NUCLEAR AMRC

CATAPULT High Value Manufacturing

CCUS supply chain intervention strategy

March 2022

Foreword from the
CCUS Supply Chain Working Group Chair

The Supply Chain Working Group of the CCUS Council was set up in September 2021 and the group held its first meeting in October. We were very fortunate that we were able to hit the ground running by building on the previous work of CCSA in their report "Supply Chain Excellence for CCUS" which was published in July 2021.

We very quickly concluded that there was a need to assess the readiness of potential supply chains in the UK to make the most of potential opportunities and were delighted when Nuclear AMRC (part of the High Value Manufacturing Catapult) stepped forward with an offer to conduct a sprint review for the working group, building on their previous experience of conducting similar reviews in other parts of the Energy Sector (Nuclear and Offshore Renewables).

This excellent piece of work has been carried out in under 4 months and provides some truly valuable insights and some key pointers on what needs to happen next.

The report confirms that there is indeed a major opportunity here for the UK, building upon our proven strength and global capability to serve the oil and gas industries. But it also highlights that the UK needs to move fast to establish this capacity in its home market before moving on to secure a position within the global supply chain for CCUS.

We know that there are many UK manufacturers who could quickly step up to be part of the supply chain, but we also need to make them aware of the opportunities and build their confidence in the size and scale of the opportunity which exists. This is also a great opportunity to address issues of UK productivity and competitiveness, and engagement with industry, particularly SMEs, also presents an opportunity to apply manufacturing process improvements to existing technologies as well as new ones.

The report highlights the need to expand this capability and capacity review to the full suite of components involved in CCUS and Hydrogen processes, not just the amine-based processes which this sprint review has necessarily focused on. The report also raises the potential to integrate a number of similar studies across other Energy supply chains. This is an approach worthy of consideration in enabling those who are contenders to be part of several supply chains to see the full scale of the opportunity and also identify possible synergies.

I would like to express my thanks to Nuclear AMRC for enabling us in the Supply Chain Working Group to make so much progress in producing our first output in such a short time.

Dame Judith Hackitt, DBE FREng
Former Chair of the Health and Safety Executive, currently Chair of Manufacturing trade body MakeUK, and of Enginuity, the Engineering and Manufacturing Skills body. A non-Executive Director of the High Value Manufacturing Catapult

Foreword from the

Head of UK Office of the Carbon Capture and Storage Association (CCSA)

The opportunity for UK Supply Chains to service a dramatic growth in Carbon Capture, Utilisation and Storage (CCUS) is immense. Due to geographical advantages and world-leading skills and expertise, the UK has a unique opportunity to become a global leader in the development of CCUS, making a significant and essential contribution to delivering net zero.

The High Value Manufacturing Catapult's report builds on the work that the Carbon Capture and Storage Association (CCSA) published last year, Supply Chain Excellence for CCUS, and assesses the readiness of part of the UK manufacturing and fabrication supply chain to meet the demand of this growth industry. The UK needs to respond fast to establish its capability, competence, and capacity in its home market, if it is to drive down costs and compete in supplying a much larger global opportunity.

If we act now, we will be able to maximise the huge potential of building a world-leading CCUS industry in the UK. The next decade is critical for CCUS deployment and by taking the steps set out in this report, we have the opportunity to create a strong UK supply chain, boost the UK's prosperity and make a significant contribution to the Government's levelling up agenda, whilst at the same time creating important export opportunities for UK companies in a global market.

We now need to work together as an industry to agree the clear steps we need to take, both in the immediate and longer-term future, to make sure that we build and transfer the knowledge, skills, expertise and capabilities we need to make this a reality. The CCSA will continue to work with its members and wider stakeholders to raise awareness and agree a programme of works to ensure this opportunity is not lost.

Olivia Powis
Head of UK Office – Carbon Capture and Storage Association

Executive summary

This report describes the opportunity to increase UK manufactured content in the emerging carbon capture sector, creating economic growth and export potential while helping achieve the UK's commitment to net zero emissions. It draws on existing market research and adds new analysis on the UK manufacturing supply chain's capability and readiness to support this rapidly growing market.

Key findings

- The UK's net-zero initiatives present the UK manufacturing sector with a multi-billion pound opportunity to supply equipment for new plant which incorporates carbon capture, supported by the carbon dioxide offshore storage opportunity enabled by the UK oil & gas sector.
- An initial supply chain readiness level exercise exposed weaknesses in the UK supply chain. With targeted development, UK manufacturers can supply all parts of a carbon capture plant. However, the UK needs to act quickly to establish its capability, competence and capacity in domestic projects if we are to drive down costs and compete in the much larger global market.
- Businesses which are contenders to be part of the supply chain will need clear early communication of the market needs and other support to develop capability, competence and capacity. It is not clear where this will come from, or how it will be funded.
- Interventions to foster UK growth will require cross-sector support including lead developers, trade organisations, construction contractors and relevant government bodies.
- Many of the skills and capabilities required for deploying carbon capture plant overlap with other technologies in the energy sector. These supply chains may be developed separately, or a more integrated approach may be beneficial.
- Enhanced by its experience with the UK manufacturing supply chain for nuclear work, HVM Catapult is well equipped to provide high-impact support to the carbon capture supply chain using proven business improvement tools.

Recommendations

To realise the benefits of this opportunity, we recommend the following five key actions:

1. Building on the example developed by this study, **develop an inventory and schedule of key components** for a pipeline of carbon capture projects deploying different technologies at varying scales. In addition to new capture technologies, blue hydrogen, pipelines, CO_2 usage and selected storage technologies should be scheduled. This is a prerequisite for further support work.
2. Following selection of specific sub-sectors requiring development or improvement interventions, **launch a new supplier development programme** based on the proven Fit For Nuclear model.
3. **Increase the competitiveness of UK industry** with improved and new production processes. Reduced cycle time, component reliability and safety, enhanced quality and life cycle assessment of supply chains can be important areas of competitiveness and are subject to well-understood analysis and improvement exercises. The HVM Catapult has a wealth of manufacturing process improvement ability to improve competitiveness.
4. **Prepare and execute a CCUS-wide supply chain analysis programme.** The desktop analysis in this report was funded by HVM Catapult, but a full programme requires industry and government support with substantial funding. A short-term pilot exercise would be of considerable value.
5. **Decide on the scope of the exercise** to support CCUS enabled plant – should this look across all energy sectors, or stay focused on CCUS? The government should advise on whether a new national hub or facility focusing on supply chain intervention is appropriate.

Contents

Introduction

This report aims to estimate the readiness of the UK manufacturing and fabrication supply chain to service the dramatic expected growth in carbon capture, usage and storage (CCUS) technologies. It provides a value proposition to accelerate the realisation of resulting opportunities to contribute to the UK's commitment to achieving net zero emissions by 2050, increasing UK manufactured content, providing jobs to support regional economic development, and creating potential for exports. It has been prepared at the request of the CCUS Council's Supply Chain Working Group, whose membership is shown in Appendix B. It draws on existing market research and adds new analysis on the UK manufacturing supply chain's capability and readiness to support CCUS.

The seven High Value Manufacturing Catapult (HVM Catapult) centres, led by the Nuclear AMRC, have collaborated to profile a potential high-growth manufacturing supply chain for solvent-based carbon capture technology. As detailed in the Approach section below, this technology is expected to make up a significant proportion of the future installed base, and therefore represents a reasonable cross-section of spend. Similar work on other established and emerging technologies will be needed to provide a comprehensive outlook.

The output is a summary overview based on fast-track desktop activities undertaken during Q4 2021 using a comprehensive range of in-house tools, processes, research methodologies and techniques. Further evaluation work included desktop-based technical and manufacturing supply chain capability assessments of selected systems from within a generic CCUS project. Information used included mid-decade industrial source information with meaningful levels of definition and valuation projections, at both component and plant level, for pre- and post-combustion plant and pipelines.

The work focused on areas where intervention and supply chain harmonisation activities can be applied to the benefit of the UK, in terms of future sustainable growth and realisable economic value, with a focus on:

- Increasing UK high value employment and GVA.
- Improving competitiveness.
- Reducing cost and risk.
- Increasing UK manufactured content.
- Driving capability and productivity improvements.
- Creating export opportunities.

This report includes recommendations on intervention strategies, along with a more detailed outline of the methodologies applied and the product findings.

There is a substantial and rapidly growing opportunity in the UK and internationally to develop carbon capture facilities. This broad set of technologies will be vital in meeting the UK's net-zero commitments and will offer significant opportunities to the UK's manufacturing supply chains. Relevant and mature capabilities already exist in several industry sectors to support this growth opportunity, and this report focuses on the potential to use tried and tested capability assessment and development techniques developed by the Nuclear AMRC and other HVM Catapult centres.

The effectiveness, efficiency and scale of the UK supply chain for CCUS could be transformed by the ability to create a coordinated map of demand, match it to existing and projected supply chain capabilities, and identify the gaps and interventions required.

The HVM Catapult centres can deliver this improvement by launching a full demand model for UK CCUS developments using their unique combination of manufacturing innovation and supply chain programmes. The recommendations for action focus on this proposal and the progress to be made in 2022.

Context

The UK is getting ready for a significant increase in investment in new, cleaner industrial plant enabled by CCUS.

In line with the Paris Agreement to limit global warming to below 2°C and pursue efforts towards 1.5°C, the UK government aims to cut emissions by 78 per cent (compared with 1990 levels) by 2035, and by 100 per cent by 2050.[1] These objectives were enshrined into law in 2019 in an amendment to the Climate Change Act 2008.[2]

The UK government has set out plans for different economic sectors to meet these goals and play their part in achieving the overall target. For industry, the Industrial Decarbonisation Strategy[3] sets out how CCUS technologies, alongside renewable and nuclear power, can play a significant role in decoupling environmental emissions from economic growth.[4] The government's 2020 ten-point plan for a green industrial revolution committed to deploying CCUS in two industrial clusters by the mid-2020s, aiming for four clusters by 2030, with the goal of capturing up to 20–30 million tonnes of carbon dioxide (MtCO2) a year.[3,5] This strategy aims to invest £1 billion in relevant infrastructure and capture 3 $MtCO_2$ a year by the mid-2020s.

The UK government is also developing business models for industrial and power CCUS, low-carbon hydrogen production and CO_2 transport and storage to support CCUS projects and stimulate private sector investment, with the aim of finalising business models in 2022. The government published a CCUS supply chain roadmap in May 2021, and business models for power and industrial CCUS – the dispatchable power agreement (DPA) and industrial carbon capture (ICC) – in October 2021.[6]

In early 2021, the CCUS Council requested the Carbon Capture and Storage Association (CCSA) produce a preliminary report on the supply chain[7] which provided additional specific context for this study.

Aims and objectives

There is clearly a large multi-billion pound opportunity in CCUS for UK manufacturers to supply these new plants, providing new skilled jobs, driving regional economic regeneration, and increasing GVA. Growth in the same industries in other world economies is also planned, offering export opportunities. It has been estimated that deployment of CCUS and low carbon hydrogen in the Humber region alone has the potential to support a total of up to 33,000 direct jobs and £2.5 billion a year in direct GVA in the period 2024–31.[8]

This project, which seeks to optimise the success of UK businesses in the manufacturing and fabrication sector, is the first phase of a three-phase proposal lasting several years which aims to develop the opportunities presented by CCUS. Collaboration across the HVM Catapult centres has identified the value, gaps and opportunities in the CCUS supply chain, and assessed its readiness levels at component level. HVM Catapult's capabilities, tools, techniques and assets can deliver improvement in the UK manufacturing supply chain capacity and capability across several industrial sectors to realise these opportunities. Supporting the CCUS Council, it focuses on developing the UK supply chain for CCUS enabled projects, making use of the Nuclear AMRC's extensive experience with Fit For Nuclear (F4N) and related supply chain programmes.

HVM Catapult

The High Value Manufacturing Catapult brings together seven manufacturing research centres to help companies accelerate new concepts to commercial reality.[9] These centres have developed a wide range of value-added services to help UK manufacturing businesses compete at a global level.

Led by the Nuclear AMRC, the HVM Catapult centres have collaborated to test, challenge and ensure the use of existing supply chain capabilities and leading-edge practices in future CCUS manufacturing supply chains. The work focused on manufacturer and supply chain development, value chain mapping, capability readiness and resilience assessments, using established methodologies and industry data. Through cross-centre harmonisation and standardisation activities, the HVM Catapult centres will enhance the supply chain and industry value in areas such as supply chain resilience, performance, cost, capability, competitiveness and productivity. This will also improve links to wider HVM Catapult technical and manufacturing R&D capabilities, on a one-stop shop basis. This report and associated research work were self-funded by HVM Catapult and undertaken as part of the effort to achieve national and Catapult goals.

Approach

This report assesses the current capacity and capability building blocks within the UK manufacturing supply chain for CCUS, with future domestic and international economic growth potential in mind.

Due to constraints in time and resources, the report focuses on one characteristic technology within CCUS. The analysis should be extended to other technologies, including new technologies as soon as resources can be deployed. Amine solvent capture technology was assessed as the most prevalent and representative technology in the sector. Currently, nine of the largest CCUS projects in the world use amine-based chemical solvents for carbon capture, with a total annual capacity of around 11 $MtCO_2$.[4] A recent report by BEIS shows the carbon abatement potential of solvent-based carbon capture technologies to be as high as 89 per cent across a variety of industries.[10] It was also identified as the most suitable area for matching UK engineering and manufacturing strengths with credible economic opportunities. Solvent capture technology requires a supply chain mix that is highly representative of carbon capture plant solutions, because of the parallels and synergies with existing oil and gas sector equipment types and corresponding supply chains.

Potential interventions have been identified at the component level, using value–speciality matrices to identify the most significant component classes for action. Future demand mapping areas are also set out for a more comprehensive investigation. Measures to support CCUS supply chains development are recommended, with a business case based on proven capabilities available through the HVM Catapult network.

Findings

Much of the envisaged growth in carbon capture is expected to come through government-assisted project development funding across a range of industrial clusters. Much of the required skills, expertise and industrial capabilities already exist within the UK's oil, gas, petrochemical and other sectors.

The HyNet (North-West England) and East Coast (Teesside and Humber) clusters have been identified for early CCUS deployment – both were prioritised as track 1 projects by government in October 2021, with the Scottish Cluster in reserve.[6] This study has identified around 20 prospective onshore CCUS-enabled projects, costing around £10 billion, which will need to be completed by 2030 to contribute to net-zero targets.

For optimal transitioning and deployment, delivery will need to draw on existing UK-based onshore and offshore energy supply chains. UK manufacturers must be competitive and have the necessary capacities and capabilities to take advantage of this and similar fast-evolving opportunities.

The study shows that there are very few UK value-adding manufacturers capable of producing most of the component groups with both high value impact and high equipment speciality. This was the case for the larger plants considered, but further interrogation and analysis of existing large-scale dockside fabrication facilities is required to establish a clearer position. Findings from further interrogation activities are expected to lead to the establishment of stronger UK engineering, fabrication and modularised assembly capabilities, drawing on existing transferrable skills. An initial capability readiness position has been established by the desktop analysis set out by this report, albeit with limited specification material available.

The HVM Catapult's capabilities are current best practice and cover fundamental supply chain themes, including database management, manufacturing supply chain development and a range of tailored readiness and support tools. Collaboration opportunities with UK academia and industrial partners can also help leverage sector-specific support in manufacturing supply chain development.

This analysis is crucial as current onshore major energy projects in the UK are targeting a UK content of 50–60 per cent. Support based on HVM Catapult's proven supply chain intervention programmes would challenge and increase UK content levels – otherwise, we face half of the estimated project expenditure and content going outside the UK. The EINA study on CCUS[11] credits the UK engineering procurement and construction (EPC) sector (including the offshore industry) with the potential to reap £2.1 billion of annual exports by 2050, and another £2.2 billion annual exports including capture technologies and solvents.

Demand for CCUS

Domestic demand

To form a picture of industry's response to UK targets, a list of prospective carbon capture projects was collated from publications and presentations from clusters and individual companies. High-level estimates of project costs were taken from these or derived from other recent published estimates of similar plant.

The power sector and blue hydrogen production account for 70 per cent of the identified capital spend (c£18 billion) on onshore CCUS-enabled plants to the mid-2030s. To meet targets, over 20 projects (c£10 billion) need to be operational by 2030, with at least 1 power CCUS project by the mid-2020s. The momentum then needs to be sustained into the 2030s and beyond. A focused andeffective approach to supporting UK supply chains could capture a larger portion of the growth opportunity. Thiswould generate domestic jobs and business activities, as well as securing credible UK export opportunities as other countries seek to develop CCUS. Figure 1 tabulates the current ambition and targets for onshore CCUS projects.

	GOVERNMENT AMBITIONS - KEY IN BOLD				ANNOUNCED PROJECTS WHICH MATCH AMBITION
		Mid 2020s	2030	Mid 2030s	
CCUS	**2 Clusters operational**	X			Track 1 anchor projects can meet this target
	3MT/a CO2 storage	X			Track 1 projects could meet this target
	4 clusters capturing 20-30MT/a		X		44MT/a of capture projects identified
	Capture from industrial sector totalling 6MT/a		X		8.5MT/a of industrial capture identified (H2 and PC)
	>50MT/a CO2 mid 2030s			X	(This needs INDUSTRY to start FEED studies soon)
H2	1 GWth H2	X			Could be met by Essar +Teesside or Immingham
	5 GW of H2 by 2030		X		Over 6GW in blue H2 projects identified
	10-17GW of H2 by 2035			X	Target not yet met by Blue H2 projects - NB green H2
GGR	5MT/a Greenhouse Gas Removal (GHG) by 2030		X		Could be met largely by Drax

Figure 1: current ambitions and targets for CCUS deployment in the UK.

Most of the demand for CCUS is expected to be enabled by government initiatives. The UK government has launched a cluster sequencing programme[13] to evaluate and identify industrial clusters for CCUS deployment.

Figure 2 shows the locations and industries within selected clusters across the UK in which carbon capture could be deployed. The East Coast Cluster (Net Zero Teesside plus Zero Carbon Humber) covers most of the site technologies and is the only cluster planning to build all-new offshore trunk pipelines. So far, the Hynet and East Coast clusters have been confirmed as track 1 clusters for the mid-2020s, with Scotland Net Zero as a reserve.[13] Government support to these clusters will depend on value for money, for both the consumer and the taxpayer.

	Delphy	Net Zero Teesside	Scotland Net Zero	S. Wales Industrial Cluster	V Net Zero	Zero Carbon Humber
CEMENT	N	Y	N	P	Y	N	P
CHEMICALS	N	Y	Y	Y	Y	Y	Y
EFW	N	Y	P	P	Y	N	P
FERTILSERS	N	Y	Y	N	N	N	P
GGR	N	N	P	Y	P	N	Y
OIL&GAS	Y	N	N	Y	P	N	N
POWER	Y	Y	Y	Y	Y	Y	Y
REFINERY/BIOFUEL	N	Y	P	Y	Y	Y	Y
STEEL	N	N	N	N	Y	N	P

Figure 2: potential CCUS deployment opportunities in industrial clusters.
Y = project, P = potential project, N = project not found.
Figure shows eligible track 1 clusters plus estimates for South Wales.

Figure 3 maps out the projects identified and characterises them by approximate cost and a time axis, where projects that are anchors in track 1 are on the left-hand side. The bubbles are coloured according to the type of site, and sized in proportion to the maximum capture rate ($MtCO_2/a$). The largest orange bubble is 4 $MtCO_2/a$, and is coincidentally positioned at a time when the government's 20–30 $MtCO_2/a$ target has been met. "1" on a bubble denotes a track 1 cluster and "R" means carbon capture is retrofitted to a running asset. Power projects are relatively mature in terms of engineering scope, respective planning consents and other related approvals.

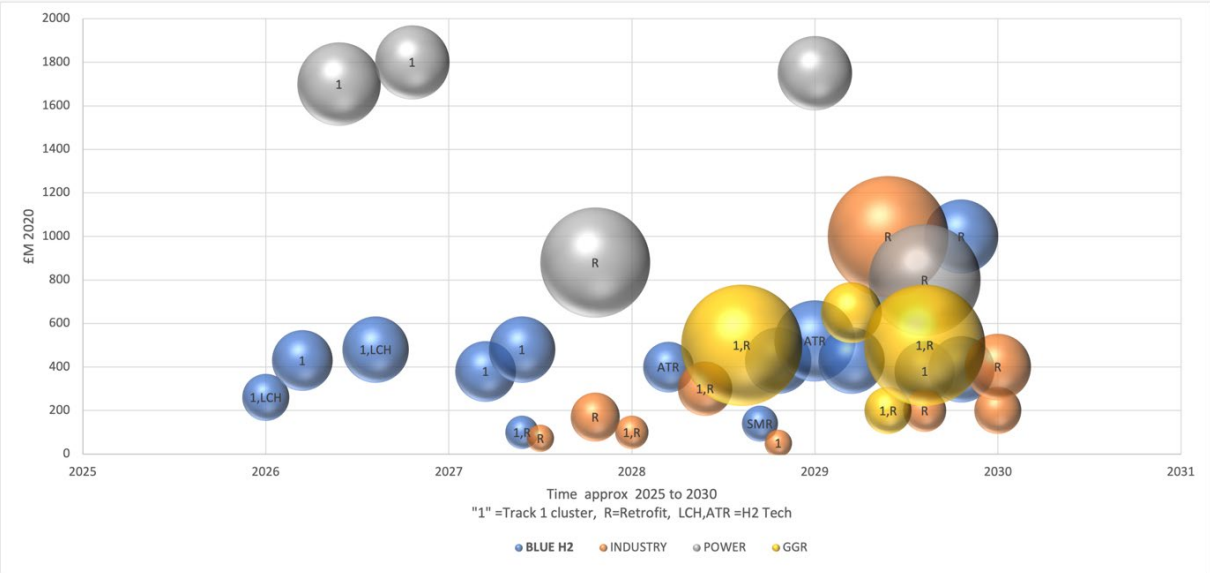

Figure 3: projects for CCUS and blue hydrogen deployment.

Figure 4 highlights the requirement for many projects to be built in quick succession, which is good for the supply chain. It also shows that for decarbonisation purposes, the power sector is important for the supply chain, closely followed by blue hydrogen. Direct capture from industrial streams will come later, and relevant projects are not currently as well defined in the open literature.

Around 85 per cent of total expenditure on the deployment of CCUS and blue hydrogen production is expected to be onshore in power generation, industrial capture, and hydrogen production plants. Studies and engineering design and cost exercises make up about 10 per cent, and engineering contracting about 13 per cent of the entire onshore spend.

International demand

Estimates of the entire global market for strict CCUS (not including power or blue hydrogen) are only around $1.9 billion in 2020.[15] However, this is expected to grow extremely rapidly to meet global decarbonisation targets. The IEA roadmap calls for storage rates to rise from 40 $MtCO_2$ today to 4,000 $MtCO_2$ in 2035, and 7,600 $MtCO_2$ in 2050. This would require an annual capital spend of around $200 billion by the 2030s.

Following a lull in construction for several years, recent national policies have initiated a rapid increase in CCUS projects. The pipeline of projects grew by approximately 50 per cent in the nine months to September 2020 alone,[16] and more have been announced since then. About half these projects were in the US, with many of these incentivised by the Californian Low Carbon Fuel Standard (favouring ethanol with CCS) and the 45Q tax incentive for carbon capture in the US Energy Act 2020. This has allowed capture from bioethanol plants, which is relatively cheap. In addition to ethanol projects, the US and Canada continue with CCUS projects in power and fuel supply. Around 20 per cent of the recently added projects in the US are blue hydrogen projects, representing a potential licensing and sales opportunity for new hydrogen technologies being developed in the UK.

A greater opportunity for the UK supply chain may be the EU, where net zero emissions by 2050 is also a legally binding target, with a commitment to a 55 per cent reduction by 2030. The carbon price under the EU Emissions Trading System is, as of February 2022, close to €100 per tonne of CO_2. The scheme is designed to gradually increase prices by restricting the supply of certificates, with a target of around €110 per tonne which would drive a sustainable CCUS market.[17] A revised EU Innovation Fund mechanism has begun for projects covering the front-end engineering design, construction and operational phases. Norway has been practising industrial scale CCUS for 25 years, and is leading the charge in Europe through its Langskip project, which is already under construction. Langskip is expected to be followed in the near term by the Porthos project in the Netherlands. The EU estimate is that approximately €11 billion will be spent on retrofitting half of all grey hydrogen plants with CCS by 2030.[17] This again offers an opportunity for the UK supply chain.

Other markets such as the Gulf states have already initiated several large CCUS investments in a variety of industries, and have a projected market of c60 $MtCO_2$/a by 2035. Over half the large point sources emissions in the Gulf Cooperation Council States are from gas fired power generation (280 $MtCO_2$/a). Industry, including the oil & gas sector, emits over 100 $MtCO_2$/a and could supply CO_2 to enhanced oil recovery projects.[16]

Demand for solvent-based carbon capture

Initial research[7,18,19] has established that solvent-based capture processes could potentially be an area of focus for UK carbon capture development support. This has provided a representative and translatable view of specific components and equipment, which can enable more practical recommendations. Details regarding plant area, commodity type, component description information and material specification were captured along with cost data. Based on feed studies[18] and consultation with CCUS expert advisors, the key supply chain components for solvent-based carbon capture in the UK were segmented in two-by-two matrices based on value and speciality. These are shown for pre- and post-combustion carbon capture using amine solvents in Figures 4 and 5.

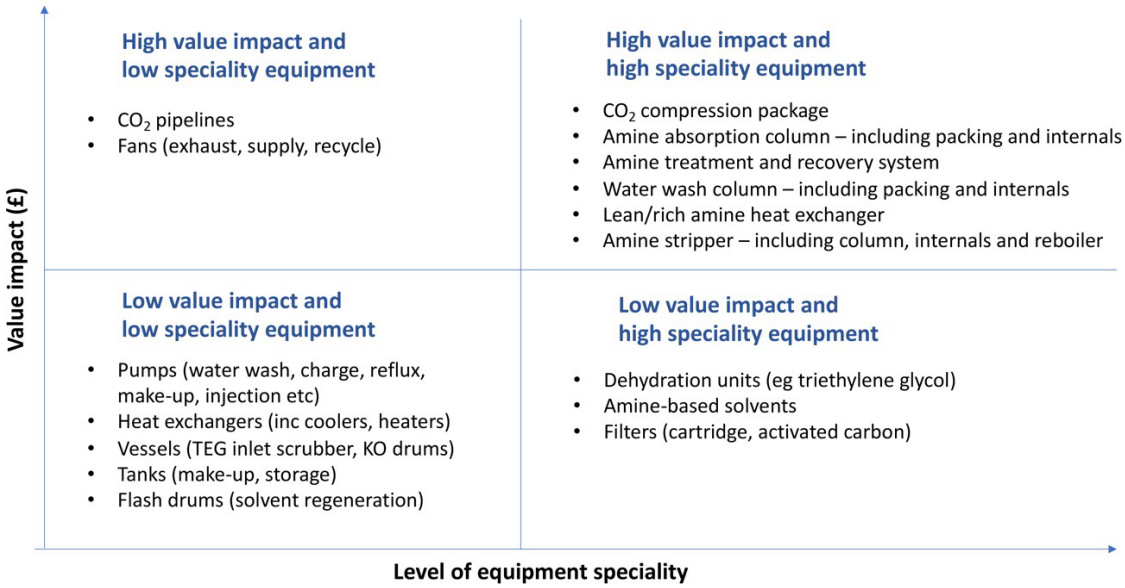

Figure 4: high value matrix for key components in pre-combustion solvent-based carbon capture.

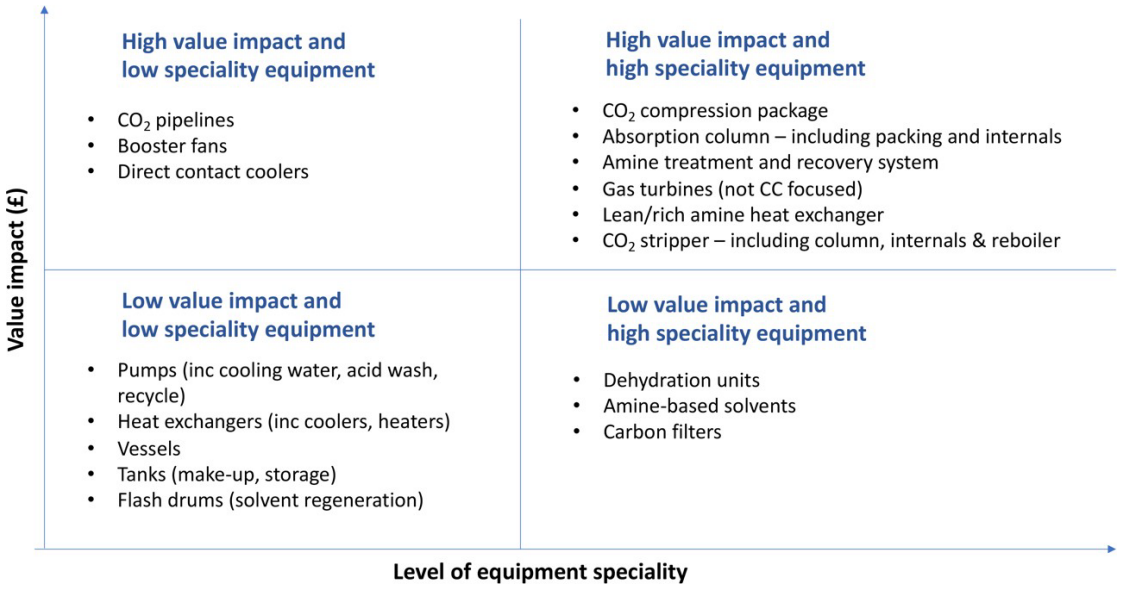

Figure 5: high value matrix for key components in post-combustion solvent-based carbon capture.

UK supply chain readiness

Methodology

HVM Catapult analysed the UK's current supply chain capabilities to determine the current supply chain readiness for carbon capture, based on high-level plant analysis work.

Supply chain mapping focused on post-combustion solutions, prioritising the component groups with high value impact. This work included the creation of a database detailing available and potentially capable UK engineering manufacturers for each component group. Selected specifications were used to assess the supply chain readiness of the identified manufacturers using an established traffic-light assessment. This methodology is widely used by the HVM Catapult and can be tailored to suit specific project and industry requirements. The criteria used for the traffic light system are shown in Figure 6.

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

Figure 6: traffic light methodology used to perform the supply chain analysis

Analysis

This approach was used to analyse the supply chain readiness of the key components from the high value impact component groups. This included manufacturers of pumps and heat exchangers based on bills of material and component schedules. Pump commodities were also included due to their wide and varied potential volume-based applications within CCUS systems in general, along with other fluid-control category equipment. A general heat exchangers category was included, as it is likely that a highly developed general heat exchanger supply chain would be able to reduce any potential shortfall in specific heat exchanger types (gas-gas or crossover) The results are summarised in Figure 7.

The carbon capture supply chain appears to have the credible potential to be further developed within the UK. There are several components and equipment types with well-developed supply chains, supported by engineering manufacturers that possess strong capabilities and experience. Manufacturers of these components may require additional investment support – however, any investment is likely to be minimal.

There are also several components for which the supply chain is underdeveloped at present. This will provide an opportunity for investment which would have a significant impact on the development of UK engineering and manufacturing, potentially including export-supporting capabilities. No elements of the supply chain were identified as severely lacking in relevant knowledge, experience, or capability, although further work is recommended to clarify the current state of CO_2 pipeline manufacturing within the UK.

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

Figure 7: summary of supply chain readiness by component type

The locations of each identified manufacturer have been mapped to show their distribution across the UK, as shown in Figure 8. This should help to identify which regions of the UK already contain capabilities relevant to the carbon capture supply chain, and which regions need greater development.

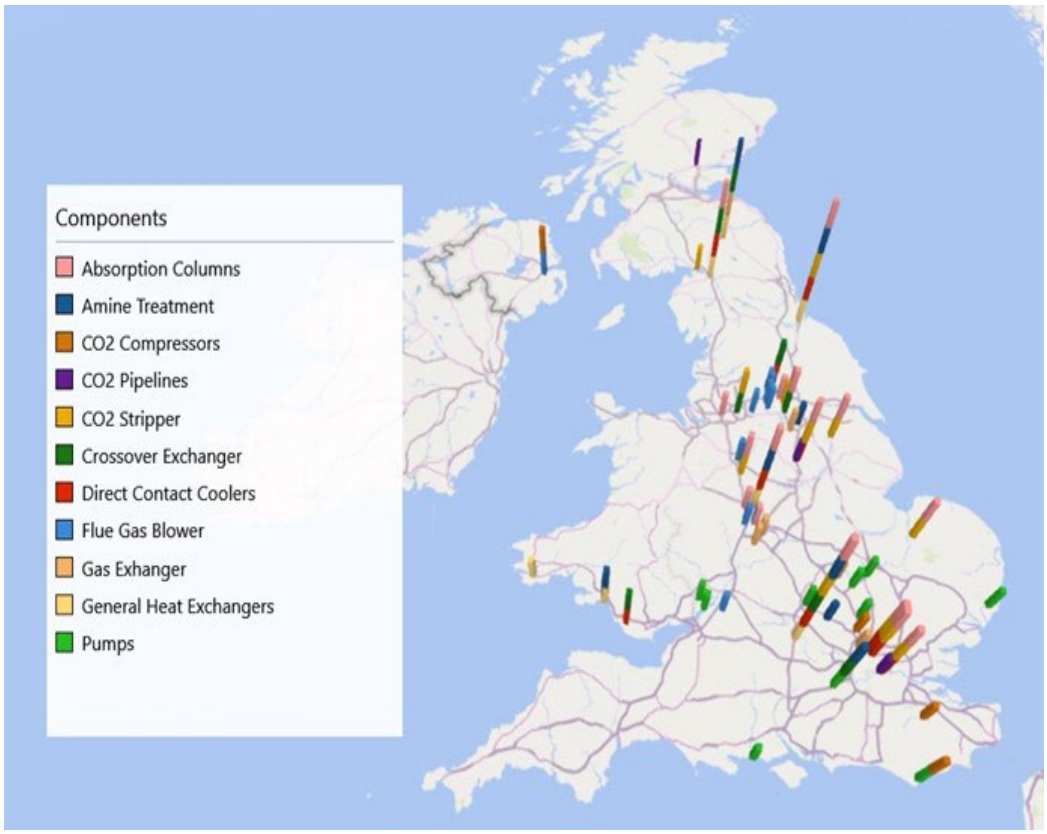

Figure 8: locations of possible carbon capture equipment manufacturers by component type.

Interventions at equipment level

This section outlines recommended interventions to increase UK manufactured content in several component areas for solvent-based carbon capture.

A recent report on the potential of CCUS technologies[19] noted that progress would be hampered unless fundamental issues including costs, regulatory incentives and technological innovation are addressed. This intervention-based observation is endorsed by the HVM Catapult, and this report focuses on the economic and technical elements to identify solvent-based carbon capture technologies as a potential area for manufacturing R&D in the UK.

Despite the well-developed supply chain for many CCUS components, several gaps in supply chain readiness were identified. This included many components falling into the amber classification, as shown in Figure 7 above. Several recommendations are presented below to drive further development of UK supply chains for each component type through direct interventions. These recommendations have a strong focus on maximising productivity, optimising production, minimising costs and mitigating project risks for future CCUS plants in the UK.

Most interventions will require cross sector support and collaboration between key industry developers, EPC contractor organisations and relevant government departments. This would include support enterprises such as the HVMC and partners. Such an approach can be used to establish a combined CCSA and UK CCUS industry, supplier and manufacturing supply chain enabling service, with direct support from the HVMC. All required funding streams would be expected to be facilitated by international development organisations such as sector Primes, large international organisations and sector trade organisations that have the impact and resources to set sector strategy, funding and development globally.

Throughout this report, reference has been made to both capacity and capability assessment activities. Initial supply chain assessment work has been desk-based, without direct organisation verification. Capacity considerations would require more detailed and in-depth assessment activity to establish gaps, including direct supply chain dialogue and confirmation of specific scopes. These efforts would be project-specific and would need to be aligned with programme timelines to be informative and credible.

The solvent-based carbon capture supply chain analysis focused on the availability of components for solvent-based carbon capture technology and identified components for large-scale plants. The interventions and recommendations below are based only on the sample of prioritised components selected, and the scope of the recommendations may not be applicable to a wider range of CCUS approaches. Many of the amber companies identified may be more capable if a smaller plant is required.

CO_2 compressors

Few international manufacturers currently produce equipment at the high end of the scale required, resulting in a gap in the UK supply chain. The companies with facilities in the UK have many of their operations based abroad. To address the gap, opportunities may exist in the following areas:

- The UK could take the lead in producing large transportable modules, using multiple manufacturers in the UK in a close-knit designer-fabricator-manufacturer ecosystem. This is only possible if gaps are filled in areas such as the sourcing or manufacture of bespoke impellers and casings.
- The UK could focus on expanding the capabilities of internal centrifugal pump manufacturers, pivoting their capabilities toward centrifugal compressors.

Absorption columns

Based on the specifications provided, the estimated size for the largest absorption columns is too large to be produced by UK manufacturers of steel pressure vessels. The largest columns may not be transportable and could potentially be fabricated on site by a UK fabricator.

- UK off-site fabrication shops could support production for average or smaller plants and pressurised capture with a maximum size of 6 metres by using existing manufacturers of steel pressure vessels.
- UK capabilities can be expanded by using the UK construction sector to adopt techniques such as slip forming. The UK can work to develop solutions for larger plants using concrete towers instead of steel pressure vessels.

Amine treatment

Capability currently exists in the UK to produce tanks and vessels, with a variety of different alloys available. Reboilers are very similar to shell and tube heat exchangers, and the high maturity of the shell and tube heat exchanger supply chain suggests that there is potential for future growth into the carbon capture sector.

- Minimal investment may be required o develop the CCUS supply chain, but discussion and consultation with existing manufacturers is needed to assess potential.

CO_2 pipelines

Although capabilities are not necessarily in place, a small number of companies are starting to establish a level of relevant experience by participating in CCUS projects. Currently, CO_2 pipes are sourced from outside the UK.

- Further work is required to assess current manufacturing capabilities for the UK supply chain.

Flue gas blower

Many industrial fan manufacturers in the UK are capable of producing flue gas blowers, with a wide range of sizes available. This provides a good opportunity for the development of smaller plants. Manufacturers producing components of the required size for large carbon capture plants are currently lacking.

- Further examination of and interaction with UK manufacturers is needed to establish if specifications can be met for larger units by the existing supply chain.
- A more detailed analysis would reveal how the existing supply chain can support carbon capture.

Direct contact coolers

The towers needed by direct contact coolers are similar to those needed for absorption columns.

- Further work should engage UK construction companies to determine how they can participate in developing the CCUS supply chain for this component.

CO_2 stripper columns

Existing manufacturers should be able to produce these components, as the geometric requirements do not fall too far outside the upper size limit of current production capabilities.

- Additional research is needed to determine whether improving readiness is possible with a minimal investment into equipment and factory space, or if there are significant constraints that would necessitate more substantial investments.

Pumps

These components fall into the low value and low speciality category. The supply chain is well-established in the UK, and current manufacturers can supply for CCUS with minimal investment.

Heat exchangers

These generally fall into the low value and low speciality category. The UK has a well-developed manufacturing base for industrial heat exchangers, mainly for the oil and gas market. The scale and range of the parts being produced demonstrates the capability of the current supply chain to work on new or different exchanger types.

There are several high value and high speciality component types that fall under the broad category of heat exchangers:.

- Gas-gas exchangers (CCGT specific solution) – several gas-gas exchanger manufacturers have been identified as working across a variety of sectors. A few of these manufacturers currently offer customised solutions, using in-house design and manufacturing capabilities and relevant heat exchanger experience. These companies are potentially able to manufacture gas-gas exchangers for carbon capture if investment is made to increase their manufacturing capabilities.
- Crossover exchangers – existing heat exchanger manufacturers can manufacture these components. However, it may be necessary to invest in developing the manufacturing capabilities of these companies as a clearer view of future CCUS system specifications is developed.

Business case

This section summarises the high-level business case and detailed benefits from the proposed supply chain interventions and information management.

This exercise estimated the spend on onshore CCUS enabled projects to meet targets in the early 2030s to be around £18 billion. This comprises around 30 projects, many of which are very similar in terms of technology. These are ripe for developing profitable supply chains which would last for decades and, in several cases, have export potential. Much of this cost is equipment manufactured and fabricated off-site – in the published cost estimates used to underpin the work, purchased equipment made up 30 per cent of the entire capture plant cost. In published estimates for a power plant complete with a new CO2 pipeline and store, the equipment is also over 30 per cent of the project cost. Installed piping was the highest single line item in this estimate.

Supply chain management is used to improve competitiveness, which manufacturing UK companies will need if they are to secure a share of the anticipated project expenditure and provide skilled jobs. Current onshore major energy projects in the UK are targeting a 50–60 per cent UK content, but much of this is project development and construction costs, suggesting the scope to increase UK manufacturing participation is very high. Many of these jobs could be generated in regions targeted for economic development.

At sector level, reports reviewed in the study[8] quoted an average 120,000 annual jobs (direct, indirect and induced) and £8 billion a year GVA for the UK CCUS and blue hydrogen sector over 2024–31.

Commercial activity has already started for several CCUS projects, with track 1 cluster projects scheduled to be running by the mid-2020s. This means the need to support the supply chain is urgent.

Supply chain intervention and development

The CCUS sector is new and evolving. UK manufacturing supply chains already exist in several sectors, including oil & gas, energy, refining and chemical processing, which could match the needs of the CCUS sector.

To maximise the value for the UK supply chain, the creation of a strategic supply chain development programme based on the Nuclear AMRC's proven Fit For Nuclear (F4N) programme is strongly recommended. This would strategically develop existing manufacturing businesses to match to CCUS sector requirements.

Launched in 2011, F4N lets companies measure their operations against the standards required to supply the nuclear industry and take the necessary steps to close any gaps in six key categories of business operation and performance. F4OR is a journey of business improvement and targeted capability building, typically taking 12–18 months from initial assessment to granting.

Around 120 companies are currently granted F4N after putting their action plan into practice, ranging from contract manufacturers with no nuclear experience aiming to enter the sector, to established suppliers wanting to benchmark their position and drive business excellence. To date, participating companies have reported that the F4N programme has helped them win over £1.4 billion worth of new contracts in nuclear and other sectors.

The Nuclear AMRC has worked with the Offshore Renewable Energy Catapult to adapt the F4N programme to the requirements of the offshore wind sector. The Fit For Offshore Renewables (F4OR) programme was piloted on a regional basis in key locations for the sector, with the first national programme launched in early 2022.

A Fit For CCUS (F4CCUS) programme can easily be set up, with support from an industry-led working group to develop the sector-specific elements and funding streams.

F4CCUS
Fit For Carbon Capture, Usage & Storage

Supply chain information management

Supplier and manufacturing supply chain information management is a key enabler for Industry 4.0 practices and technologies. This is a particular area of strength for HVM Catapult, representing a fundamental differentiator in terms of market contribution, impact and return. HVM Catapult can support CCUS equipment manufacturers with leading-edge industrial technical expertise and value in relevant information management. This includes a range of products, processes, and essential associated business services that can be further enhanced to meet CCUS project requirements. Interventions can include:

- How best practices and processes can be harmonised, standardised and or re-structured.
- How these practices and processes can be applied to a CCUS project as a pilot, to identify potential interventions that align with the CCSA report and the wider industry stakeholder base.

Interventions would also be geared towards development activities for indigenous manufacturing supply chain capabilities, acting as enablers for strengthening the emerging new product introduction characteristics for CCUS projects within the UK. These are set out below and summarised in Figure 9.

Database management

Many different engineering and manufacturing capability databases exist across a variety of organisations supporting or within the solvent based CCUS supply chain. Variations exist in terms of data characteristics, quality, integrity, and key details captured. Each has viability, maintenance and other support needs, with duplication which could be reduced. An intervention focusing on open-access information management presents a real opportunity for future CCUS infrastructure and industrial project campaigns. This will improve information integrity and quality, and end-user responsiveness. Value can be gained from efficiency in one fully comprehensive and easily accessed system for end users, which will benefit from an open architecture with multi-sector application and usage characteristics. Such an information management database toolset will close existing capability and capacity knowledge gaps, especially at localised and regional levels, while also driving Industry 4.0 developments on parallel growth programmes. This is an important recommendation, based on HVM Catapult infrastructure programme experiences during the last decade.

Information and data management is a core research skill, capability, and strength within the HVM Catapult network. This includes open-access capability intelligence tools and databases with search option functionalities. Other search capabilities would allow for component or product searches, including multi-sector, and other regional or company specific attributes. Further capability enhancements could also be delivered through development of open-access database offerings such as the Nuclear AMRC's F4N Connect portal. Developing this for CCUS market applications would be a logical and configurable tool extension, achievable during the first half of 2022 with full industry and developer organisation support.

Manufacturing supply and value chain mapping

There is growing market interest in industry-level supply and value chain mapping capabilities, especially across the low carbon and clean energy sectors. Development of a best-in-class standardised approach to supply and value chain mapping, for multi-programme applications and on a shared and or open access basis, is recommended. This would require facilitated support and input from developer and leading contractor organisations, including management teams associated with front-end engineering design.

Adoption of methodologies and standards for detailed analysis-based activities is also recommended and would include enhanced baseline supply chain readiness level (SCRL) assessment, a capability which is already widely used within the HVM Catapult network by external client organisations.

Supply chain readiness levels

From experience across a wide range of technology development programmes, including infrastructure and industry-specific initiatives, supply chain capability readiness level (SCRL) assessments can deliver a significant increase in value.

As with supplier development work, SCRL assessment activities employ a disciplined and structured working approach, underpinned by robust architectural and repeatability characteristics. SCRL activities depend on input information which is generally at a work breakdown level in terms of structure and detail and can be undertaken at strategic supply chain cluster levels or component definition levels. In all cases, defined methodologies are used alongside toolsets which provide reportable outputs including knowledge and readiness level gap identification, leading to intervention-based action planning. HVM Catapult is experienced in SCRL and is seeing increased demand for this type of assessment and resulting interventions such as the Fit For programmes.

This report has outlined the SCRL for potential CCUS market needs, at the system level and by component type. The analysis used to complete the CCUS provision assessment has been completed using sample bill of material and schedule data, on a sector and product-specific basis. Even with a relatively small cross section of components assessed, the findings are consistent with expectations. Recommendations include that SCRL activities should be developed further and more widely for a larger cross-sector of other CCUS products, systems, and equipment fabrication types. This recommendation includes further expansion considerations through to sub-component or original material manufacturing levels. The colour-coded assessment process summarised in Figure 7 shows where development efforts should be focused.

Other HVM Catapult contributory attributes and offerings

The HVM Catapult network has well-established foundations and credentials within leading UK University structures, and it can draw on and access a wide cross-section of industry valued industry assessment and other research-based capabilities. This report has included references to other areas of support available, for example resilience, environmental, modelling and simulation, (cost), alongside innovation-inspired engineering and manufacturing research and development. These offerings are complementary activities for supplier, engineering and manufacturing supply chain interventions, and can add client specific value, on a project-by-project basis.

Summary

The combined outcomes of the offerings described are:

- Increased UK content at primary and or sub-component levels on infrastructure programmes, resulting in increased direct and indirect jobs.
- Increased market and landscape awareness and readiness credentials on the part of the UK SME manufacturing supply chain.
- Enhanced UK domestic capability definitions, geared to Industry 4.0 practices, which can be better aligned to match evolving programme timescales.
- Improved time to market in terms of matching and capability data and knowledge.
- Improved competitiveness, productivity levels, capability and cost outcomes, positioning UK manufacturing companies to drive exports.

These benefits are not exhaustive but provide insight into opportunities to deliver multiple carbon capture projects during the current decade and beyond. Figure 10 presents a summary table of interventions.

Intervention Theme	Attribute	Ownership & Leader	Facilitator	HVMC Intervention Support
Prequalification (sourcing) campaign, including potential supplier selection(s)	UK content enhancements	Developer and or EPC	Trade Organisation CCSA)	Funded campaign support activities
Procurement strategy guidance	UK competitiveness	Developer and or EPC	Trade Organisation CCSA)	Funded advisory support (panel) activities
Supply chain databases/portals - Industry 4.0	UK capabilities and capacities - content	Developer and or EPC		Funded development activity and rolling upkeep programme
Supplier development programme - (F4CCUS)	UK capability and productivity readiness	Developer and or EPC	Trade Organisation CCSA)	Funded supplier focused development activity and rolling F4CCUS delivery programme
Supply chain capability readiness assessment - (SCRA)	UK capability readiness	Developer and or EPC	Trade Organisation CCSA)	Funded, supply chain focused development and project specific SCRL
Supply chain capability readiness level (SCRL)		Developer and or EPC	Trade Organisation CCSA)	Funded supply chain capability matching to WBS component level inventory/BoMs)
Resilience assessment	UK capability stability	Developer and or EPC		Funded supplier and or supply chain resilience assessment
Opportunity matching (tier 3-4) portal	UK capabilities and capacities - content	Developer and or EPC		Funded buyer to supplier opportunity connection/matching portal
Engineering and manufacturing innovation	UK competitiveness	Developer and or EPC		Funded developer and or supplier specific innovation and process/technology improvement activities
Modularisation development	UK competitiveness	Developer and or EPC		Funded developer and or supplier specific innovation and process/technology improvement activities
Product design and engineering for manufacture	UK competitiveness	Developer and or EPC		Funded developer and or supplier specific innovation and process/technology improvement activities
Localisation analysis	UK capabilities and capacities	Developer and or EPC		Funded localisation impact and benefits analysis
Directed supply chain research	Outcome specific	Developer and or EPC		Funded directed project specific industrial and or academic research activities
Landscape familiarisation and readiness	UK landscape knowledge - content	Developer and or EPC		Funded event and or CCUS specific landscape orientation activities

Figure 9: HVM Catapult capability and support offerings to CCUS.

Next steps

The proposed next steps will focus further analysis and research work on the key areas detailed below. The time plan in Figure 10 demonstrates the urgency for action.

	Plan	When
1	Acceptance of report and recommendations	March 22
2	Creation of specific working groups for each intervention	April 22
3	Create detailed plan for each intervention in CCUS	May – August 22
4	Initiate delivery of each plan	September 22
5	Delivery of quick wins	End 22 / early 23

Figure 10: time plan for each key area.

Assessing key components for carbon capture

It is recommended that further work is undertaken to establish the anticipated unit sizes for the pipeline of UK CCUS projects, as the currently established component specifications are based on historic projects. This could be used to approximate the potential demand for individual components to meet UK requirements. This task is twofold: creating a baseline component specification that encompasses the potential UK pipeline project equipment requirements; and using these reference specifications to estimate the number of each unit required, to demonstrate manufacturing demand for both labour and components.

The implementation of carbon capture technologies could also be streamlined by forecasting the quantity of material and equipment required, and preparing a supply chain base to meet it.

Developing the CCUS supply chain for UK manufacturing supply

To develop the UK manufacturing supply chain for CCUS, certain specific strategic interventions are required to grow capacity, capability and competency. This report highlights specific products and components that require high level interventions. A F4CCUS programme will work strategically across the sector at a business improvement level. SCRL assessments will be used to develop a sector manufacturing strategy. The HVM Catapult has the skills and experience to deliver these interventions.

Further investigation into various carbon capture technologies

While only solvent-based pre- and post-combustion capture systems were considered in this report, multiple other carbon capture technologies could be used or developed as part of the UK decarbonisation process. Following this report, a further investigation into alternative technologies and their associated equipment should be completed.

By considering various carbon capture technologies, a greater impact can be made on the UK decarbonisation process through the broadening of CCUS-compatible industries and matching them to the most applicable carbon capture methods. Through utilising multiple technologies across a range of sectors, competition can be reduced within industry to procure components specific to a given carbon capture technology.

Investigation into blue hydrogen and associated carbon capture techniques

This report has considered carbon capture from a hydrogen production process. This may be considered to satisfy the term 'blue hydrogen' (as it involves the removal of CO_2 during hydrogen production), but does not meet the most accepted definition of blue hydrogen in full (which involves steam methane or autothermal reforming of natural gas). Due to the growing interest in blue hydrogen, it is recommended that further research should be conducted into the components for defined blue hydrogen facilities.

Blue hydrogen generation may become increasingly important over the next decade. Understanding the most efficient carbon capture technology for this developing sector could be essential to fulfil anticipated future project demands.

UK pipeline specification

Transport of captured CO_2 will be essential, and pipeline availability is critical to all carbon capture and storage projects in the UK. A potential specification for the UK pipeline to the Endurance reservoir in the North Sea was approximated for this report. As the specification was created from multiple theoretical reference cases, further research into the pipeline would be required to define the necessary material requirements and coatings with more certainty. Further clarification is needed on whether the UK pipeline projects intend to transfer the captured carbon dioxide as a gas, liquid or supercritical fluid, as this will also influence the pipe material and coating selection.

In one of the published reference cases used by this exercise (a Teesside power plant with CCUS and new offshore CO_2 store) about 18 per cent of the project build cost was pipelines. If the CO_2 capture plant is considered in isolation, about 8 per cent of the build cost was pipelines.

It is critical for the development of pipeline carbon capture networks that the physical properties of the transported CO_2 are defined, as parameters such as the level of impurities, temperatures and pressures may impact pipeline design.

Storage and use of carbon dioxide

The current research has only briefly touched on the storage of CO_2, and not in the level of detail required for development of a supply chain structure. Usage of CO_2 is not covered within the current report. Further research is required to investigate the storage requirements of CO_2 from a component perspective, and the new and existing usage technologies and processes across UK manufacturing industries. The anticipated storage and usage requirements could help identify the number and requirement of key components for transportation, usage and storage between UK locations and the Endurance reservoir.

Research into further reference data for carbon capture

Data for this project have been primarily drawn from two references cases: the example post-combustion capture plant, and the Quest carbon capture facility. The design of these plants has been influenced by their size, application and required carbon capture efficiency and capacity. Variability of these requirements, and additional factors such as incorporation of recycle streams, could change the equipment and component sizes. As variability of the anticipated unit sizes will potentially affect the supply chain infrastructure, additional research specific to the pipeline UK projects is recommended.

Process improvements by HVM Catapult

HVM Catapult's offerings in manufacturing innovation and supply chain development form a unique through-cycle industry service, which can be used to develop new production processes for the manufacture of required CCUS equipment. They can also reduce current cycle time to improve efficiency and improve UK supply competitiveness and capabilities. Further work could address enhanced quality assurance and inspection performance standards, reduction in manufacturing and sub-component process costs, modularisation and factory build enhancements, and enhanced and continuing safety improvements at product and industry levels.

Supporting net-zero supply chains through life cycle assessments

Life cycle assessments (LCAs) with direct links to net zero targets and other environmental or sustainability topics, at industry or specific organisation levels, can help demonstrate sustainability throughout the CCUS supply chains. Institutions such as the University of Sheffield Management School can assist this undertaking through consultative collaborations with manufacturers and solution providers in the value chain.

Creation of a national facility

A national facility or hub for CCUS supply chain interventions, coordinated by HVM Catapult, could manage a range of programmes and help align a potential critical mass of CCUS supply chain organisations from across the UK. This should be located in a region with active CCUS activities and capabilities. All CCUS clusters would continuously assess their supply chain readiness and resilience with the CCUS supply chain interventions programme through the national hub. The capabilities for understanding supply chain readiness, resilience, assessment and management should be evidence-based, using HVM Catapult tools and techniques such as SCRL assessments and a Fit For CCUS supplier development programme.

Leveraging R&D collaboration opportunities

Future recommended work could include industry-academia collaborations to Increase UK supply chain content and productivity levels. The new Translational Energy Research Centre (TERC) at the University of Sheffield is a multi-technology, integrated platform for CCUS research, development and innovation co-funded by ERDF and BEIS. Specialised and state-of-the-art post-combustion CO_2 capture plants at TERC are fully integrated with upstream and downstream processes to demonstrate integrated operation of technologies at pilot scale. These include capture technologies from a variety of fuels (upstream combustion, with a focus on biomass/biowaste fuels and demonstrating net negative emissions potentials), and the manufacturing of sustainable jet fuel (downstream utilisation of the captured CO_2). There is a strategic emphasis on post-combustion carbon capture and the development of next-generation solvents and processes, incorporating process integration, intensification, and efficiency improvements.

The experimental data and other research outputs from TERC can be passed on to other research teams in the University of Sheffield Energy Institute to aid development of techno-economic analyses, feasibility studies, supply chain evaluations, environmental impact assessments, full life cycle analyses of comparative CO_2 capture options, and integrated systems process modelling and validation.

Closing remarks

The impact of climate change, energy transitioning and rapidly evolving technological developments has created new business opportunities in CCUS.[20] This report has set out several interventions and recommendations to develop the UK manufacturing supply chain to realise these opportunities, to generate jobs and contribute to the economic regeneration of the UK's industrial regions.

The HVM Catapult possesses the capabilities, tools, techniques and assets required to map the CCUS manufacturing supply chain, to analyse gaps and areas for development, and to match the supply chain capabilities with the recommended analysis to assess the overall demand for plants and components in the UK and internationally.

A business case has been presented to leverage opportunities for using HVM Catapult methodology harmonisation and structural standardisation techniques across the supply chains. This has focused on a portfolio of information management and supply chain development tools, all at a potentially differentiating level within this evolving sector.

While there are other prevailing conditions impacting both national and global markets, this report has focused on platform creation, driving differentiators for change relating to engineering manufactured content and growth. Factors considered include those impacting future UK manufactured supply chain market knowledge, cost competitiveness, productivity and capability readiness, all fundamental to an Industry 4.0 economy.

As a result, this work has identified a wide range of opportunity-based manufacturing sector development needs. HVM Catapult can deliver manufacturing techniques and innovation, supply chain development programmes and enable the integration of multiple supply chains across sectors to drive cost and productivity improvements, using existing HVM Catapult capabilities.

In summary, the recommendations for specific interventions during 2022 to develop the manufacturing supply chain for CCUS are:

- Strategic sector engagement to develop close working relationships with CCUS developers and main manufacturing contracting organisations. This will support new product introduction and supply chain readiness activities associated with UK manufactured content.
- Assisting and advising effective demand-based supply chain engagement and associated procurement strategies in the manufacturing sector.
- Identification of wider CCUS plant, system and component requirements to enable more comprehensive readiness assessments of UK manufacturing supply chain capability and capacity.
- In-depth assessment of HVM Catapult supplier and supply chain development tools, creating a one-stop shop for industry support. This includes CCUS-focused supplier development activities through the proposed Fit For CCUS programme and SCRL assessment.
- Deployment of standardised approaches and capability tool sets for information intelligence management, already available through HVM Catapult and partner networks.

Across all these intervention themes and activities, HVM Catapult advisory support will be focused on UK engineering manufacturing organisations responsible for material, equipment, component, fabrication and modularisation supply. Industry support offerings available for development through the HVM Catapult network are summarised in Figure 11.

Given the highly credible CCUS opportunity potential, HVM Catapult will, with external endorsement and support, be able to bring an unparalleled impetus to the UK's objectives for decarbonisation and long-term sustainable growth. This will impact domestic manufacturing for the UK, and supply chain capability readiness for export programmes. The interventions will draw extensively on the unique combination of HVM Catapult's high-calibre manufacturing supply chain market offerings, and world-class engineering and manufacturing research innovation and development facilities.

The fast-track study leading to this summary report represents a practical, focused, timely and pragmatically comprehensive assessment, which can be considered for potential benchmarking, monitoring and evaluation purposes.

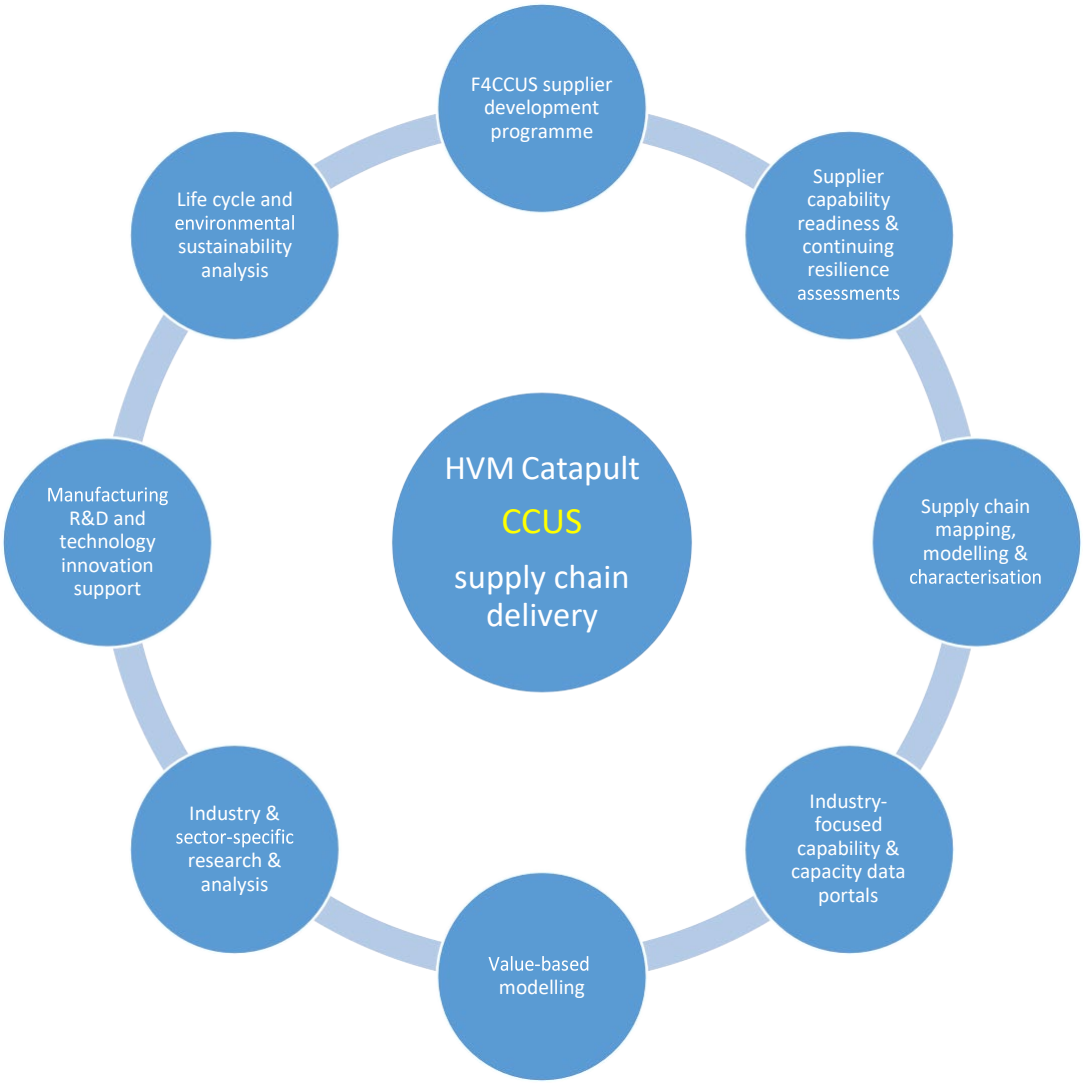

Figure 11: overview of HVM Catapult supply chain offerings.

Glossary

Blue hydrogen	Hydrogen produced by reforming light hydrocarbons, incorporating capture and sequestration (or utilisation) of the carbon in the hydrocarbon as carbon dioxide.
CCUS	Carbon capture, usage and storage is the collective name for technologies which capture carbon dioxide (CO_2) from industrial plant or air, convert it into a useful product, or provide transport and safe permanent storage for it.
CCSA	The Carbon Capture and Storage Association is the UK-based trade association promoting the commercial deployment of CCUS.
EPC	Engineering, procurement and construction contracts are a form of turnkey contract used for the building of industrial plant and infrastructure projects. Organisations which carry out such work are termed EPC contractors.
F4N	Fit For Nuclear is a service provided by the Nuclear AMRC (part of HVM Catapult) to help UK manufacturing companies get ready to win work in the nuclear supply chain. The programme has been adapted for other sectors, for example Fit For Offshore Renewables (F4OR).
GVA	Gross value added is an economic productivity metric that measures the contribution of a company, region or sector to an economy.
HVM Catapult	The High Value Manufacturing Catapult is an organisation established by Innovate UK to help businesses by providing access to world-class research and development facilities and expertise that would otherwise be out of their reach. It brings together seven specialist technology and innovation centres around the UK.
Industry 4.0	Industry 4.0 (aka the Fourth Industrial Revolution) refers to a variety of emerging manufacturing technologies based on digitalisation, automation and embedded connectivity.
Post-combustion capture	A technology where CO_2 is captured from a flue gas (or other) stream created by combustion of a carbon-containing fuel.
Pre-combustion capture	A technology where carbon is captured from a fuel before its combustion, commonly leaving hydrogen as the main constituent of the decarbonised fuel.
SCRL	Supply chain readiness level assessments are a collection of tools which score the UK's ability to industrialise innovation and supply manufactured products.

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Appendix A: Acknowledgements

This report was put together with help from a number of sector experts from the following organisations and individuals:

Jay Shaw

Kevin Shepherd

Anna Boland

Charanjeet Singh

Katie Richardson

Alex Smith

Benoit Fernandez

Victor Guang Shi

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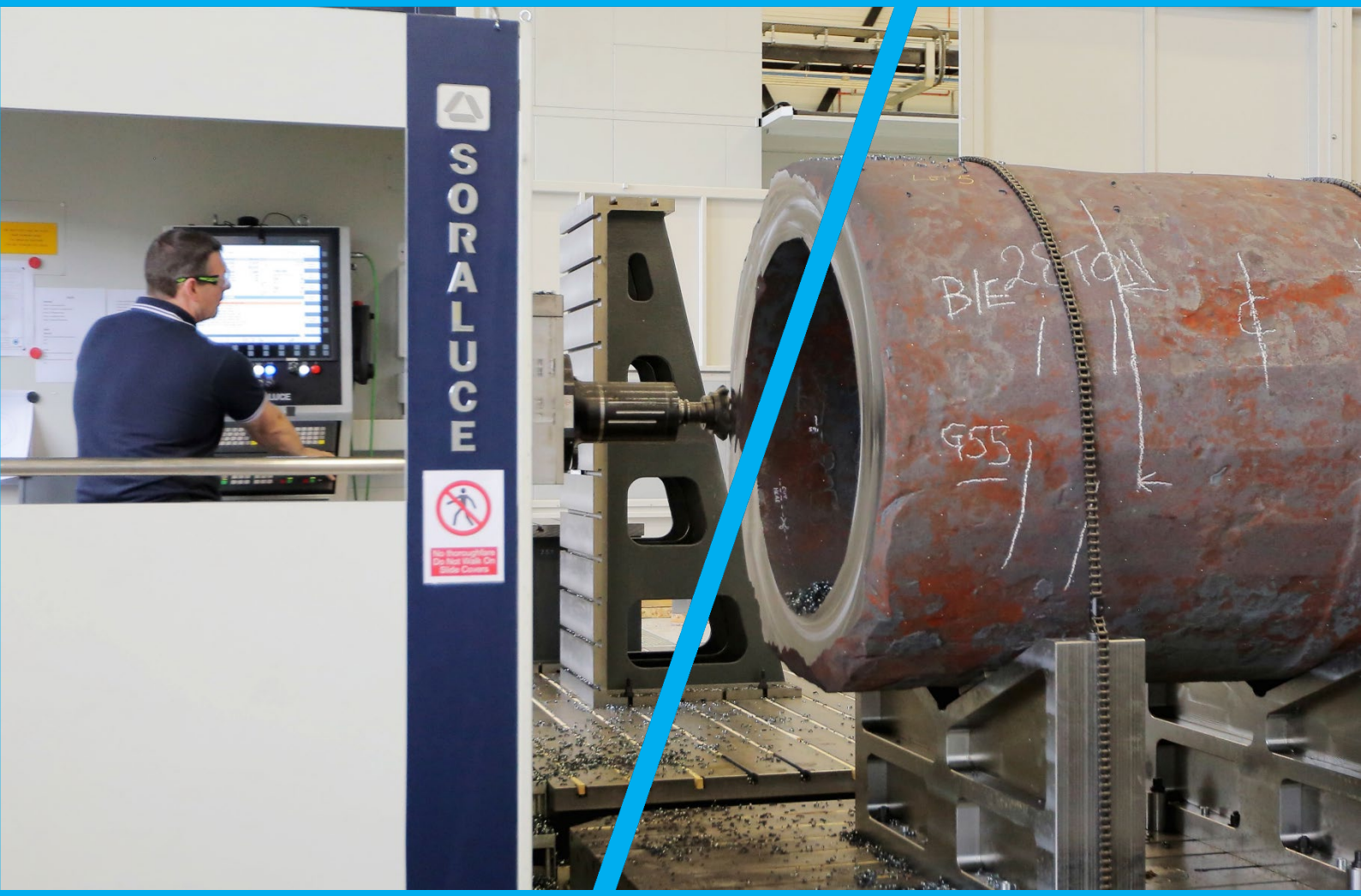

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