or transport pressure and then remove any excess water which could be harmful to the pipeline.

3.3 ARCHETYPE SUPPLY CHAIN DEMAND

As per our analysis of the Paper Mill with CHP and the Cement Plant archetypes, the supply chain requirements to retrofit post-combustion capture technology to these sites are very different. There are several factors which impact the equipment required for each retrofit including the process of the existing facility, the available capacities of services at the existing facility and the capture rate of the carbon capture plant.

For the equipment required within the battery limits of the carbon capture plant, the demand on the supply chain for the Paper Mill with CHP vs the Cement Plant mainly differ due to the different capture rates as it impacts the size and quantity of equipment required for each process component. For example, a Cement Plant, capturing 1000kt per annum of CO_2 will most likely require multiple trains to capture all the CO_2, therefore requiring multiple equipment and increasing the supply chain demand.

From the study of the typical services available at a Paper Mill and a Cement Plant, it was seen that the equipment and services required to operate these plants are relatively similar. A key differentiator for the BOP equipment required for each archetype is the scale of the carbon capture plant. Our research has concluded that smaller scale capture plants are able to integrate into the existing facility more easily, taking services such as water and steam from the process. Therefore, this means that the BOP equipment required for a Paper Mill with CHP (capture rate of circa 50kt per annum) was minimal in comparison to a Cement Plant (capture rate of circa 1000kt per annum).

Hence, we conclude that retrofit of the capture plant at a Paper Mill with CHP capturing circa 50kt per annum, will have a lower demand on the supply chain. As seen from the block flow diagram, the existing services of the Paper Mill will be able to supply water, steam and process waste-water generated by the capture plant. Furthermore, the addition of CHP plant means that steam is already available and waste heat recovery from flue gas is not required. The addition of a flue gas pre-treatment may be required as, in our experience, the flue gas may contain impurities which are not suitable for the carbon capture technologies. Therefore, the majority of the new equipment required for the Paper Mill with CHP is the equipment required for CO_2 processing before entry into the CO_2 pipeline network. In this case, we estimate that CO_2 compressors, CO_2 pumps, control and metering units, cooling units (likely heat exchangers) and dehydration units will be required.

In contrast, retrofitting a carbon capture plant to a Cement Plant capturing circa 1000kt per annum will result in more BOP equipment required and therefore more demand on the supply chain. This is due to the unlikeliness of the Cement Plant having the capacity to supply support services to a capture plant of such a large scale. Therefore, a stand-alone demineralised water plant, waste-water treatment plant and cooling water system will be required to support the capture plant. Furthermore, the Cement Plant will not produce sufficient steam requiring installation of a steam boiler or a waste heat recovery steam generator to raise steam by utilising the waste heat in the flue gas leaving the Cement Plant. For the cement industry, due to the poor quality of the flue gas leaving the plant, it is concluded that flue gas pre-treatment will be required.

It is important to note that although the retrofit of this scale capture plant to a Cement Plant will result in an increased demand on the supply chain, the required BOP equipment is standard industry equipment, used throughout many different industries. Therefore, we have concluded that the BOP equipment required can be easily procured, with limitations to supply being the scale required and the capacity of the supply chain.

CO_2 processing will be required for both archetypes, assuming that they will be connecting into a local CO_2 pipeline network, such as HyNet or East Coast Cluster. Therefore, CO_2 processing equipment will be necessary for most of the retrofit capture plants. The type of equipment will depend on the location of the facility and its proximity to the CO_2 pipeline network and the required CO_2 pipeline conditions. The rest of the services required can in some cases be taken from the existing facility, if support services at the existing facility have sufficient capacity, and the impact on performance of the facility is manageable. The likelihood of tying into the existing facility will decrease the demands of the capture plant BOP on the supply chain.

As mentioned previously, the two archetypes will require similar equipment within the carbon capture plant battery limits. The difference will be in the size and quantity of equipment required. The smaller scale carbon capture plant deployed at the Paper Mill with CHP will require only one train and therefore have a lesser demand on the supply chain. Furthermore, we have concluded that due to the smaller scale more “off-the-shelf” equipment can be used which will cause less issues in sourcing equipment and materials from the supply chain. It is important to note that for some technologies, bespoke design may be required due to small scale of the capture plant. This is unlikely to be an issue at the scale of the Paper Mill with CHP, 50kt per annum of CO_2, and more likely an issue at pilot scale (5-10kt per annum).

The larger scale carbon capture plant at the Cement Plant will most likely require multiple trains of the commercially available carbon capture technologies and therefore pose a larger demand overall on the supply chain. Multiples of the same equipment will be required which may be easier to source equipment and materials. The multiple trains, in most cases, will require “off-the-shelf” items as the technology providers will generally specify standardised equipment which are easily procured, fabricated and transported to sites.

During Phase 1, we engaged with the supply chain in the UK to understand the skills and capabilities of the UK market. We have concluded that the equipment which is likely to be mass produced such as the flue gas blower, pumps, heat exchanger, etc will most likely be manufactured outside of the UK. More bespoke equipment such as the tanks and column vessels will more likely be fabricated in the UK. Therefore, procuring the equipment for the carbon capture plant will be highly dependent on suppliers outside the UK as currently there is not much incentive for these suppliers to manufacture in the UK.

4 SUPPLY CHAIN ANALYSIS

4.1 PROCESS ENGINEERING SUPPLY CHAIN SITUATION

In general terms, the manufacturing industry for process engineering can be split between:

- Small scale manufacturers, who provide bespoke equipment for specific needs; and
- Large scale manufacturers, who provide high volumes of standardised equipment.

While there is some overlap, these two types of manufacturers are not necessarily in competition. For example, it can be very costly for large scale manufacturers to alter construction lines from standardised operations to make bespoke equipment. On the other hand, small scale manufacturers do not have the economies of scale to compete efficiently with larger manufacturers.

Our supplier and industry engagement indicates that the UK supply chain is focussed 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.

For bespoke manufacturing it is generally beneficial to operate in the UK, as:

- It provides direct face-to-face access and opportunities to discuss specifications and needs in person;
- There is a strong skilled workforce and R&D infrastructure for bespoke and specialist engineering development; and
- Proximity to end-customers allows easy remedy of snagging issues and other problems.

Our engagement suggests that UK manufacturers would likely situate any new manufacturing facilities in the UK to further capitalise on these opportunities, for business continuity, and because of knowledge of the existing workforce.

The potential for the UK's strong SME focussed supply chain to serve the ICCUS market depends on the nature of equipment demand. If each plant is different and there is limited opportunity for standardisation, then the UK supply chain is well placed. If there is standardisation then the small-scale operations in the UK are unlikely to be able to compete with large-scale manufacturers in Germany, Italy and Poland. This is covered in the section on Future Needs below.

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.

As highlighted, much of the equipment required can be manufactured by both small and large-scale manufacturers. For example, one CO_2 compressor vendor we engaged with, was a small-scale, UK based manufacturer. They specialise in bespoke designs and therefore had limited production capacity in the UK. However, they highlighted the supply chain for CO_2 compressors also included large-scale manufacturers such as Siemens, Atlas Copco, Baker Hughes, etc.

This is a common trend seen for much of the equipment required for the Carbon Capture Plant. The equipment can be supplied by both small and large- scale manufacturers, with the UK manufacturers commonly being the small-scale manufacturers who provide more bespoke designs.

Based on the vendor engagement conducted by WSP, a list has been provided below of the equipment that can be provided by small-scale manufacturers. A comment column has also been included to highlight if the item can also be provided by large-scale manufacturers.

Table 4 – Small-Scale Manufacturers – WSP Engagement

Equipment Type	Comments
Column Vessels	WSP interaction has mainly been with small-scale, UK based manufacturers of column vessels. Can be manufactured outside of the UK but large capability in the UK for this equipment.
CO_2 Compressors	CO_2 Compressors can also be provided by large-scale manufacturers such as Siemens, Atlas Copco, and Baker Hughes.
Tanks	Tanks can be provided by both small and large- scale manufacturers. UK based suppliers will be small-scale manufacturers.

WSP analysis.

From the equipment identified as being provided by small-scale manufacturers, the column vessels are a high value item. As shown previously, the column vessels make up a large percentage of the equipment cost for the Carbon Capture Plant. Therefore, collaboration with the UK supply chain for column vessels will be critical as post-combustion Carbon Capture Plants will require multiple columns for each retrofit.

4.2 SUPPLY CHAIN COMPETITIVENESS

To illustrate this point, we have undertaken a cost comparison exercise for the following equipment based on in-house benchmarks for the location of manufacture:

- Absorbers (column vessels and internals)
- Tanks
- Heat Exchangers
- Pumps

Table 5 below, however, only presents cost received for the tanks. As the absorbers are more bespoke design, WSP experience has found manufacture on the scale required can be achieved in the UK and therefore, engagement with UK manufacturers has been pursued. Alternatively, heat exchangers required for CCUS are more likely to be mass produced and therefore, in WSP experience, are most likely to be manufactured outside of the UK. This, therefore, did not allow for a comparison of UK v international supplier costs for these items.

Furthermore, WSP did have in-house costs for pumps which were both from UK supplier and international Suppliers. However, the items quoted by the UK Suppliers were niche items and therefore not comparable to the mass-produced Pumps quoted by the international suppliers.

From Table 5 below, it can be seen there is no clear pattern in the cost of procuring a tank from a UK v International Supplier. This is mainly due to the limited data set currently available in-house. Further clarity and trends could be identified by engaging with more suppliers in the UK and internationally.

Table 5 - ICCUS Supply Chain Cost Comparison

Scale of Plant (tonnes/day)	UK Supplier (£)	International Supplier (£)	UK Advantage (£)

20	45,000	140,000	94,790
500	650,000	585,000	-65,000

WSP analysis.

In addition to this analysis, we have undertaken a high-level review of the UK's CCUS supply chain manufacturing competitiveness against key international competitors.

In our discussions with stakeholders, Italy, Poland and Germany were highlighted specifically as the location of key international competitors. Notably, Asian manufacturers were not raised as typical competitors. This is particularly for large scale manufacturing, which is a point covered in further detail later in this report.

We have considered the following key factors that influence manufacturing costs:

- **Ease of doing business** (source: World Bank) – based on the World Bank's doing business rankings from 2020 (as it is now discontinued). This ranking considers non "cost" areas of doing business such as business regulation, taxation, trading processes and the legal environment, amongst other things. The higher the Ease of Doing Business score, the lower the burdens and the more competitive we consider the country.
- **Corporation tax** (source: WSP research) – the level of tax on corporate profits.
- **Salaries** (source: Eurostat, ONS) – staffing costs are a key input cost. These are exclusive of wage overheads such as national insurance costs.
- **Energy prices** (source: Eurostat, ONS) – electricity price is another key input cost. These have been converted to GBP for ease of comparison. Note that this is data from before the war in Ukraine, so is not reflective of current issues relating to energy prices.
- **Rent** (source: BNP Paribas) – another key input cost. This is based on annual cost per square meter for logistics space. This has similar requirements to industrial space, so is a good proxy for comparing industrial costs.
- **Access to market** (source: WSP research) – this specifically focusses on the ease of access to UK CCUS opportunities. This is largely a geographical issue, as proximity reduces transport costs, increases direct and face to face engagement with suppliers, and improves ease of access for ongoing snagging or maintenance. For competitors, UK markets will require transport over land and sea to reach the end user industries. The UK has a significant advantage in this regard.

Table 6 shows that in general the UK is on a par with competitor countries. However, UK rents are clearly a differentiator, being significantly higher than the competition.

Table 6 - International Competitiveness Assessment

Factor	UK	Italy	Germany	Poland
Ease of doing business score (out of 100)	**83.5**	**72.9**	**79.7**	**76.4**
Corporation Tax (% profits)	19%	24%	15%	15%
Average Wage (per annum)	£40,306	£29,031	£37,492	£24,571

Electricity Prices (per kWh)	£0.13	£0.16	£0.19	£0.11
Rent (per sqm)	£149	£46	£70	£35
Access to market	Excellent	Fair	Good	Fair

World Bank, Eurostat, ONS, BNP Paribas, WSP research.

4.3 SUPPLY CHAIN CAPABILITY

We have had limited responses to our RFIs, and limited uptake on interview requests. This reflects the small scale, bespoke nature of UK manufacturing – particularly in the process engineering sector.

UK manufacturers are often SMEs, with fewer than 50 employees. This means there is limited capacity in the business for taking on additional activities, such as engaging in studies such as this one. Often the market insight and business development role will all be part of the responsibility of the MD or sales director.

This is covered in further detail in the subsequent information on small scale manufacturing.

We have had two responses from suppliers that indicate current manufacturing capacity. One, a tank manufacturer, indicated that with the right order book they could optimise production to 50 tanks per year. Another, a column vessel manufacturer, indicated they had capacity for 70 columns per year.

Our analysis indicates that achieving 10 MT of ICCUS capacity by 2030 would require around 120 tanks and 170 columns. On face value, this suggests that a single supplier could provide the necessary equipment comfortably.

However, there are several considerations:

- CCUS is not the only target market. Conventional process engineering and hydrogen markets will also be demanding the same technology, putting additional pressure on supply chains;
- Assuming a typical manufacturing facility is operating at a utilisation rate of 70%, this leaves limited head room for additional supply to the CCUS market, especially if hydrogen is also a potential target market, or export markets are available; and
- Specific requirements, such as large tanks or towers, will take up a significant proportion of factory floor space, reducing the total manufacturing capacity significantly.

Depending on requirements, there could be a supply shortfall and we expect investment is required in the UK manufacturing base to service additional CCUS markets. Even if there is manufacturing capacity, it does not necessarily mean the UK is cost competitive. As highlighted above, the UK is at a significant cost disadvantage to international competitors, particularly regarding rents.

Therefore, the UK supply chain is not in a position where it is guaranteed to capitalise on the CCUS market.

The Nuclear AMRC published its CCUS supply chain intervention strategy in March 2022. This considers the UK's supply chain readiness by component type. Their summary is presented in Table 7, with their components broadly aligning with the supply chain list we have presented below. The report also provides details of opportunities for specific components, which we do not replicate here. The Nuclear AMRC report highlights that capacity considerations would require more detailed and in-depth assessment to establish gaps, including direct supply chain dialogue.

This assessment aligns with our understanding of the industry, feedback from Requests for Information to industry and targeted interviews with specific manufacturers and other industry players. CCUS is not innovative because it is a new technology. It is innovative because it is using existing technologies in a new way. The supply chain for these technologies is already strong in the UK.

Table 7 - NAMRC Assessment of CCUS Supply Chain Readiness by Key Component

Component	Number of Suitable Manufacturers	Capability	Experience	UK 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				Green
Gas-gas exchangers				Green
Crossover exchangers				Green

NAMRC CCUS Supply Chain Intervention Strategy.

We have undertaken an assessment of supply chain capability based on our supply chain engagement.

Table 8 - CCUS Supply Chain Capability

Equipment	Supply Chain Capacity and Capability	UK Capability
Column Vessels	The UK supply chain can meet the demand for multiple CCUS projects as UK has multiple fabricators for the column vessel. The main challenges will be the quantity required (number of projects at one time) and need for skilled labour for installation.	High
Column Internals	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
Pumps	The pumps (centrifugal, progressive cavity etc.) will most likely be supplied from outside of the UK, unless more bespoke/ niche design is required. Supply chain issues may be seen if each individual carbon capture plant requires a bespoke design for the pumps. Other challenges such as need for skilled labour and raw materials will also apply.	Low

Equipment	Supply Chain Capacity and Capability	UK Capability
Heat Exchangers	The different type of heat exchangers will most likely be supplied from outside of the UK, unless more bespoke/ niche design is required. Different types of heat exchangers are typically manufactured at different locations which would further emphasise reliance on external supply chain. Other challenges such as need for skilled labour and raw materials will also apply.	Low
Tanks	Tanks can be supplied from both UK and outside of the UK. Due to simplicity of the equipment, supply chain challenges will be minimal with skilled labour and material availability the only possible challenges.	High
Flue Gas Blowers	Flue Gas Blowers will most likely be manufactured outside of the UK. High complexity of these items is the main reason for reliance on external supply chain.	Low

WSP analysis.

COSTS

We have developed estimates for the equipment costs for a typical CO_2 plant. Table 9 summarises this analysis by showing which equipment is likely to have the highest value to the supply chain. This table splits CCUS plant by equipment that is inside Carbon Capture Limits and equipment that is outside Carbon Capture Limits:

- Equipment inside limits refers to the equipment considered under “Carbon Capture Plant” in the section CCUS Supply Chain Elements; and
- Equipment outside limits refers to the equipment considered under “Balance of Plant and CO_2 Processing Equipment” in the section CCUS Supply Chain Elements.

Table 9 - Indicative CCUS Equipment Costs

Item	Percentage
Equipment inside Carbon Capture Limits	**65%**
Column Vessels	41%
Column internals	8%
Heat exchangers	4%
Tanks	3%
Pump	1%
Other	8%
Equipment outside Carbon Capture Limits	**35%**
Cooling Water Package	14%

Item	Percentage
CO_2 Dehydration units	5%
CO_2 Compressor	5%
Demin Water Plant	3%
Steam Boiler	2%
Fire System	3%
Other	2%

WSP analysis.

From this analysis, column vessels are the biggest single item by value. This is a clear area to target for the UK supply chain. As explained in the CCUS Supply Chain elements section, column vessels are key elements of the CCUS process, providing the direct contact cooler, absorber, absorber wash column, stripper, and stripper wash column. These items will be required for any size of capture plant – for both low and high energy intensity sites.

Table 9 only includes equipment costs. There are a range of other costs involved in developing a CCUS facility, including development of the substructure and superstructure, EPC costs and contingency. The remainder is set out in the table below. Indicatively, the equipment cost is likely to comprise around 17.5% - 30% of total project costs, which equates to the first two rows of the table. Note that the table presents costs as ranges as costs will depend based on the specifics of each plant. Therefore, the range totals may not add up to 100%.

The values that are provided in Table 10 are indicative and will vary depending upon various factors, including the equipment vendors used, the required BOP equipment, procurement approach, and contingency amongst other things. Our research and vendor engagement covers the mechanical equipment. It is therefore difficult to provide an indication of the UK's strength in each of these areas as they may vary from project to project. This would require further discussions with construction companies, installers and other parts of the supply chain.

Table 10 - Indicative Total CCUS Project Costs

Cost Item Description	Typical Range
Mechanical Equipment (inside battery limits)	15 – 20%
Mechanical Equipment (outside battery limits)	2.5 – 10%
Mechanical Bulks	2.5 –10%
Electrical Equipment & Bulks	1.5 – 3.5%
Control & Instrumentation Equipment & Bulks	1.5 – 3.5%
Substructure	2.5 – 5%

Cost Item Description	Typical Range
Superstructure	2.5 – 7.5%
Installations	25 – 30%
Commissioning (including inventory)	1 – 3%
Engineering, Procurement and Construction	7.5 – 10%
Contingency	10 – 20%

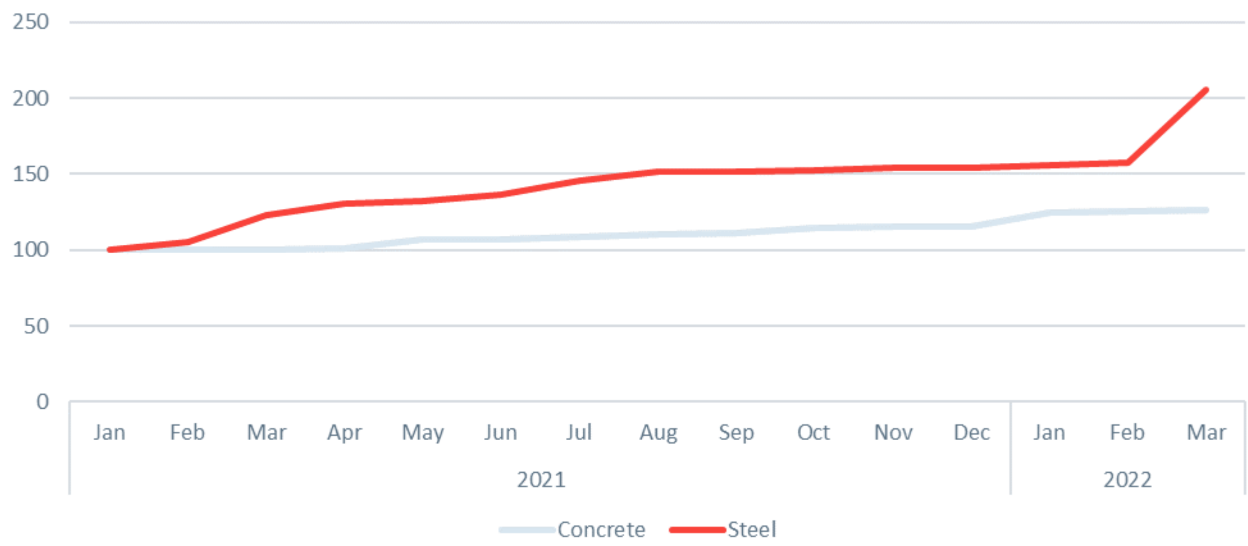
WSP analysis.

COST RISKS

Since 2020, manufacturing and construction has faced a range of supply chain uncertainties caused by issues such as Covid-19, Brexit and the invasion of Ukraine. This has led to cost inflation that could affect CCUS project costs. Two main input materials to a CCUS project are steel and concrete. Figure 4 shows the increase in steel and concrete costs since the start of 2020.

Iron and steel prices have risen by 106% since January 2020, and 32% since January 2022. Concrete prices have increased by 26% since January 2020, but only 1% since January 2021. These are significant increases and mean there is uncertainty over pricing of future CCUS projects.

Figure 4 - Construction Price Cost Indices (Jan 2021 = 100)

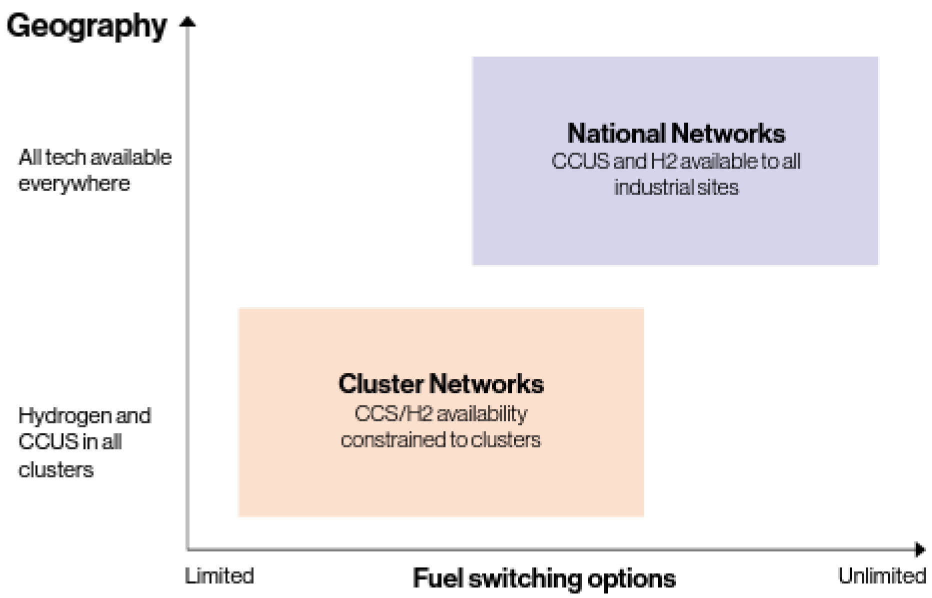


ONS: Basic Iron and Steel and of Ferro-Alloys for Domestic Market, Concrete Products for Construction Purposes for Domestic Market.

5 PIPELINE

The UK Government has generated several scenarios for ICCUS activity by 2050. Its Industrial Decarbonisation Strategy considers two plausible worlds for decarbonisation. One where there are national networks which make CCUS and hydrogen available to all industrial sites, and another where CCUS and hydrogen are only available to industrial clusters. These plausible worlds are summarised in Figure 5.

Figure 5 - Industrial Decarbonisation Strategy - Plausible Worlds



BEIS Industrial Decarbonisation Strategy.

The strategy also considers two decarbonisation options for Iron and Steel:

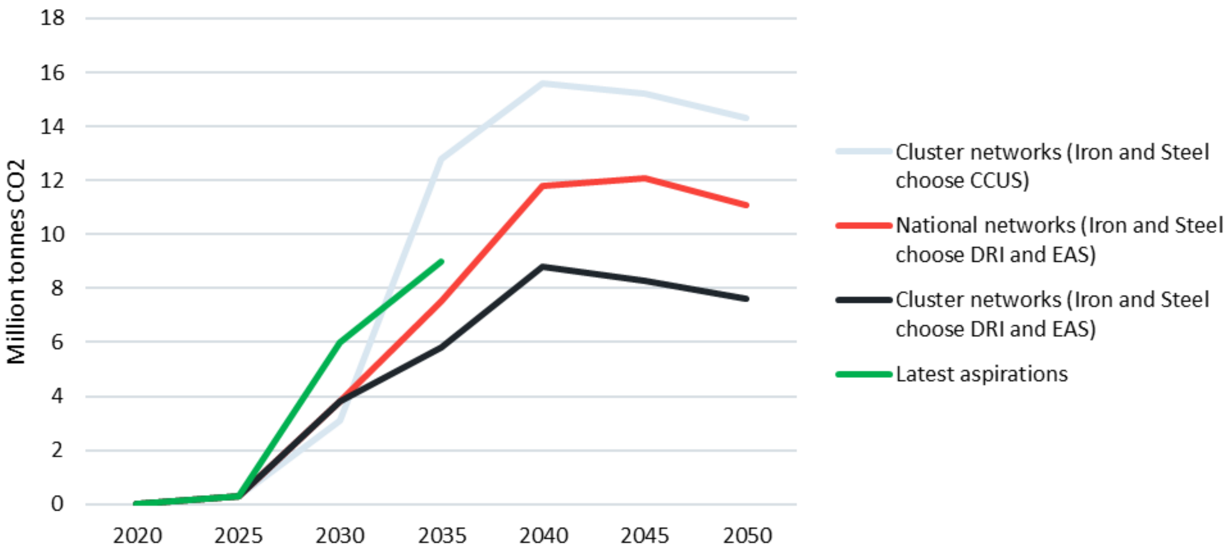
- Deployment of CCUS; and
- Electric Arc Furnaces (EAF) with hydrogen replacing conventional feedstocks and use of Direct Reduced Iron.

By combining the plausible worlds with the decarbonisation options for Iron and Steel, the Industrial Decarbonisation Strategy identifies three scenarios for industrial CCUS:

- Cluster networks, where Iron and Steel choose CCUS;
- National networks, where Iron and Steel choose EAF and DRI; and
- Cluster networks, where Iron and Steel choose EAF and DRI.

In addition, the UK Government has stated new aspirations to achieve 6 million tonnes of ICCUS by 2030, and 9 million tonnes by 2035, presented in its document “Carbon Capture, Use and Storage: An update on the business model for Transport and Storage”. These latest aspirations are represented as “latest aspirations” in the chart below., alongside the three scenarios from the Industrial Decarbonisation strategy.

Figure 6 - ICCUS Scenarios



BEIS Industrial Decarbonisation Strategy.

Based on the Archetypes developed above, we have developed an indicative equipment list for a range of different capture plant sizes. Table 11 indicates the number of each type of equipment for each size of capture plant.

Table 11 - Capture Plant Equipment Requirements

Equipment Type	250k tpa Plant	500k tpa Plant	1mil tpa Plant
Tanks	4	4	8
Pumps	35	35	70
Heat Exchangers	21	21	42
Column Vessels	5	5	10
Column Internals	5	5	10
Dehydration Unit	1	1	2

WSP analysis.

Using these indicative plants, we have developed an indicative pipeline based on a portfolio of capture plant sizes. Based on our understanding of proposed CCUS plants in the UK, we have assumed the following portfolio of plant sizes:

- 20% capacity provided by 250k tonnes per annum plants;
- 40% capacity provided by 500k tonnes per annum plants; and
- 40% capacity provided by 1,000k tonnes per annum plants.

This results in the following indicative equipment requirements under each scenario for 2030, 2035 and 2040. We stop at 2040 as it is the peak or near peak CCUS demand across the different scenarios.

The latest aspirations would see a near doubling in demand for equipment compared to the industrial decarbonisation scenarios.

Combining with the costs outlined in “Costs” above, the equipment cost of delivering 20-30 million tonnes of CO_2 of CCUS capacity by 2030 could be in the order of £3.0 to £4.5 billion. Of this, delivering 6 million tonnes of CO_2 of ICCUS capacity could be in the order of £0.9 billion.

Table 12 - Equipment Pipeline for 2030

Scenario	Tanks	Pumps	Heat Exch.	Column Vessels	Column Internals
Cluster networks (Iron and Steel choose CCUS)	36	315	189	45	45
National networks (Iron and Steel choose DRI and EAS)	36	315	189	45	45
Cluster networks (Iron and Steel choose DRI and EAS)	36	315	189	45	45
Latest aspirations	60	525	315	75	75

WSP analysis.

Table 13 - Equipment Pipeline for 2035

Scenario	Tanks	Pumps	Heat Exch.	Column Vessels	Column Internals
Cluster networks (Iron and Steel choose CCUS)	120	1,050	630	150	150
National networks (Iron and Steel choose DRI and EAS)	72	630	378	90	90
Cluster networks (Iron and Steel choose DRI and EAS)	64	560	336	80	80
Latest aspirations	88	770	462	110	110

WSP analysis.

Table 14 - Equipment pipeline for 2040

Scenario	Tanks	Pumps	Heat Exch.	Column Vessels	Column Internals
Cluster networks (Iron and Steel choose CCUS)	152	1,330	798	190	190
National networks (Iron and Steel choose DRI and EAS)	120	1,050	630	150	150
Cluster networks (Iron and Steel choose DRI and EAS)	88	770	462	110	110
Latest aspirations	-	-	-	-	-

WSP analysis.

EQUIPMENT ANALYSIS

We have considered the supply chain potential of each of the main ICCUS equipment types in the table below against the following criteria:

- WSP's view of the supply chain complexity and the UK's capability as per Table 8;

NAMRC's view of the supply chain readiness as per

- Table 7;
- The equipment cost as a proportion of total CCUS plant equipment cost as per Table 9;
- The applicability of the equipment types to other CCUS applications as per "Cross Sector Development" below (this includes industrial sites, EfW, and CHP); and
- The applicability of the equipment types to other sector applications as per "Cross Sector Development" below (this includes nuclear, renewables, oil and gas, petrochemicals, pharmaceuticals and process industries.

Table 15 – ICCUS Equipment Supply Chain Potential Analysis

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.

Overall, this suggests that the UK is well placed for an expansion in column vessels manufacturing given the current capability, readiness, size of market and applicability to other markets. Column internals also appear a potential expansion area but are less applicable to other markets.

Other equipment types are a smaller market for the supply chain, but could still be developed in the UK, especially given the size of the future market. Compared to column vessels and internals, manufacturing of heat exchangers, pumps and flue gas blowers generally include more imported components. To create a competitive supply chain for these equipment types could require development of a supporting supply chain cluster, which adds complexity to the process.

Although the UK is well placed in certain areas of the supply chain, there are clear risks to mitigate to deliver supply chain expansion. Under the recommendations section below, we highlight several barriers to overcome to support supply chain expansion, which include market visibility, market access, skills and investment costs.

6 FINDINGS AND RECOMMENDATIONS

There is a strong pipeline of CCUS projects, and that the UK supply chain has capability to access this market. However, through our supply chain engagement and wider experience in developing CCUS projects, we have identified several barriers that may inhibit the UK supply chain fully capitalising on this market. We have also identified opportunities that could be expanded upon to maximise the UK supply chain's involvement in CCUS. We consider the barriers and opportunities below, along with recommendations for industry and government to work on together.

Details on each area and specific recommendations are provided in the section below. We have divided these into high priority, short term activities, cross cutting activities and broader activities.

HIGH PRIORITY ACTIVITIES

Of the barriers and potential activities, we consider the following to be high priority and to be accelerated in the short term, as they are fundamental in establishing new supply chain capacity in time to capitalise on emerging CCUS projects:

- **CCUS Market Visibility** – government has a coordinating role across the various activities currently under way in this area;
- **Access to Decision Makers** – this will ultimately be an industry decision, but government has a role in engaging with decision makers and creating a "push" campaign demonstrating the breadth and depth of the existing UK supply chain; and
- **Encouraging Supply Chain Expansion** – any additional funding is likely to be a government responsibility.

CROSS CUTTING ACTIVITIES

As part of the above recommendations, it will be important to capture the **installation** and **cross sector development** opportunities, as these will expand the scope of the supply chain and size of market for potential supply chain expansion to new sectors and activities.

BROADER ACTIVITIES

The following are broader issues, where there are CCUS specific issues to consider in wider government and industry activities:

- **Skills**
- **Land Availability**
- **Net Zero Procurement**

For each recommendation area, we highlight specific actions, status of wider work in this area, highlight the role for government and highlight the role for industry.

6.1 BARRIERS

CCUS MARKET VISIBILITY

Understanding the future market is a fundamental element in deciding to invest in new manufacturing capacity. A manufacturer will not invest without reasonable certainty over the future market that will guarantee a return on investment. In an ideal world this will include contracted capacity from a confirmed client, but there could be speculative investment based on knowledge of a large and growing market.

We have already highlighted the UK's SME focussed supply chain, and how an SME set up means there is rarely available resource for additional tasks. This is a key issue when looking at future markets like CCUS. Large manufacturers operating at multiple sites have a large cost base and can more easily afford market research and business development teams that can undertake market scoping.

However, many UK suppliers rely on senior staff in related roles to undertake this work. This means it is difficult for companies to establish the certainty to invest in an expansion in manufacturing capacity.

We understand this to be a particular issue for CCUS. In conversations with suppliers, it was clear that CCUS is not currently seen as a significant market. Conventional orders, and discussions on hydrogen projects, are the major focus for the UK supply chain as things stand.

Therefore it appears that there is a lack of market visibility for CCUS. This is a barrier to investment in new manufacturing capacity.

Recommendations

In response, we propose the following actions for industry and government:

- Development of a UK CCUS pipeline analysis, which highlights the volume of demand for specific items of equipment from the CCUS Cluster Competitions, as well as potential demand from future industrial decarbonisation. This could include locations and timings. This should be made available to all the UK CCUS supply chain.
- A "key client" list that indicates who the main decision makers are for awarding these contracts, noting the "access to decision makers" recommendation below.

Status	We understand that there are several projects underway that could help provide this visibility. This includes work from Offshore Energy UK, the energy pathfinder tool from NSTA, the "Fit4CCUS" programme led by NAMRC and Make UK and the CCSA delivery plan.
Role for Government	Government will have an important role in co-ordinating and rolling out this analysis to the supply chain.
Role for Industry	Industry will be the main data source and user of this analysis. Membership bodies have a role in creating market visibility products and bringing together industry to make sure they are comprehensive and user friendly.

LAND AVAILABILITY

There are three ways the UK can expand its equipment manufacturing supply chain capacity:

- Reconfiguring or upgrading existing manufacturing activities;
- Expanding existing facilities; and
- Developing new facilities.

The second and third points require access to appropriate industrial land with good transport and skills access. For larger manufacturing facilities, a quayside location allows direct access to large equipment and raw materials.

Our supply chain engagement indicated that there is a lack of appropriate industrial land in the UK, and that this is a key barrier to further investment, particularly for SMEs that are not looking to move location significantly. This is supported by a recent study by the Industrial Land Commission highlights a "critical industrial land shortage", with London (24% reduction over the last 20 years), Greater Manchester (20%) and the West Midlands (19%) all losing significant industrial floorspace. It also highlights that industrial vacancy rates are down to 4% in 2021, from 16% in 2001 – showing significant increase in demand. There are similar issues across Europe, with Savills reporting an average vacancy rate of 4.6% in Europe.

This has been compounded by a surge in demand for logistics facilities to support growth in online sales. Alongside this, an upturn in manufacturing and a potential trend for supply chain re-shoring due to impacts of Covid has seen increasing demand from the manufacturing sector. Both would compete with the CCUS supply chain, reducing access to prime land and driving up rents. which has resulted in increasing rents for such land.

We note that our supply chain engagement was not comprehensive. Whilst our understanding of the industrial real estate market is that there is a shortage of industrial land, particularly in England, there is still likely to be appropriate land available for newly established manufacturing facilities that do not have specific geographical ties. However, even if there is land available it may be that it is either a perceived barrier, or that some firms are unaware of available land.

This is a broader issue than just CCUS manufacturing, and it may not be an area that can be addressed directly by BEIS.

Fabrication yards are also potentially appropriate locations for new manufacturing. Fabrication yards are sites combining quay side access, laydown, buildings and steel working infrastructure that were historically used for developing offshore infrastructure. Many such sites have been repurposed to support offshore wind infrastructure. Table 16 shows indicative sizes and land use for a range of sizes of fabrication yards in the UK.

Table 16 - Indicative Fabrication Yard Statistics

Yard Size	Total Area (Ha)	Buildings Area (Ha)	Laydown (%)	Quay Length (m)	Draught (m)
Small	2	1	50	100	4
Medium	15	2	80	350	6
Large	50	5	95	700	9

WSP analysis.

With the size, access and existing infrastructure, such sites could be well suited to manufacture of large equipment such as column vessels. However, with the projected growth in offshore wind build out rate, there is likely to be very strong competition for fabrication yards.

Recommendations

In response, we propose the following actions for industry and government:

- Work with CCUS supply chain to highlight the opportunities in Freeports, particularly those with a focus on clean energy and manufacturing; and

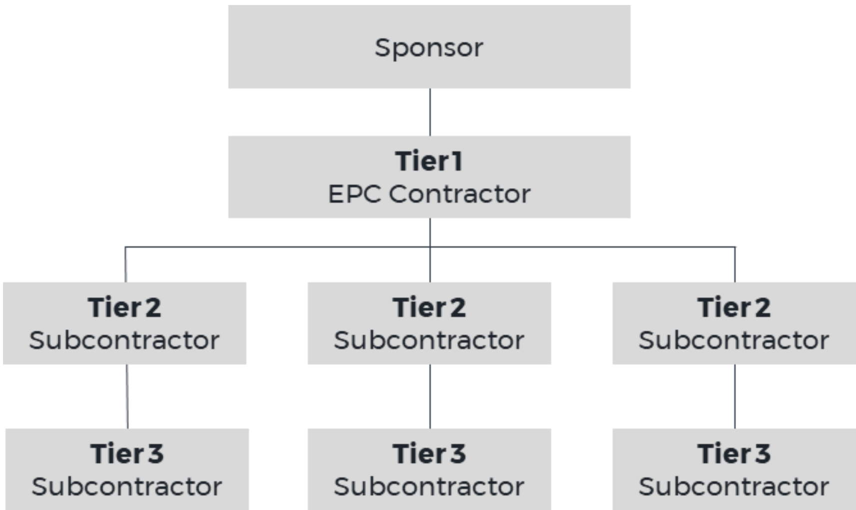
- Develop a database of fabrication yards and similar quayside land, including availability, geography and proximity to CCUS developments.

Status	There is broader government work that is already addressing these issues. Firstly, Build Back Better: our plan for growth includes specific acknowledgement of the need for land remediation and assembly for infrastructure development. Secondly, the UK Freeports programme is specifically focussed on unlocking previously unviable industrial land in the form of tax sites. The 8 UK Freeports will unlock hundreds of hectares of prime industrial land by 2026, including several sites with quayside or near-quayside access.
Role for Government	Government should continue its activities in land remediation and assembly for infrastructure development and engage with Freeports on opportunities to bring in CCUS manufacturing activity.
Role for Industry	Industry should confirm the scale of the land availability issue and identify to government specific geographies where space is lacking and engage with fabrication site owners to identify appetite for use for CCUS supply chain activity.

ACCESS TO DECISION MAKERS

For UK suppliers to effectively access the ICCUS market, they need to be able to be access the relevant procurement decision makers. Infrastructure and power projects, particularly ones with multiple components, often follow an Engineer, Procure and Construct (EPC) procurement structure. In this structure, the EPC contractor takes on design and construction risk. In bidding for an EPC contract, the EPC contractor will take the lead in forming its consortium of subcontractors, known as Tier 2 contractors. Tier 2 contractors may in turn appoint their own Tier 3 contractors, and so on.

Figure 7 - Indicative EPC Contractual Structure



WSP analysis.

In this situation, the key decision maker is the EPC contractor, not the project sponsor. Major EPC contractors for CCUS type projects may not always have full visibility of offerings from the UK supply chain and therefore the UK supply chain may be missing out.

Creating EPC contractor awareness of the UK supply chains would help support the delivery of UK content. It is likely that the EPC contractor will have identified its sub-contractors ahead of tender submission, so identifying post-tender award may be too late. EPC contractors often work on a basis of pre-approved vendor lists or frameworks. UK supply chain will need to be part of these vendor lists ahead of any major procurement exercise. As an indication, we have highlighted a potential procurement timeline for a project funded via the Carbon Capture and Storage Infrastructure Fund. These activities are not strictly sequential and have overlap:

Table 17 – Indicative Carbon Capture and Storage Infrastructure Funded Project Timeline

Activity	Archetype 1 – Paper Mill with CHP (50ktpa CO_2 capture)	Archetype 2 – Cement Plant (1000ktpa CO_2 capture)
Planning, Consenting and Permitting	12 -15 months	18 - 22 months
Front-End Engineering Design (FEED)	6 - 8 months	8 - 12 months
Detailed Design	8 -12 months	10 - 15 months
Procurement & Delivery to Site	15 -18 months	20 - 24 months
Construction	18 - 24 months	24 - 30 months
Commissioning	4 - 6 months	4 - 8 months
Total FEED and EPC Duration	**2.5 – 4.5 years**	**4 - 6 years**
Operational Phase	25 years	25 years

WSP analysis.

Recommendations

Ensuring EPC contractors are aware of the UK supply chain is key. Industry and government can work together to:

- Instigate a UK supplier showcase for major EPC contractors and developers involved in the CCUS supply chain;
- Develop a platform / database of UK supply chain contacts and capabilities for access by EPC contractors and other procuring entities;
- Engage with EPC contractors to introduce UK supply chain to their pre-approved vendor lists; and
- Consider opportunities for project sponsors to promote visibility of UK suppliers as part of major project procurements. This could be supported by strong engagement with local authorities and LEPs.

Status	We note that many developers and EPC contractors may have tender portals through which they seek potential suppliers. Ensuring that as much of the UK supply chain as possible is a listed supplier or has access to these portals would be beneficial for development of the supply chain.
Role for Government	Government has a role in developing a central platform, showcasing UK suppliers and engaging with UK contractors, either leading or supporting the work in collaboration with industry.
Role for Industry	Ultimately is for industry to be as open as possible in its procurement. Industry can play either a lead or supporting role alongside government as per "Role for Government" above, but it also has a broader role in "pushing" supply chain opportunities as broadly as possible.

SKILLS

The UK's engineering and technical skills shortage is well known. It has been consistently raised as an issue in our engagement. A growth in the UK's ICCUS supply chain capacity will require a growing workforce, which will require a concerted skills plan. As explained previously, CCUS is innovative in the way that it uses existing technologies, rather than in being a new technology in itself. Therefore, the supply chain will continue producing similar equipment as before, but it will be integrated and installed in new ways. This results in the following requirements:

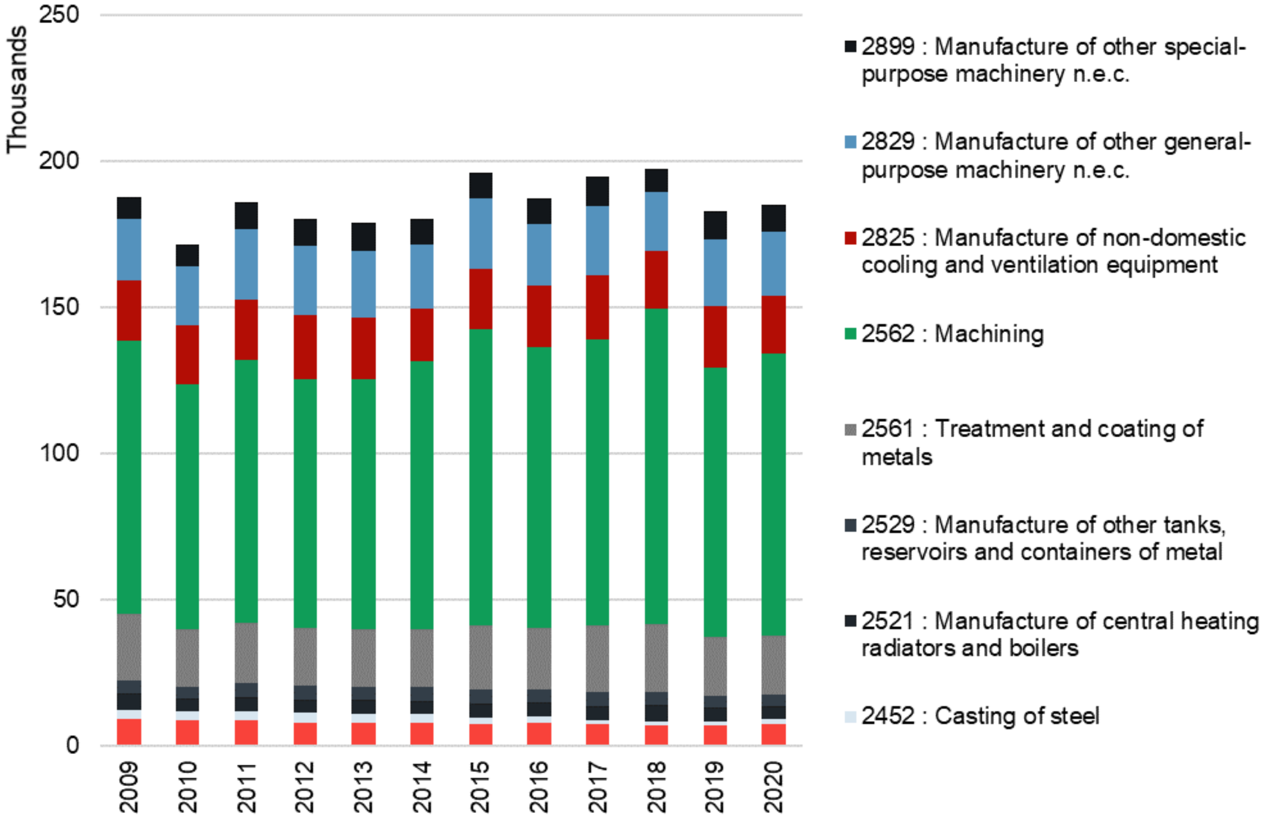
- Sufficient workers with existing skills to expand existing supply chain operations, and attract new inward investors; and
- New teams specialised in the installation and integration of equipment for the purposes of CCUS. Note that this is not the role of the EPC contractor, but a specialist role as a subcontractor for installing specific equipment. This is covered in more detail under installation below.

We have assessed employment in relevant skill areas to consider how skills have changed since 2009. We have considered a range of industries based on SIC code, which we identified by considering the SIC codes identified on Companies House for relevant companies:

- 2420: Manufacture of tubes, pipes, hollow profiles and related fittings, of steel;
- 2452: Casting of steel;
- 2511: Manufacture of metal structures and parts of structures;
- 2521: Manufacture of central heating radiators and boilers;
- 2529: Manufacture of other tanks, reservoirs and containers of metal;
- 2561: Treatment and coating of metals;
- 2562: Machining;
- 2825: Manufacture of non-domestic cooling and ventilation equipment;
- 2829: Manufacture of other general-purpose machinery N.E.C.; and
- 2899: Manufacture of other special-purpose machinery N.E.C.

In total, employment in these industries has contributed between 0.6% and 0.7% of total UK employment since 2009. The majority of this comes from the machining industry, which has occupied between 47% and 54% of the supply chain employment totals, contributing greater fluctuations in the total than any other industry. Over the period, there has been limited change in the sector. Scaling up to meet the ICCUS pipeline is likely to require an increase in skills to match an increase in manufacturing capacity.

Figure 8 - Historical Employment by SIC Code



NOMIS.

Recommendations

Developing the necessary skills pipeline will require a unified effort across government and industry. We do not propose to make any recommendations that duplicate or contradict existing work. Instead, we have highlighted specific areas raised in our discussions with the supply chain:

- Supply chain feedback highlighted historical successes in bringing together regional supply chain players with local skills institutions to develop the specific courses required for the region; and
- It is also clear that ICCUS aligns closely with other sectors, including hydrogen and conventional process engineering. This critical mass can support a significant skills programme. This is covered in further detail under cross-sector development.

Status	CCUS Supply Chains: a roadmap to maximise the UK's potential highlights that Government and industry has been working together to assess the skills and capabilities necessary to achieve deployment ambitions for CCUS in the 2020s. In addition, skills is a cross-cutting issue and links to activities at the Department for Education and the Department for Work and Pensions. The Green Jobs Taskforce also published its recommendations on delivering the ambition of two million green jobs in the UK by 2030.
Role for Government	Government will need to communicate and ensure consistency across departments to ensure that ICCUS and other linked sectors are represented in the development of skills programmes.
Role for Industry	Industry should consider geographical and sectoral collaboration to design and deliver new skills programmes and courses.

ENCOURAGING SUPPLY CHAIN EXPANSION

The above barriers focus on providing the framework for the UK supply chain to succeed in supporting CCUS. The CCUS investor roadmap highlights commitments to the development of a CCUS supply chain and highlights a range of activities to support this. Physically, a major expansion of the supply chain will require significant financial investment in new premises, equipment and "soft" investments, such as skills. This has two facets:

- Ensuring that UK SME suppliers have the necessary access to capital to allow developments to go ahead in a way that maintains their competitiveness; and
- Where feasible and advantageous to the UK, attracting large scale manufacturers from the likes of Poland, Germany and Italy to establish new facilities.

The UK has a successful recent precedent in establishing new major manufacturing facilities. The Offshore Wind Manufacturing Investment Scheme (OWMIS) attracted two major facilities – GE and SEAH – to the UK. Its success has led to the planned "FLOWMIS" equivalent for floating offshore wind. Similar concepts may be feasible for the ICCUS supply chain.

Whilst OWMIS has been successful, it is important to establish schemes that do not exclude or adversely impact UK businesses. As explained previously, large and small-scale manufacturers are not necessarily in competition, so attracting a major international investor should not adversely affect existing supply chains.

In addition, it may be suitable to develop separate schemes that can maximise potential for inward investment and domestic expansion in the existing supply chain. There are existing funding sources available (see below under "status").

Recommendations

Government could consider the following in supporting the expansion of UK CCUS equipment manufacturing:

- Consideration of an "OWMIS" equivalent to attract inward investment in major manufacturing facilities for key CCUS equipment;
- Ensuring existing funding initiatives are visible to the UK supply chain and have proportionate bidding costs; and

- Where funding initiatives are not available, consideration of a “clean engineering fund” that provides grants or match-funding to UK suppliers that are looking to invest in new equipment, expansion of existing facilities or establishment of new sites.

Status	There are various active funding schemes, as summarised in the list below: - The Industrial Decarbonisation Challenge fund; - Carbon Capture, Usage and Storage (CCUS) Innovation 2.0 competition; - Accelerating Carbon Capture and Storage Technologies (ACT) 3 (BEIS, international, up to £5m); and - CCUS infrastructure fund & revenue support mechanisms. However, as noted previously, the SME nature of the CCUS supply chain could limit awareness and resources to seek out and bid for such funding. In addition, this funding is focussed on supporting the development of clusters and innovative technologies rather than the supply chain specifically. The UK Infrastructure Bank may also be a funding source, depending on whether CCUS supply chain aligns with their Investment Principle 2: “The investment is in infrastructure assets or networks, or in new infrastructure technology”.
Role for Government	Government has a key role to play in providing new funding for SMEs and potential large scale new entrants.
Role for Industry	Industry will need to engage and advise on the scale and scope of funding interventions and engage proactively in the design and application of any fund.

6.2 OPPORTUNITIES

INSTALLATION

The supply chain for ICCUS is not limited to just the manufacture of equipment. A key part of any infrastructure project is the installation of the equipment.

This is a separate role to the EPC contractor. An equipment subcontract is also likely to include the costs relating to installation. Feedback from our supplier engagement suggests the share of installation costs are usually between 25% of the contract value for simple projects, up to 50% for complex installations, for example involving multiple cranes. This aligns with our experience of projects as set out in the “Costs” section above.

This is a significant proposition of the supply chain. The UK is ahead of Europe in its CCUS activities, with projects at pre-FEED and FEED stage rather than feasibility. The UK has an opportunity to be a first mover and generate significant expertise in the installation of CCUS projects.

Installation is often undertaken by domestic suppliers because of the geographic proximity, and our supply chain engagement has highlighted that the UK has a strong installation capability. Developing this capability in to CCUS could create a high skilled and potentially exportable, given the innovative nature of the work.

However, availability of skills could be an issue, particularly with the volume of CCUS projects due to come online at similar times through the CCUS cluster competition. With high installation demand, some installation may need to be undertaken by overseas suppliers.

One supplier highlighted the useful example of maintenance scheduling at industrial clusters, where operators collaborate to develop a rolling schedule of maintenance across the site. Similar activities have been undertaken for offshore work in the North Sea. This smart scheduling allowed a smaller maintenance team to deliver all maintenance work.

A similar scheme of coordinated scheduling may be beneficial in delivering construction work at the proposed clusters. However, aligning such a process with the commercial incentives at the various private partners in each cluster is likely to be challenging.

Recommendations

- Installation capability should be considered as a key part of the supply chain, and should be considered as part of any skills programmes; and
- While the commercial realities may be difficult, developing a coordinated installation programme could help develop the UK's installation capability and accelerate the pace of overall pace of delivery. This would require facilitation, potentially by government, and strong collaboration across industry to agree an appropriate phasing and scheduling of construction programmes.

Status	Installation is a key part of the CCUS supply chain, at between 25% and 50% of project cost.
Role for Government	Government will need to communicate and ensure consistency across departments to ensure the value of installation and specialist construction jobs as part of the CCUS supply chain.
Role for Industry	Consider opportunities to develop a mutually beneficial construction programme that does not overwhelm the UK supply chain.

LOCAL CONTENT

Our supply chain engagement has suggested that UK companies face significant international competition, including from "low cost, low quality" providers. One way to guarantee the UK supply chain a share of the ICCUS market is by imposing a local content requirement (LCR). However, we understand that an LCR would not be implementable in the UK. Local content requirements are not permitted under WTO rules, or the EU-UK TCA and similar arrangements are facing challenge under WTO rules.

There are potential softer approaches to LCRs, such as the approach taken by the Offshore Wind Sector Deal to agree sector targets for UK content. However, even this has not been straightforward. The European Commission was reported to be reviewing the supply chain requirements that formed part of the fourth Contracts for Difference auction.

Recommendations

A local content requirement would undoubtedly result in UK supply chains taking a share of ICCUS developments. However, it does not appear to be feasible. Compared to Offshore Wind, the UK has a stronger manufacturing base for CCUS. A combination of the other interventions suggested above could deliver strong UK supply chain engagement without the obligations placed by LCR.

Status	Local content requirements are not permitted under WTO rules or the EU-UK TCA.
Role for Government	No role anticipated.
Role for Industry	No role anticipated.

CROSS SECTOR DEVELOPMENTS

CCUS equipment is not solely used for ICCUS applications. Firstly, the equipment that is required as part of the CCUS projects for industrial sites will primarily be transferable across other CCUS applications. In fact, the equipment required for the Capture Plant, supporting plant and CO_2 Processing Plant will be relatively similar across industrial sites, EfW and CHP retrofits. These industries will all require post-combustion carbon capture technologies from technology licensors offering similar solutions. Differences in the equipment may arise in the supporting plant equipment where the equipment required will vary depending on the technology licensor, the capacity of the Existing Facility and the scale of the capture rate. Differences in the CO_2 Processing Plant equipment may also occur due to the CO_2 product specification, however, is likely to be variations of similar equipment required.

The equipment required for "Blue" CCUS enabled hydrogen will be different to the other three CCUS industries mentioned above. To capture CO_2 emissions in a blue hydrogen process, a steam reformer is required. Therefore, different technology licensors will be required to provide the capture technology. After the steam reformer, the stream will likely pass through various columns vessels (with internals) before the CO_2 will be removed. Furthermore, between the columns will likely be a variety of other equipment. Therefore, the equipment required for blue hydrogen capture will be similar to the other retrofits but will likely be used in a different manner.

The table below provides a summary of the equipment which will be required across all CCUS industries and the equipment which will be specific to a specific CCUS industry:

Equipment	Applicable CCUS Industries
Post-Combustion Carbon Capture Plant including: ▪ Column Vessels and Internals ▪ Pumps ▪ Heat Exchangers ▪ Tanks ▪ Blower / Compressor	Industrial Sites, Energy from Waste, Combined Heat and Power. CCUS enabled Hydrogen (but potentially used in a different manner).
Steam Reformer	CCUS enabled Hydrogen.
Steam Boiler	All (Industrial Sites, CCUS enabled Hydrogen, Energy from Waste, Combined Heat and Power).
Cooling Water Package (including Cooling Towers, Chillers, Fin-Fan Coolers, etc)	
Demineralised Water Plant	
Wastewater Treatment Plant	

Equipment	Applicable CCUS Industries
Instrument Air Plant	
Fire System	
Flue Gas Pre-Treatment	
Waste Heat Steam Generation	
CO_2 Compressor	
Dehydration Unit	

WSP analysis.

The equipment shown for the different CCUS industries is also used across various other industries. For example, column vessels are commonly used in the following industries:

- Nuclear
- Renewables
- Oil and Gas
- Petrochemical
- Pharmaceutical
- Process Industries

The use of column vessels in other industries highlights the development of the technology, the wealth of suppliers worldwide and therefore likely availability. This statement can also be applied to other equipment shown such as the pumps, heat exchangers, tanks, water packages, steam boilers and more.

Recommendations

- Broaden CCUS market visibility analysis to include all similar technologies, providing a clear vision of the size of the UK market for potential investors.

Status	ICCUS supply chain is applicable across industries.
Role for Government	Government will need to communicate and ensure consistency across departments to ensure synergies are recognised.
Role for Industry	Industry should co-ordinated engagement across government so that it is clear that there are synergies in supporting the ICCUS supply chain.

NET ZERO PROCUREMENT

Procurement processes are typically broken down into price and quality elements. Environmental and Net Zero measures can be factored into the quality elements, but positive externalities from green interventions are rarely factored into the price element. Therefore, as things stand, higher cost green cement or steel would lose out to conventional cement or steel.

There are several major public sector led infrastructure programmes underway in the UK. Government can use these infrastructure programmes to play a role in standardising the consideration of Net Zero in procurement. This could accelerate the uptake of CCUS, particularly for construction materials.

Given the lead time on construction of CCUS plants, it is unlikely that a procurement could directly pay for contributions towards a CCUS plant for a cement factory to produce green cement. However, there may be opportunities to consider contractual mechanisms to provide a higher weighting to suppliers that have made binding commitments or investments to installing CCUS, or to "net off" certain costs from the supplier's fee proposal if investments in CCUS are underway.

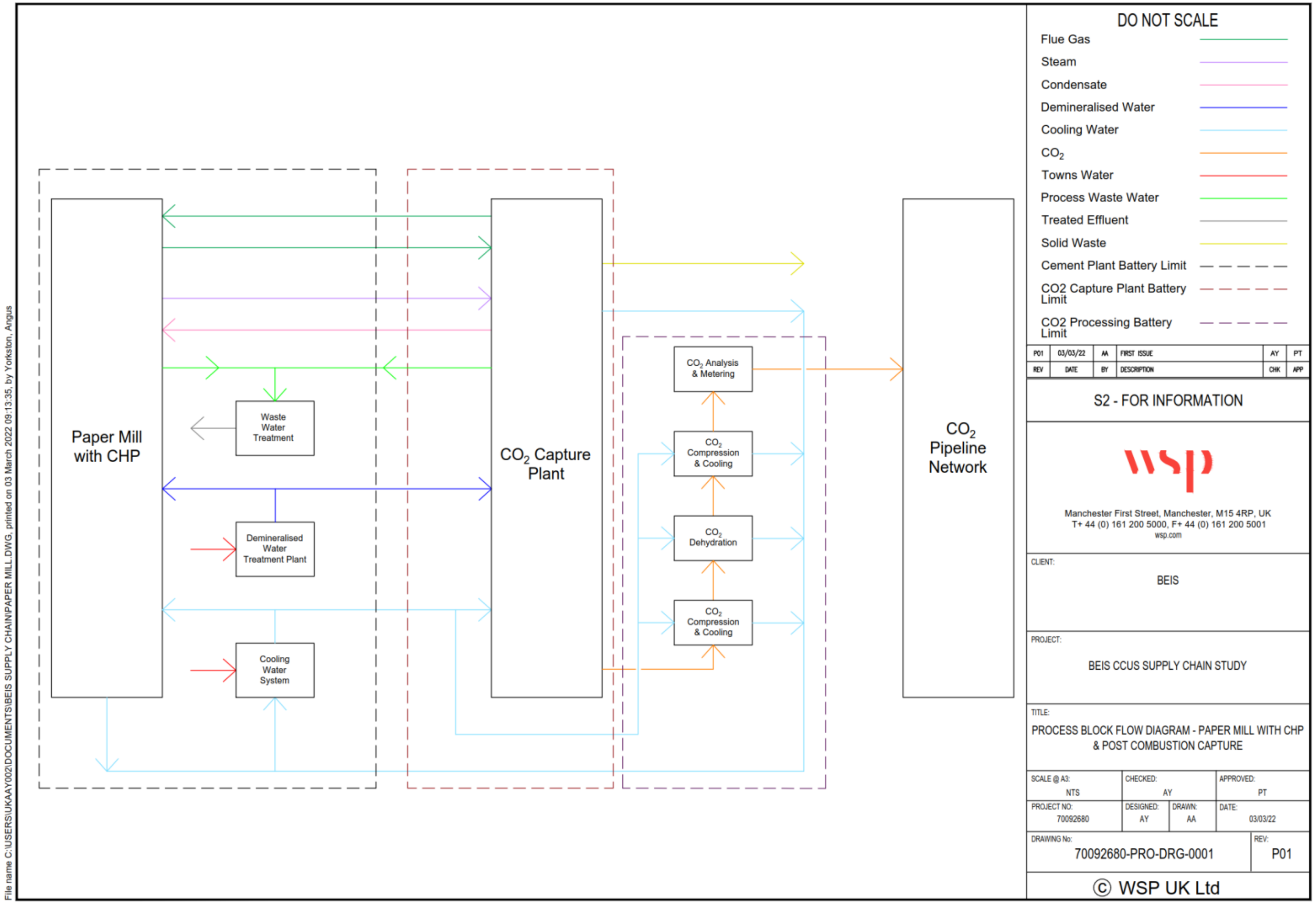
Recommendations

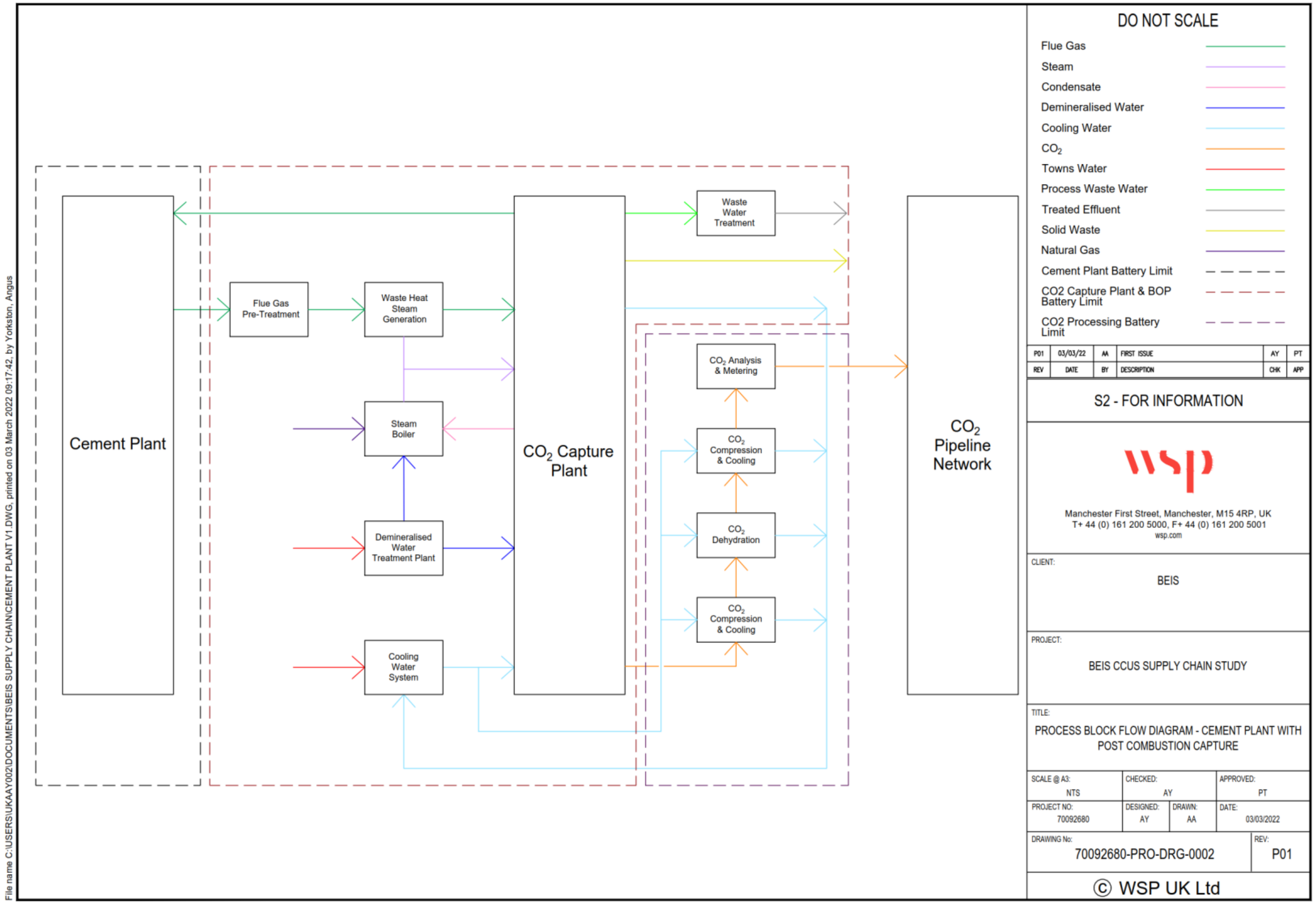
Procurement processes need to be legally robust and deliver commercially sound outcomes for the procurer and supplier. However, there may be opportunities to introduce strong weightings for construction suppliers that have installed CCUS or have installations underway, depending on timing. Such approaches should be considered, particularly by government for major public investments in infrastructure.

Status	UK government has put in place rules for prospective suppliers bidding for contracts above £5million a year to have committed to the government's target of Net Zero by 2050 and have published a carbon reduction plan. There is currently a consultation on including a climate change clause in the NEC4 suite of contracts.
Role for Government	Continuing its commitment to Net Zero in large procurement contracts, and active consideration of how ICCUS use in the supply chain could contribute to this.
Role for Industry	Active engagement with relevant sectors – for example, with construction industry to advertise the potential of CCUS enabled construction materials (cement, iron and steel, glass) as a Net Zero procurement option.

Appendix A

CCUS PLANT BLOCK FLOW DIAGRAMS


DO NOT SCALE
Flue Gas
Steam
Condensate
Demineralised Water
Cooling Water
CO_2
Towns Water
Process Waste Water
Treated Effluent
Solid Waste
Cement Plant Battery Limit
CO2 Capture Plant Battery Limit
CO2 Processing Battery Limit
P01 03/03/22 AA FIRST ISSUE AY PT
REV DATE BY DESCRIPTION CHK APP
S2 - FOR INFORMATION
Manchester First Street, Manchester, M15 4RP, UK
T+ 44 (0) 161 200 5000, F+ 44 (0) 161 200 5001
wsp.com
CLIENT:
BEIS
PROJECT:
BEIS CCUS SUPPLY CHAIN STUDY
TITLE:
PROCESS BLOCK FLOW DIAGRAM - PAPER MILL WITH CHP & POST COMBUSTION CAPTURE
SCALE @ A3: NTS
CHECKED: AY
APPROVED: PT
PROJECT NO: 70092680
DESIGNED: AY
DRAWN: AA
DATE: 03/03/22
DRAWING No: 70092680-PRO-DRG-0001
REV: P01
© WSP UK Ltd
Paper Mill with CHP
Waste Water Treatment
Demineralised Water Treatment Plant
Cooling Water System
CO_2 Capture Plant
CO_2 Analysis & Metering
CO_2 Compression & Cooling
CO_2 Dehydration
CO_2 Compression & Cooling
CO_2 Pipeline Network
File name C:\USERS\UKAAY002\DOCUMENTS\BEIS SUPPLY CHAIN\PAPER MILL.DWG, printed on 03 March 2022 09:13:35, by Yorkston, Angus



File name C:\USERS\UKAAY002\DOCUMENTS\BEIS SUPPLY CHAIN\CEMENT PLANT V1.DWG, printed on 03 March 2022 09:17:42, by Yorkston, Angus
Cement Plant
Flue Gas Pre-Treatment
Waste Heat Steam Generation
Steam Boiler
Demineralised Water Treatment Plant
Cooling Water System
CO_2 Capture Plant
Waste Water Treatment
CO_2 Analysis & Metering
CO_2 Compression & Cooling
CO_2 Dehydration
CO_2 Compression & Cooling
CO_2 Pipeline Network
DO NOT SCALE
Flue Gas
Steam
Condensate
Demineralised Water
Cooling Water
CO_2
Towns Water
Process Waste Water
Treated Effluent
Solid Waste
Natural Gas
Cement Plant Battery Limit
CO2 Capture Plant & BOP Battery Limit
CO2 Processing Battery Limit
P01 03/03/22 AA FIRST ISSUE AY PT
REV DATE BY DESCRIPTION CHK APP
S2 - FOR INFORMATION
Manchester First Street, Manchester, M15 4RP, UK
T+ 44 (0) 161 200 5000, F+ 44 (0) 161 200 5001
wsp.com
CLIENT:
BEIS
PROJECT:
BEIS CCUS SUPPLY CHAIN STUDY
TITLE:
PROCESS BLOCK FLOW DIAGRAM - CEMENT PLANT WITH POST COMBUSTION CAPTURE
SCALE @ A3: NTS
CHECKED: AY
APPROVED: PT
PROJECT NO: 70092680
DESIGNED: AY
DRAWN: AA
DATE: 03/03/2022
DRAWING No: 70092680-PRO-DRG-0002
REV: P01
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Appendix B

SUPPLIER ENGAGEMENT

Below is a list of the vendors who were contacted during the vendor engagement.

Equipment Type	Vendor
Column Vessels	Portobello
Column Internals	Koch Glitsch
Pumps	Flowserve
	Sulzer
Heat Exchangers	Kelvion
	Alfa Laval
CO_2 Compressors	Gas Compressors
CO_2 Dehydration Unit	Linde
	Axens
Tanks	Hartwell
Cooling Towers	DHD Cooling
Demin Water Plant	Culligan
Steam Boiler	TIBS
Wastewater Treatment Plant	H&E

Appendix C

INDUSTRY ANALYSIS

WSP undertook an analysis on the current and projected state of the eight manufacturing industries identified:

- Iron and steel
- Chemicals
- Food and drink
- Ceramics
- Pulp and paper
- Glass
- Refining
- Cement

For each industry, we have considered the following elements to consider the potential for CCUS:

- **Opportunity for reduction** – the current level of emissions in the sector. High emissions provide greater potential for the use of CCUS.
- **Trend** – the trend in industrial production in the sector. A positive trend provides a stronger environment to invest in CCUS, as there is more likely to be a long-term market to pay back the investment.
- **Role of CCUS** – the degree to which CCUS is a primary technology to deliver decarbonisation in the sector.
- **Scale** – CCUS has a high investment cost, requiring large scale operations for volumes to provide payback opportunities.
- **Current projects** – whether there are ICCUS projects currently under development in the sector in the UK.

Based on the above, we provide an overall outlook for the use of ICCUS in the sector below.

IRON AND STEEL

Opportunity for Reduction

Iron and steel are core materials for several sectors in the UK and globally. Construction, infrastructure, automotive manufacturing and oil and gas all use products manufactured from the iron and steel industry. In 2021, the Iron and Steel industry contributed to 0.1% of total UK economic output, 13.5% of all manufacturing GHGs and 2% of total UK GHG emissions, making CCUS one of the main technological options considered for industry decarbonation. The industry faces challenges from foreign competition, namely the overwhelming production capacity from China, and the increasing cost of local production in the UK.

Current emissions are significant at 11.2 million tonnes of CO_2, which is 13.8% of manufacturing emissions and 2.4% of total UK emissions. This is a high opportunity for reduction.

Trend

Between 2010 to 2020, UK steel production generally declined, with a short increase in production between 2013 and 2015, which was followed by a sharp decrease. Overall, there has been a decline in production at a CAGR of 5.23%.

Role of CCUS

There are various potential decarbonisation options for Iron and Steel. The Industrial Decarbonisation Strategy focuses on two possible approaches:

- Deployment of CCUS.
- Electric Arc Furnaces with hydrogen replacing conventional feedstocks, (ie coal) for use in direct reduced iron process. Electric Arc Furnace (EAF) are used instead of traditional blast furnaces which might be considered a process change rather than fuel switching, (A switch of fuel takes place but a new EAF is also required to replace the blast furnace).

The highest use of this in the Industrial Decarbonisation Strategy is in the "Cluster networks, where Iron and Steel choose CCUS" scenario. This results in the following emissions abatement.

Table C-1 - Iron & Steel: Emissions Abated each year by 2050 (Mt, millions)

	All Tech	CCUS	BECCS	Hydrogen	Electricity
Cluster Networks	8	7	-	<1	-

While CCUS could be a key element in decarbonisation of the iron and steel sector, this is reliant on iron and steel producers choosing CCUS over EAF.

Scale

There are two major steel producers, offering scale for CCUS deployment.

Current Projects

No Iron and Steel CCUS projects have been identified in the UK.

Iron and Steel Industry Summary

Opportunity for Reduction	High
Trend	Decline
Role of CCUS	Medium
Scale	Large
Current Projects	None
Overall CCUS Outlook	Medium / Low

CHEMICALS

Overview

The UK's chemical industry provides chemical materials to a range of sectors such as pharmaceuticals, aerospace and construction. Products include petrochemicals, plastics, consumer chemicals, fertilisers and bulk chemicals Chemical manufacturing in the UK is geographically distributed across four main clusters: Hull, Teesside, Runcorn and Grangemouth. These are all connected by pipeline for ethylene, a key feedstock for production.

Current emissions are significant at 11.7 million tonnes of CO_2, which is 14.4% of manufacturing emissions and 2.5% of total UK emissions. This is a high opportunity for reduction.

Trend

The UK chemicals sector has experienced steady growth in terms of economic output, with GVA growing at a CAGR of around 1% per annum since 2010. Production has not grown unanimously across all sub-sectors. The greatest contributor to GVA is soaps and detergents, which in 2020 contributed 36% of GVA and 10% of total sales value, followed by petrochemicals, which contributed 21% of GVA. Overall, growth has been steady.

Role of CCUS

The chemical sector is one of the most energy intensive industries nationally. Key areas of focus to achieve decarbonisation include ICCUS, energy efficiency technologies, sustainable feedstock, further clustering, waste heat recovery and embedding renewables. For complete decarbonization, CCUS will be required.

Scale

There are four main clusters for chemicals production, offering scale for CCUS deployment.

Current Projects

ICCUS projects for fertilisers and grey hydrogen are under consideration in the UK.

Chemicals Industry Summary

Opportunity for Reduction	High
Trend	Steady
Role of CCUS	Potentially significant
Scale	Large
Current Projects	Yes
Overall CCUS Outlook	Medium

CERAMICS

Opportunity for Reduction

The ceramics sector employs high temperature kilns to produce bricks, wall tiles and tableware. The sector directly employs 20,000 people in the UK across 160 sites. The market size of the industry has grown 3.2% on average between 2017 and 2022. Products are made through specific mechanical and chemical processes that convert raw materials into powders, solids or slurries which are then manipulated mechanically, dried and fired at high temperatures, requiring a significant amount of energy consumption. The ONS reports CO_2 emissions for glass and ceramics on a combined basis.

Combined, glass and ceramics current emissions are 3.1 million tonnes of CO_2, which is 3.8% of manufacturing emissions 0.7% of total UK emissions. This is a medium opportunity for reduction.

Trend

There is limited data on ceramics production.

Role of CCUS

Production of ceramics uses significant carbon from firing kilns and drying. CCUS will be a key measure in reducing carbon emissions.

Scale

Ceramic plants are often small scale, with 160 sites across the UK, 97% of which are SMEs. This does not offer the scale for CCUS deployment.

Current Projects

No ceramic CCUS projects have been identified in the UK

Ceramics Industry Summary

Opportunity for Reduction	Medium
Trend	-
Role of CCUS	Potentially significant
Scale	Small
Current Projects	None
Overall CCUS Outlook	Low

PULP AND PAPER

Overview

Wood fibres (or recycled paper) are the raw materials for pulp production. This pulp is then processed and dried to produce paper. Further information on pulp and paper production is included in our Archetypes section. The UK is a significant user of pulp and paper, but is not a major producer, meaning the UK is one of the world's largest importers of paper and board.

Paper and paper products current emissions are 2.2 million tonnes of CO_2, which is 2.8% of manufacturing emissions 0.5% of total UK emissions. This is a medium opportunity for reduction.

Trend

Pulp and paper experienced steady growth in terms of economic output, with GVA growing at a CAGR of around 1% per annum since 2010.

Role of CCUS

The roadmap for Net Zero in the UK paper manufacturing industry is focused on Improving energy efficiency by replacing equipment, which could cut emissions by 25%, and allow for combined heat and power technologies for production. It is also looking at improving conversion efficiency to process alternative raw and intermediate materials such as biomass and the reuse of recycled material. CCUS would be required to achieve full decarbonisation. However, the Paper Industry Technical Association has identified that CCS and CCUS technologies do not achieve cost-benefit standards needed to be adopted by pulp, paper or forest fibre industries.

Scale

ONS data identifies 170 pulp, paper and paperboard manufacturers. Of these, 165 are micro or SMEs - only 5 are considered “large” with over 250 employees. This suggests there is limited scale for pulp and paper manufacturing.

Current Projects

No pulp and paper CCUS projects have been identified in the UK.

Pulp and Paper Industry Summary

Current Emissions	Medium
CCUS role in Decarbonisation	Required for full decarbonisation, but lower priority
Industry Prospects	Steady
Scale	Small
Current Projects	None identified
Overall CCUS Outlook	Low / medium

GLASS

Overview

The UK glass manufacturing has ten industrial companies operating on 17 sites throughout the UK. Flat Glass is the main type of glass and is used in everyday homes. The big flat glass manufacturers are Guardian, NSG, Saint Gobain and Nippon Electric Glass. The ONS reports CO_2 emissions for glass and ceramics on a combined basis.

Combined, glass and ceramics current emissions are 3.1 million tonnes of CO_2, which is 3.8% of manufacturing emissions 0.7% of total UK emissions. This is a medium opportunity for reduction.

Trend

Overall sales of glass have been steady at around £2.5 billion per annum since 2010, growing at a CAGR of around 0.5%. However, the COVID-19 pandemic stalled progress. The UK’s largest manufacturer of glass (Pilkington) was forced to close several sites in Spring 2020, although a few sites remained open to serve customers.

Role of CCUS

In terms of decarbonisation, BEIS and British Glass have produced a roadmap for Net Zero emissions in the UK glass industry. This includes a reduction in carbon emissions through switching fuel to electricity, switching fuel to hydrogen and carbon capture and storage.

Switching fuel to electricity is the biggest emission saving step that can be taken in this industry, with new oxyfuel hybrid furnaces allow for electricity to be the primary input into the manufacturing of container glass. Switching fuel to hydrogen from natural gas would also aid in decarbonisation plans. Existing furnaces that run on natural gas can be transitioned to run on hydrogen which should reduce emissions by 0.054 tCO_2/t.

Carbon capture and storage can reduce emissions and can be implemented for larger furnaces running on low cullet (waster / broken glass) ratios.

Scale

ONS data identifies 15 “large” glass manufacturers with over 250 employees. This could provide the scale for CCUS deployment.

Current Projects

ICCUS projects for glass facilities are under consideration in the UK.

Glass Industry Summary

Current Emissions	Medium
CCUS role in Decarbonisation	Potentially significant for larger furnaces
Industry Prospects	Steady
Scale	Combination of large and small
Current Projects	Yes
Overall CCUS Outlook	Medium

REFINING

Overview

There are six major refineries in the UK, producing a range of fuels and petroleum products – the majority being used for road transport, air transport or product exports.

Manufacturing of refined petroleum products results in emissions of 13.8 million tonnes of CO_2, which is 17.0% of manufacturing emissions and 2.9% of total UK emissions. This is a significant opportunity for reduction.

Trend

Since 2010, refinery output has decreased from 68.6 million tonnes to 45 million tonnes at a CAGR of 4%. In recent years, oil refinery plants in Milford Haven, Teesside and Corringham have closed meaning refining capacity has decreased.

Role of CCUS

Energy consumption is a major cost element for oil refineries and the industry has historically focussed on managing energy efficiency over the past 20 years. A range of measures have been considered for refining activities, including continued improvements in energy efficiency, improved waste heat recovery and use of CCUS for onsite CHP plants.

Current Projects

ICCUS projects for refineries and waste to fuel plants are under consideration in the UK.

Refining Industry Summary

Current Emissions	Significant
CCUS role in Decarbonisation	Potentially significant
Industry Prospects	Declining
Scale	Large
Current Projects	Yes
Overall CCUS Outlook	High / medium (noting long term prospects)

CEMENT

Overview

Cement is a core input to concrete, which is crucial to the construction sector. The section on Archetypes provides further details on a typical cement plant.

Manufacturing of cement and lime results in emissions of 10.8 million tonnes of CO_2, which is 13.3% of manufacturing emissions and 2.3% of total UK emissions. This is a significant opportunity for reduction.

Historical and Forecasted Trends

Cement production has been steady since 2010, growing from 7.8 million tonnes to 8.0 million tonnes.

Industry Emissions and Decarbonisation Status

The MPA (Minerals Products Association) has estimated that CCUS can deliver a reduction in emissions between 62 and 81 percent, depending on whether technical and financial hurdles can be overcome. CCUS is a major driver of decarbonisation for cement.

Scale

There are 12 manufacturing plants with two grinding and blending plants which produce around 10 million tonnes of cement each year. This offers the scale for CCUS development.

Current Projects

Cement CCUS projects have been identified in the UK.

Cement Industry Summary

Current Emissions	Significant
CCUS role in Decarbonisation	Potentially significant
Industry Prospects	Steady
Scale	Large
Current Projects	Yes
Overall CCUS Outlook	High

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