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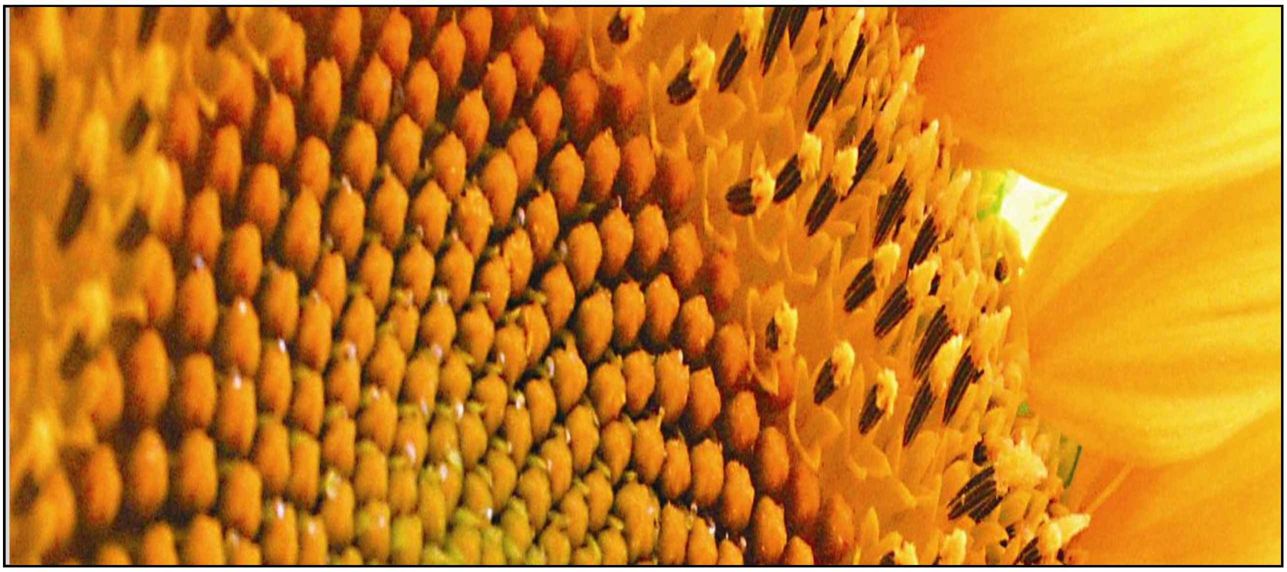

Assessing the Domestic Supply Chain Barriers to the Commercial Deployment of Carbon Capture and Storage within the Power Sector

Title

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Executive Summary

Carbon capture and storage (CCS) is central to the Government's goal of moving the UK to a low carbon economy, while ensuring energy supplies remain both secure and affordable. Development and deployment of CCS will, however, require major investment over the coming decades, which is why it is vital to ensure that barriers to the roll out of CCS are minimised. The CCS supply chain will be crucial to this roll out. Because of this, DECC commissioned AEA to carry out an objective appraisal of the CCS supply chain - to identify potential CCS supply chain barriers, and to examine the scope for growth in the UK CCS supply chain during the 2020s.

ES Box 1 Objectives, definitions and key findings

The two **objectives** of this study were:

(i) To examine CCS supply chain barriers; and
(ii) To assess the scope for growth in the UK CCS supply chain in the 2020s.

The following **definitions** were used:

- *'Current and near future'* supply chain capability was defined as the 2020 level of CCS supply chain capability.
- A *'supply chain barrier'* was defined as an impediment within part (or all) of the CCS supply chain that could affect the roll out of CCS within the UK power sector and that is not expected to resolve itself as the UK CCS market grows.

CCS market demand was based on a scenario of 2 GW of UK CCS deployment by 2020, rising to 10 GW by 2030 – a level based on DECC's Carbon Plan.

Key findings

1) Supply chain barriers

- **We believe that there are currently no significant supply chain barriers to the commercial deployment of CCS between now and 2030. Any potential barriers, outlined below, are expected to resolve themselves as the UK CCS market grows.**
- Furthermore, the current evidence from the literature and from stakeholders consulted suggests that the UK supply chain has moderate to high capability in most categories. Indeed, industry experts believe that the UK supply chain has the ability to deliver CCS during the early commercialisation phase (i.e. early projects under the Commercialisation Programme), providing a solid base for the decade that follows (i.e., the 2020s).
- Despite these strengths, however, some CCS industry-related potential barriers may exist:
  - One such potential barrier is uncertainty over the future CCS industry structure. This is because the deployment of CCS will require the creation of value chains across previously separate areas - such as power plants, capture plants, transport pipeline and storage site in addition to other cross-cutting services and uncertainty over the degree of integration across these areas could be important. For example, if companies in the power sector (who currently have their own established supply chains) were to expand their operations to cover CO_2 transport and storage, it would require them to expand their supply chains into these areas as well.
  - Another potential barrier is the concern that returns on investment in CCS research and development and skills could be lost overseas. While this risk applies to many sectors, in the case of CCS, the door is wide open for new innovations such as the development of new solvents and new processes in several technology areas.

- Turning to the labour required in the CCS industry in the future, one potential barrier identified was around the supply of skills. Those associated with CCS are similar to those currently found in the energy, process and oil and gas industries. As a result, the deployment of CCS will require expertise currently available in the UK. However, significant numbers of engineers and construction workers will be required, and so a "skills gap" (i.e., a situation where demand exceeds supply) might be an issue.

- A related barrier is that competition for skills (particularly related to construction and engineering) between the renewable, nuclear and CCS industries in the late 2020s could exacerbate the skills gap described above.

- Finally, there are some CCS categories where the UK is currently behind in terms of expertise, and these could become important in the 2020s. Expertise in areas related to CO_2 capture technologies, such as pre-combustion capture, air separation (where there are currently no centres of technical expertise or manufacturing sites in the UK), CO_2 compression and CO_2 monitoring instrumentation need further development in the UK over the next decade.

As noted above, these potential barriers are expected to be resolved as the UK CCS market grows.

2) The scope for domestic supply chain growth

- The cumulative CCS market between 2021 and 2030 was valued at £15.3bn (in 2010 prices) in the base scenario with average annual market demand in 2030 standing at £2.7bn.

- The overall cumulative difference between estimated UK 2020 supply chain capability and cumulative domestic CCS demand between 2021 and 2030 was estimated at £10.9bn of investment. This represents the maximum growth potential of the UK supply chain if it were to capture the entire UK supply chain. It is unlikely that the UK supply chain will be able to take 100% of the UK CCS market, but there may also be export opportunities for the UK supply chain. Overall, this suggests a significant opportunity will exist for UK CCS supply chain companies to expand their business, expertise and skill base over this period.

  It was estimated that, under the base scenario, around 280,000 man-years would be required during the 2020s. Most of the skills required (72%) are in three major disciplines: mechanical engineering, process engineering and the construction sector (crafts). Other skills are required in offshore engineering, geology and legal and financial services.

- The evidence suggests that the global supply chain will be able to meet any gap between domestic demand and domestic supply chain capability.

It should be noted, however, that projecting outcomes many years out into the future is inherently subject to considerable uncertainty. These results should therefore only be treated as illustrative.

Scope and methodology

This study looks to identify supply chain barriers to the commercial deployment of CCS within the power sector, and the scope for growth in the domestic CCS supply chain following the commercial roll out of CCS in the 2020s.

The study looks to identify supply chain barriers between now and 2030. But for the scope for growth in the domestic supply chain, the assessment focuses on the 2020s. This was partly due to data limitations (which made a robust assessment of the supply chain prior to this period difficult) - but also reflected the fact that CCS supply chain barriers are not expected during the CCS Commercialisation Programme (i.e., in the run up to the 2020s). This latter view was echoed by CCS industry experts consulted during this study.

To assess supply chain barriers AEA conducted a literature review and a stakeholder consultation. The scope for growth in the domestic CCS supply chain, meanwhile, was examined by modelling CCS demand between 2021 and 2030 and then assessing the UK CCS supply chain's current and near future ability to meet this demand (the difference between the two therefore represents the scope for growth in the domestic supply chain). The data to conduct this modelling exercise was collected from the literature and verified by stakeholder consultation.

The scope of the study meant, however, that it did not:

1. Make an evaluation of the UK supply chain's ability to grow to meet demand after 2020 (the 2020 level of supply chain capability was flat lined after 2020 for this study); the assessment is limited to the maximum potential for the UK supply chain in the event it captured the entire UK supply chain ;
2. Evaluate the scope for the transfer of skills between industries (which may be competing with each other for skilled labour);
3. Assess the export potential for UK supply chain companies.

The supply chain categories covered within this study are project management, design & engineering, procurement, manufacturing, construction, commissioning and legal & financial services. The manufacturing sector was further split into different physical component supply chain categories (e.g. boilers, turbines, heat exchangers, amine absorption columns, air separation unit, CO_2 compressors, etc.)

The evaluation methodology was based on data obtained through a review of recent publications and stakeholder consultation. A model was then used to estimate market demand, current / near future capability (based on 2020 levels) and the maximum potential for UK supply chain between 2021 and 2030 (abstracting from export consideration which were beyond the scope of this project).

To undertake the study, data were collected on (1) the UK and global supply chain strengths and weaknesses, (2) skill requirements in the energy and oil & gas sectors, (3) the capital costs associated with CCS, and (4) on the share of UK companies in the CCS market (obtained from a previous study by AEA[1] and verified again with stakeholders during this study).

The technologies considered were combined cycle gas turbines (CCGT) with post-combustion capture, pulverised coal (PC) with post-combustion capture, integrated gasification combined cycle (IGCC) with pre-combustion capture, and oxyfuel. The future demand in the various supply chain categories were estimated for the base scenario described above.

Capability of the UK CCS supply chain

A review of the CCS supply chain and the accompanying stakeholder consultation revealed that the UK has existing expertise and strengths in many supply chain categories. This is because UK companies are already involved in the project management, design and engineering, and construction and commissioning of projects in the energy and oil and gas industry. In many of the categories, the UK supply chain is already available and has the capability to deliver a significant proportion of the demand stemming from projects under the UK CCS Commercialisation Programme.

However, as CCS deployment increases in the 2020s, the difference between current capability and future demand is expected to increase rapidly and to different levels depending on the supply chain category considered. This will require the UK supply chain to grow both in size and expertise, to meet increasing CCS demand. However, we also believe that there are currently no significant supply chain barriers that would hinder the deployment of CCS during this period (although some CCS potential barriers may exist, and these are discussed in Section 5).

The supply chain was analysed by considering the carbon capture, transport and storage areas, along with cross-cutting services such as environmental impact assessment (EIA). An overview of the

[1] AEA Technology, Future Value of Carbon Abatement Technologies in Coal and Gas Power Generation to UK Industry, 2010

strengths of the UK CCS supply chain is given in ES Box 2 whilst a fuller assessment of the strengths and weaknesses is given in Table ES-2 below.

ES Box 2 Current strengths of the UK CCS supply chain:

- There are already several thousand employees[2] working on CCS in the UK in academia, industry and Government;
- Several universities in the UK have already started MSc and PhD CCS programmes;
- Several UK consultants and engineering companies are involved in CCS projects overseas;
- There are several large CCS pilots in the UK including CCPilot100+ and Oxycoal;
- Around twelve major companies and many other smaller companies in the UK are involved in collaborative R&D projects;
- Many equipment suppliers for supplying pumps, heat exchangers, fans, control systems exist in the UK.

The skills and supply chain requirements for CO_2 capture are similar to the current practice in other industries in the UK. For example, chemical absorption via amines, which is the technology of choice for post-combustion capture, has been in application for many decades in natural gas sweetening to reduce the content of CO_2 in natural gas to levels below 2%. Both post-combustion and oxyfuel capture technologies have been tested in the UK on a small scale. Examples of small scale post combustion testing include the test facilities at Didcot and Longannet power stations. Oxyfuel has also been tested by Doosan Babcock (OxyCoal) in Renfrew[3]. The largest pilot scale post-combustion project in the UK is the CCPilot100+ project at Ferrybridge and there is a 3MW post-combustion project by RWE npower at Aberthaw.

The supply chain capabilities required for CO_2 storage and transport are similar to those in the oil and gas industry. First movers that have already emerged in the CCS supply chain are oil and gas companies which are looking to expand into new areas. The supply chain in the oil and gas industry is established and it is likely that the CCS supply chain will be very similar to what is currently available.

In addition, the practical UK R&D capability across the whole CCS chain is internationally recognised. There are 18 universities with research projects in CCS in the UK. CCS work is carried out across many departments including engineering, earth sciences, social sciences, chemistry, mathematics, economics and law.

The skills associated with CCS are also similar to those currently deployed in the energy, process and oil and gas industries. As a result, the deployment of CCS will require expertise currently available in the UK. This existing expertise can serve as the starting point for the expansion of the skills base and development of the supply chain to meet the significant CCS demand expected in the future.

Barriers to the commercial deployment of CCS in the power sector

In the longer term, the significant demand in the CCS industry may lead to a shortfall in engineering and construction skills as a result of competition with other industries such as wind and nuclear.

The CCS skills base will need to expand significantly as the market grows. It is recognised that many CCS jobs will be filled by skilled personnel transferring from other industries (e.g. oil and gas) to take up involvement in the UK CCS Commercialisation Programme. The success of this will, however, depend on the relative financial rewards available. For example the offshore renewables industry has

[2] This includes people working in all areas and activities related to CCS (consultancy, R&D, academia, engineering, etc.) and does not necessarily mean that their work is only related to CCS.
[3] The Carbon Capture and Storage Association (CCSA), A Strategy for CCS in the UK and beyond, 2011

found that the oil and gas industry can afford both to pay considerably higher wages than the renewables industry can, making it more difficult to transfer staff.

There are programmes already in place in the UK for training CCS graduates. However, post-graduate and doctorate training will need to expand to cover the wide range of disciplines required for CCS deployment. In addition there will be a need for short specialist courses to retrain people who transfer into CCS. Such courses are beginning to emerge, such as those run at the Scottish Carbon Capture & Storage association (SCCS).

Summary of model results for the scope for growth in the domestic CCS supply chain.

A summary of the model results for the base scenario is given in Table ES-1.

CCS market

The total UK CCS market value was evaluated for the scenario described above (2 GW in 2020, 10 GW in 2030). The total market associated with CCS represents the total investment in the different business areas needed to achieve the assumed CCS deployment levels. The total cumulative market associated with the post-Commercialisation Programme period (2021-2030) was valued at £15.3bn under the base scenario. The manufacturing market constitutes about 45% of the total CCS market during this period.

Current / near future capability

Current and near future capability was estimated based on the share that UK-based companies can obtain of the annual market in 2020. Based on the assumed deployment level of 2GW, this amounted to approximately £1.2bn/year, with the UK capturing 38% of the 2020 market, i.e. £463m/year. This level of capability was held constant in the period 2021-2030, not because further growth is not thought possible, but because a detail consideration of growth in the 2020s was beyond the scope of this project. This allowed the estimation of the difference between total UK CCS-related demand in the 2020s and UK supply chain 2020-level capability, which represents the potential for growth for UK-based CCS supply chain companies.

Supply chain growth potential

The cumulative difference between the UK 2020 capability and total UK CCS market (2021-2030) was estimated as shown in Table ES-1. This shows that, under the base scenario, the total cumulative maximum growth potential is approximately 71% of the total cumulative market between 2021 and 2030.

Table ES-1: Summary of model results

	Cumulative CCS market (2021-2030), £m	Cumulative UK 2020 level of supply chain capability 2021-2030, £m	Cumulative CCS maximum growth potential (2021-2030), £m
Project management	1,246	438	808
Design & Engineering	1,907	600	1,307
Procurement	919	193	726
Manufacturing*	6,860	1512	5,348
Construction	2,654	1106	1,548
Commissioning	1,226	421	805
Legal & Financial	499	177	322
Total	15,312	4448	10,864

* The manufacturing sector is split into different physical components (e.g. boilers, turbines, absorption columns, CO_2 compressors, etc.)

Skill requirements

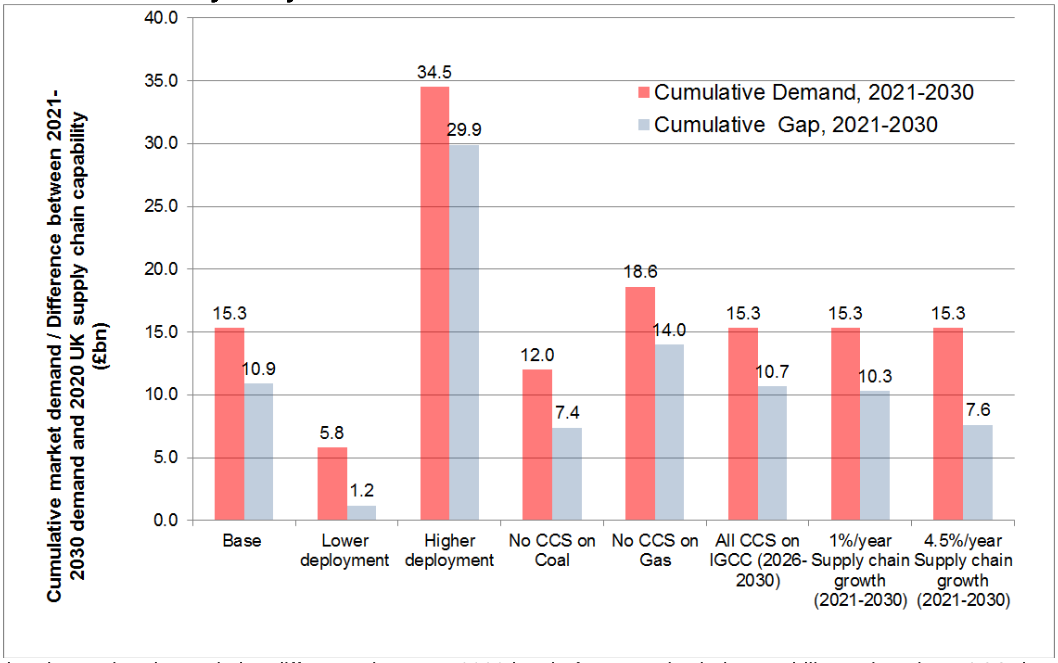
Under the base scenario, the difference between the total labour requirement between 2021 and 2030 to meet UK CCS demand and the 2020 level of UK labour was estimated to be around 280,000 man-years. The model estimates that 72% of the skills required are in mechanical engineering, process engineering and in the construction sector (i.e. crafts)[4]. These requirements could be filled through UK or global supply chain growth, or a combination of the two.

When examining the labour required, an important caveat is that it did not examine the potential for people leaving other sectors (e.g. oil and gas) and joining the CCS sector and so the jobs mentioned above do not necessarily represent additional new jobs when looking at the economy as a whole.

Scenario and Sensitivity Analysis

The effect of different assumptions within the model were tested through several sensitivities as shown in the figure below.

Figure ES-1: Sensitivity analysis



Cumulative demand and cumulative difference between 2020 level of UK supply chain capability and total UK CCS demand are over the period 2021-2030

One of the sensitivities considered was higher CCS deployment. This 'high' deployment scenario assumed 20 GW of installed CCS capacity on coal and gas power plants by 2030. Based on this, the *annual* market reaches £5.8bn/year in 2030 (with the cumulative market between 2021 and 2030 standing at £34.5bn). The difference in the supply chain demand and 2020 UK capability (and therefore the opportunity available for the UK supply chain), meanwhile, totals£29.9bn between 2021 and 2030.

A lower deployment scenario was also considered. For this 'low' deployment scenario, which envisaged cumulative capacity reaching 5GW by 2030, the market reduced to £0.8bn/year in 2030 (with the cumulative market between 2021 and 2030 standing at £5.8bn). Under this low deployment scenario, the UK supply chain growth opportunity was worth £1.2bn of the total cumulative market demand over this period.

[4] Note that due to methodological differences the labour required between 2021 and 2030 for this and the 2010 AEA study will be different. These differences are principally related to the technology mix, and the geographical coverage (the 2010 study looked at global CCS deployment, whereas this study focussed on the domestic market)

The sensitivity analysis table above shows that there is a higher market demand (and thus a higher growth potential for the UK supply chain) associated with coal power plants. This is because of the higher investment costs associated with coal power plants in comparison to gas power plants.

Though this study did not cover detailed analyses of the growth of the UK supply chain, some growth in the supply chain was also considered as sensitivity. Two growth sensitivities were considered: a growth rate of 4.5%/year and a growth rate of 1%/year. Under both sensitivities, there remained a positive differential between UK supply chain sales and total UK CCS demand, suggesting that the supply chain would have to grow at more than 4.5% per annum from 2020 to meet total demand.

We believe that the ranges tested here (1 and 4.5% per annum) represent conservative assumptions of future CCS supply chain growth (providing a cumulative growth of 10-60% between 2020 and 2030) and therefore provide conservative illustrations of how the UK supply chain capability might compare to UK demand.

These growth rates do not represent our view of how the supply chain will actually grow in the future (as detailed analysis of the scope of the supply chain growth was beyond the scope of this study). We also acknowledge that there may be some heterogeneity in the growth rates of different parts of the supply chain not captured within these aggregate supply chain growth figures. This heterogeneity in growth rates was not examined – as this was also beyond the scope of this study.

These sensitivities revealed that, for the lower growth rate, the difference between UK demand and UK supply chain sales reduces by 3%, while for the higher growth rate it reduces by 29%, relative to the baseline (of no growth in the domestic supply chain).

Table ES-2: Strengths and weaknesses across the UK CCS supply chain

Value chain category	Strengths	Weaknesses
CO_2 capture	• The UK has a strong power plant and process engineering capability. • The UK has strong expertise in the design, build, commissioning, operation & maintenance (including solvent manufacturing) and R&D activities related to CO_2 capture. • There is an existing market in the UK comprising several small scale projects ranging from pilot scale plants to feasibility and front end engineering design (FEED) studies. • The UK has capability in post-combustion capture and is developing expertise in oxyfuel combustion. • The UK supply chain has the necessary technical expertise to design, build and operate post-combustion capture. • Research is underway in the UK to develop new technologies (e.g. membranes, adsorption) for the removal and capture of CO_2. • Research is also underway in the UK to develop the next generation of solvents exhibiting lower energy requirements and lower evaporation and degradation losses.	• **Pre-combustion capture** is an area of weakness in the UK supply chain in comparison to the global supply chain. • **Air separation** units are a major part of oxyfuel and IGCC power plants. The major manufacturers and suppliers of air separation units are German and U.S. companies. • **CO_2 compression** is an area of interest and target for research in the UK in order to improve capability of UK companies. The major manufacturers of compressors are outside the UK. • There is a need to develop instruments and expertise for CO_2 monitoring and for the accurate measurement of CO_2 flow rates.
CO_2 transport	• The UK has strong capability in the construction and operation of transport pipeline. • The UK has high capability in pipe laying, both onshore and offshore. • Many existing assets, such as pipelines, thermal plants and offshore platforms, can be reused. • The UK has good expertise in gas pipeline building and welding, and in network management. • Experience from the North Sea oil industry has led to the development of high standards of integrity and safety.	• UK companies may still have international competition in areas such as network management and pipeline risk assessment in addition to pipeline supply and consultancy and R&D.
CO_2 storage	• The UK has strong capability in all CO_2 storage activities including reservoir operations and field services due to existing expertise in the UK oil & gas industry. • The UK has existing expertise and capability in sub-surface analysis, exploration, and design. • The UK has sufficient, accessible offshore storage in the North Sea. • Academia in the UK is at the forefront of CO_2 storage R&D • The UK experience from the North Sea oil & gas industry combined with the abundance of offshore geological sites provide an important storage business opportunity of European significance.	• Some of the areas where expertise in the UK can be developed are storage site characterisation, storage site risk assessment and CO_2 shipping
Other CCS-related activities	• The UK supply chain has strong capability in ancillary services associated with CCS such as planning, environmental impact assessment, managing public perceptions, verification, financing, and insurance and legal services.	
Skills	• The skills associated with CCS are similar to those currently deployed in the energy, process and oil and gas industries. As a result, the deployment of CCS will require expertise which is currently available in the UK. • Several universities throughout the UK are creating programmes for training CCS graduates. However, the number of skills required to deliver CCS deployment is significant.	• Shortage of engineering skills and construction workers may result due to retirement of existing expertise and due to competition with other industries within and outside the UK.

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1 Introduction

Carbon capture and storage (CCS) is central to the Government's goal of moving the UK to a low carbon economy, while ensuring energy supplies remain both secure and affordable. Development and deployment of CCS will, however, require major investment over the coming decades, which is why it is vital to ensure there are no barriers to the roll out of CCS. The CCS supply chain will be crucial to this roll out. Because of this, DECC commissioned AEA to carry out an objective appraisal of the CCS supply chain - to identify potential CCS supply chain barriers, and to examine the growth potential for the UK CCS supply chain over the next decade.

1.1 Objectives

The main objectives of the study were to:

- Identify any CCS supply chain barriers that may inhibit the deployment of CCS; and
- Assess the scope for growth in the CCS supply chain during the 2020s.

The analysis considered and evaluated the different components and services associated with different CCS technologies. The skills required to meet future CCS needs were also examined.

1.2 Scope and overall approach

With the study, the following definitions have been used:

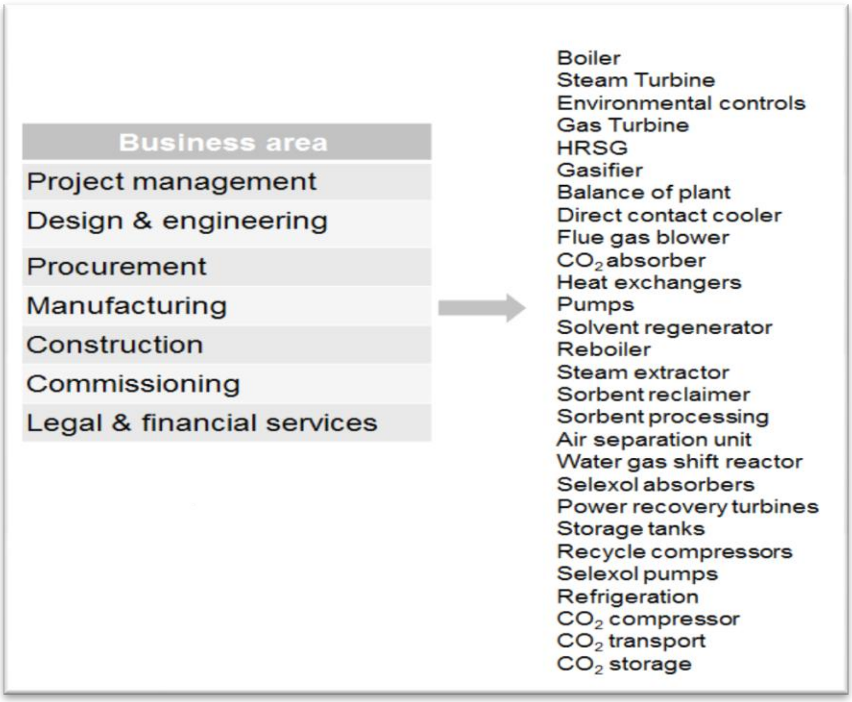
- *'Current and near future'* supply chain capability was defined as the 2020 level of CCS supply chain capability.
- A *'supply chain barrier'* was defined as an impediment within part (or all) of the CCS supply chain that could affect the roll out of CCS within the UK and is not expected to resolve itself as the UK CCS market grows.

CCS market demand in the 2020s, meanwhile, was based on a base scenario of 2 GW of UK CCS deployment by 2020, rising to10 GW by 2030 – a deployment level based on DECC's Carbon Plan.

The study:

- Covered the different **business areas** of the construction supply chain, including **project management, design & engineering, procurement, manufacturing, construction, commissioning**, and **legal & financial services** in addition to **skill** requirements and maximum potential for employment growth in the UK supply chain associated with each of these categories (Figure 1).
- Split the manufacturing business area into the different **physical components** required such as boilers, turbines, amine absorbers, heat exchangers, air separation units, CO_2 compressors, etc.

Figure 1: Business areas and components considered



- Covered the full CCS chain- including capture, transport and offshore storage

- Considered **retrofitting** (as currently planned worldwide) to existing plants in the early stages of commercialisation. However, for the deployment period between 2026 and 2030, **only new** CCS capacity (i.e. on new coal and gas power plants) was considered rather than retrofitting to existing plants (more detail is contained in Section 2.3.2)

- Considered the following power generation technologies with CCS
  - pulverised coal (PC) with post-combustion capture
  - integrated gasification combined cycle (IGCC) with pre-combustion capture
  - oxyfuel firing of coal
  - combined cycle gas turbine (CCGT) with post-combustion capture

- Estimated the value of the CCS market (full chain) for the operational phase.

Study Scope

The study looks to identify supply chain barriers between now and 2030. But for the scope for growth in the domestic supply chain, the assessment focuses on the 2020s. This was partly due to data limitations (which made a robust assessment of the supply chain prior to this period difficult) - but also reflected the fact that CCS supply chain barriers are not expected during the CCS Commercialisation Programme (i.e., in the run up to the 2020s). This latter view was echoed by CCS industry experts consulted during this study.

The scope of the study meant, however, that it did not:

1. Make an evaluation of the UK supply chain's ability to grow to meet demand after 2020 (the 2020 level of supply chain capability was flat lined after 2020 for this study the assessment is limited to the maximum potential for the UK supply chain in the [unlikely] event it captured the entire UK supply chain;

2. Evaluate the scope for the transfer of skills between industries (which may be competing with each other for skilled labour);

3. Assess the export potential for UK supply chain companies.

4. Differentiate the share of UK supply chain sales value accruing to the UK, i.e. look at value added as opposed to sales.

Report structure

Section 2 below outlines in detail the methodology for estimating the market, capability and maximum potential for UK supply chain growth for the construction phase. The methodology for estimating the value of the CCS market for the operational phase is then discussed in Section 3.

The model's results, covering the market arising from the construction and operation of CCS plants, the current and near future capability of the CCS construction supply chain and the resulting supply chain and employment growth maximum potentials, are presented in Section 4.

The capability and strengths of the UK supply chain are discussed in Section 5 where results from a stakeholder consultation undertaken for this study are also presented. The results of a sensitivity analysis on the effect of key parameters on the CCS market and corresponding maximum potentials for UK supply chain growth are given in Section 6. Finally, the conclusions of the study are summarised in Section 7.

2 Estimation of market, capability and maximum potential UK supply chain growth from the construction of CCS plants

2.1 Overall Approach

The overall methodology included

- The construction of a **model** in order to quantify CCS market demand, capability of the UK CCS supply chain and corresponding maximum potentials for UK supply chain growth. The model is also used to carry out the sensitivity analysis described in Section 7.

- A **review of recent publications** on the CCS supply chain and costs. The review also covers studies on the structure of the supply chain and skill requirements in the energy, and oil & gas sectors.

- **Consultation with key stakeholders** in the UK; stakeholders were asked about the breakdown of CCS capital costs, potential gaps in the UK CCS supply chain, and the strengths and weaknesses of the CCS supply chain – both in the UK and globally.

The model, informed by data accumulated through a review of recent publications and verified by stakeholder consultation, allowed an assessment of the current and near future capability of the UK supply chain and an evaluation of the future CCS market. The potential differences between 2020 UK supply chain capability and UK CCS demand in the 2020s were then estimated – thus highlighting the scope for growth in the UK CCS supply chain during the 2020s.

The review of recent publications helped develop an up-to-date understanding of the strengths and weaknesses of the CCS supply chain and to obtain recent cost data for use in the analysis. Data on the capital and operating costs of CCS, the share of UK companies in the CCS market and the breakdown of costs by component were obtained from a literature review and verified by stakeholder consultation. A list of key documents reviewed and references for this study are given in Appendix A.

The stakeholder consultation and follow-up telephone conversations were useful in highlighting their views on the strengths and weaknesses of the UK and global CCS supply chain. This was designed to gain a fuller understanding of potential supply chain barriers. In addition, the consultation and stakeholder discussions were used to verify the continued accuracy of the data obtained from recent studies. The list of stakeholders consulted is shown in Appendix B.

2.2 Supply chain model

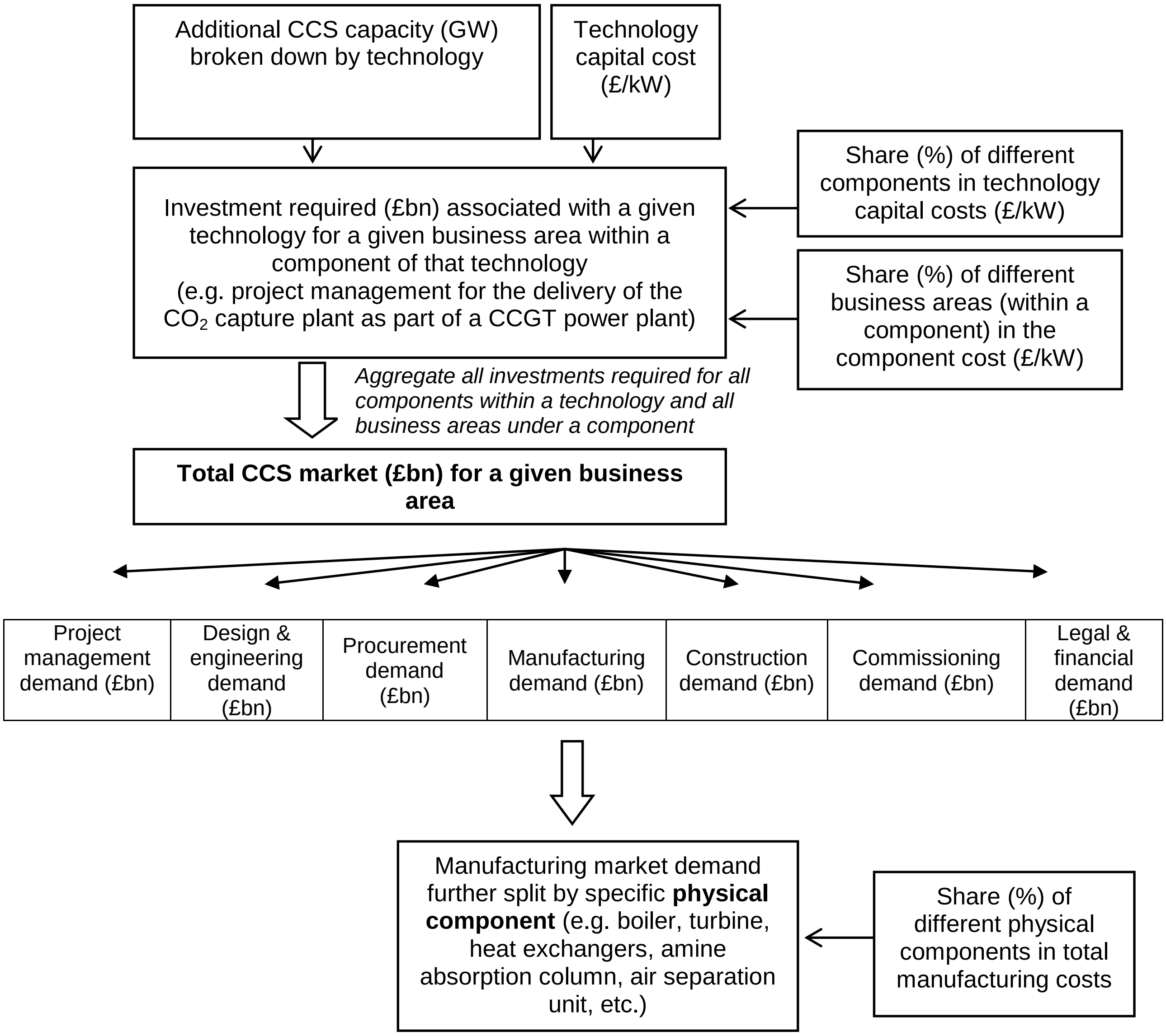
A model was constructed to evaluate the CCS supply chain needs in several business areas (see Section 1.2 for more details). The model was developed with the capability to investigate different deployment levels and technologies.

2.2.1 Estimation of CCS market

For each of the power generation / capture technologies considered, the total CCS market (£bn) was estimated as shown in Figure 2.

- A base scenario of UK CCS capacities (in GW) between 2020 and 2030 was agreed with DECC (Section 2.3.1);
- Estimates of the capital costs of new power plants with CO_2 capture, CO_2 transport and CO_2 storage (in £/kW) were collected (Section 2.3.3.);
- Together, the deployment levels and capital costs were used to derive the total investment required (note: operating costs, and therefore investment required, were treated separately – see Section 3).
- The total investment required was subsequently split into the costs of the different components (CO_2 capture, CO_2 transport, etc.) based on the data presented in Section 2.3.4;
- The costs associated with each main plant component were further split by the type of business area (e.g. project management) associated with the delivery of that specific component (based on the data presented in Section 2.3.5);
- The resulting figures were then aggregated to provide the total value of the market in each of the business areas (for example, project management, in £bn, from all technologies and components for the period 2021 to 2030).

Figure 2: Procedure for estimating the total CCS market demand



The procedure above allowed the estimation of the CCS market demand (£bn) for a given year for each of the business activity areas listed under Section 1.2 and shown in Figure 1. Further detailed analysis of the market was also performed for specific physical components (shown in Figure 1) which form part of the capture plant manufacturing supply chain:

- The share (%) of the cost of the different physical components associated with the power / capture plant in the total manufacturing cost was estimated;

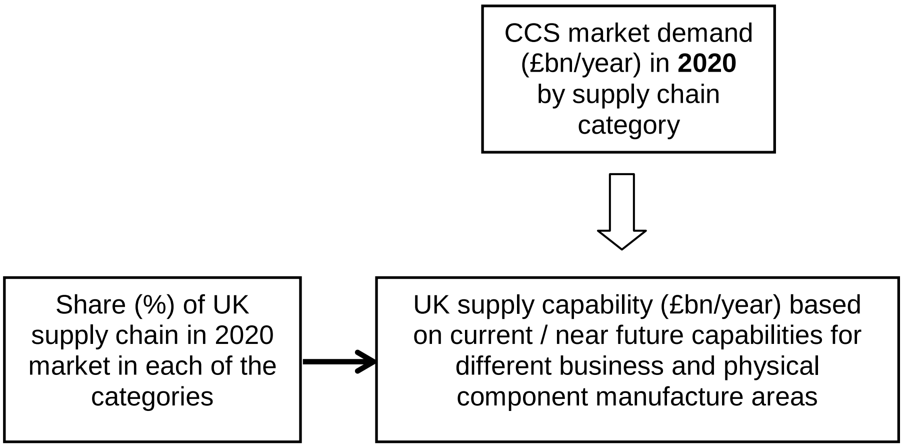
- The capture plant manufacturing market was further split into markets for the physical supply chain components associated with the power / capture plant (e.g. boilers, turbines, CO_2 absorbers, heat exchangers, CO_2 compressors ,CO_2 pipeline, etc.) as shown in Figure 2.

2.2.2 Estimation of UK supply chain capability in the 2020s

The capability of the UK CCS supply chain was estimated as follows (and as shown in Figure 3).

- Estimates of the proportion of the annual market demand in the UK in 2020 that can be met by the UK supply chain in each of the business areas (and component manufacture categories) were based on figures reported in a study by AEA[5] in 2010. These figures were verified with stakeholders to ensure their continued accuracy for this study. This approach is based on the view that the current supply chain in the UK has the capability to supply most of the components and market associated with the first early commercial plants in the UK which will be built in 2020.

Figure 3: Estimation of current / near future capability of the UK supply chain



- The UK company share (%) in a given business area as estimated above was multiplied by the CCS market demand (£bn/year) for that business area in 2020 based on a CCS deployment level of 2GW in 2020.

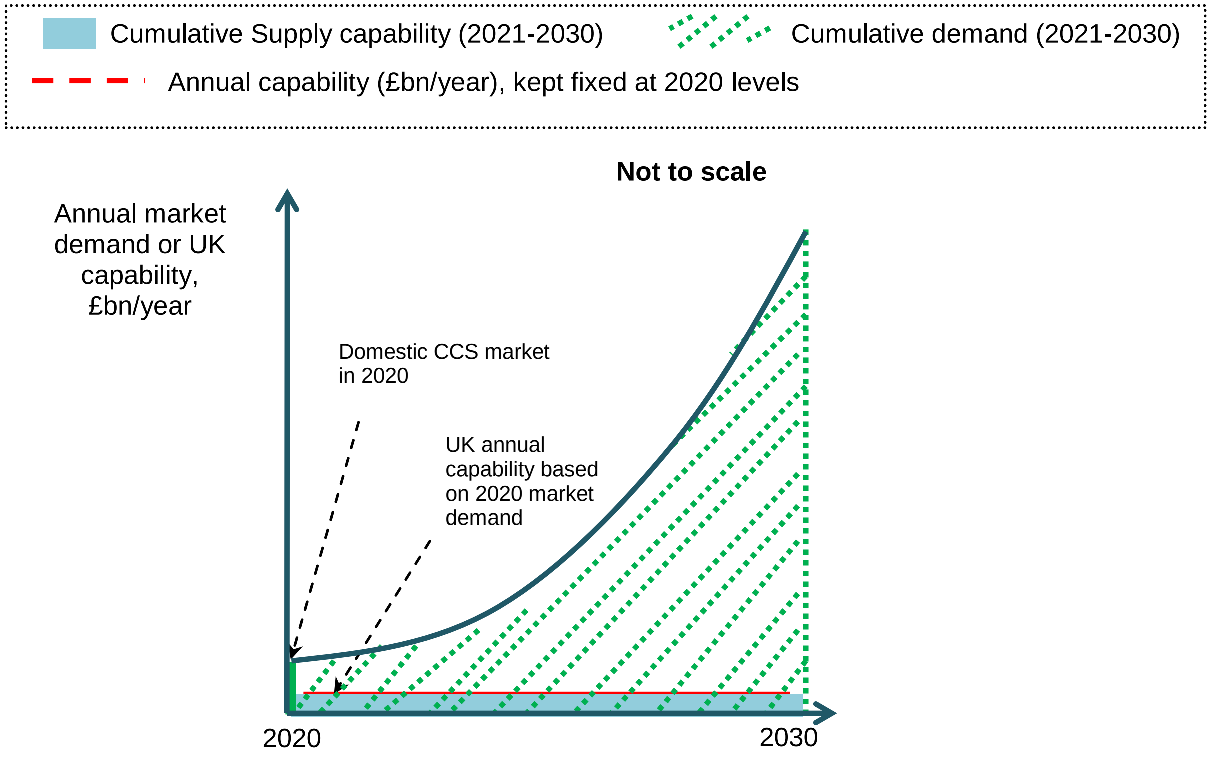
- The results were aggregated for the same business area, leading to an estimate of the UK-based supply chain capability (£bn/year) for a specific business area.

- The step above was repeated for physical components within the manufacturing sector.

Between 2020 and 2030, UK supply chain capability (in £bn/year) was fixed at its 2020 level for this analysis (Figure 4). While this approach has limitations, a detailed examination of the scope for supply chain growth in the 2020s was beyond the scope of this study. Identifying the differences between current and near future supply chain capability and CCS demand in the 2020s also highlights the future growth potential for the UK CCS supply chain industry. This flat-lining approach is relaxed under the sensitivity analysis carried out in Section 7.

[5] AEA Technology, Future Value of Carbon Abatement Technologies in Coal and Gas Power Generation to UK Industry, 2010

Figure 4: Representation of cumulative market demand, UK capability and maximum potential for UK supply chain growth in the 2020s

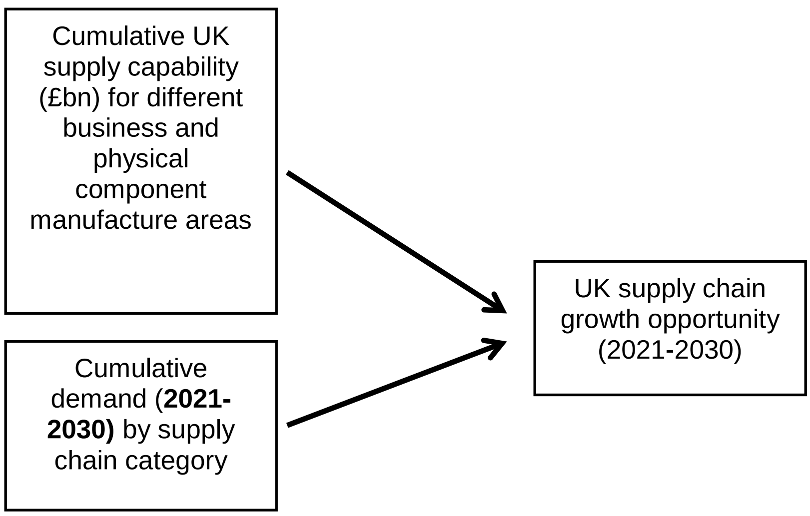


2.2.3 Estimation of the potential for UK supply chain growth in the 2020s

The difference between the 2020 level of UK supply chain sales and the total UK CCS market from 2021 to 2030 was estimated for different supply chain categories (business area or physical component)(Figure 5). This represents the maximum possible growth opportunity for the UK supply chain in the 2020s (abstracting from export opportunities which are beyond the scope of this study).

The analysis assumed that any gap that arises between the UK's needs (based on the expected deployment of CCS) and the ability of the UK supply chain to meet those needs will be met by the global supply chain. The stakeholder consultation undertaken as part of this study confirmed our view that there are unlikely to be any shortfalls in global supply.

Figure 5: Estimation of maximum potential cumulative supply chain growth (£bn)



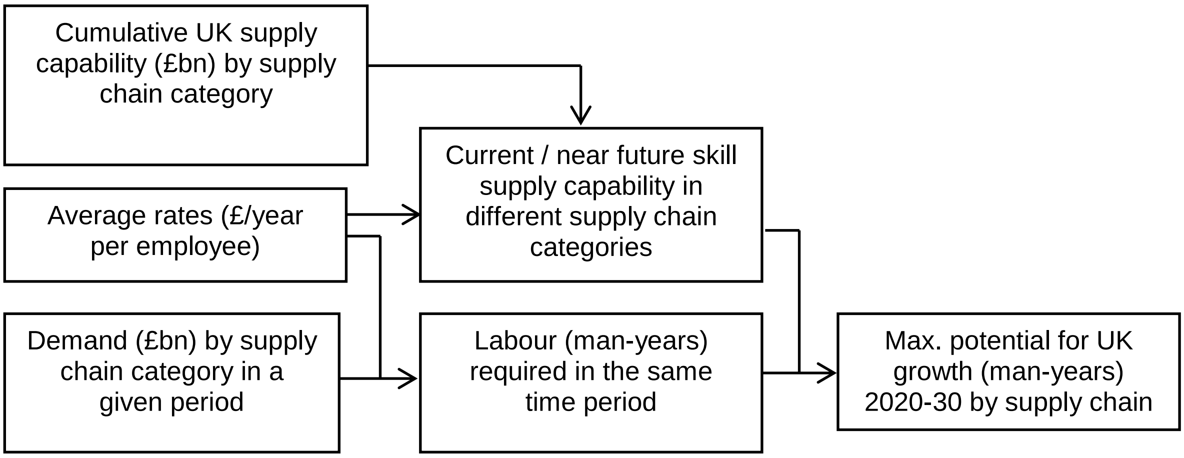
2.2.4 Estimation of skill requirements

The model also estimates the required labour demand in the 2020s. The UK 2020 capability (described as current/near-future) and potential for growth in the labour market were estimated as described below (Figure 6).

- The investment (£bn) required in the different business areas (including manufacture) were divided by business area-specific average rates (£/year per employee) to estimate the labour required in man-years for the different time periods (as shown below).

- These business-specific average rates account for the labour content of each of the business areas and so the labour man-years calculated in this way represent the total labour associated with the undertaking the different business activities. For example, while project management has a labour content of 100%, manufacturing (mostly material and equipment cost) has a much lower labour content. This is already accounted for in the average rates (see Section 2.3.8)

Figure 6: Estimation of job demand and maximum potential job growth (man-years)



The labour required and maximum potential for UK growth in supply chain jobs were then split by skill category as described below (Figure 7).

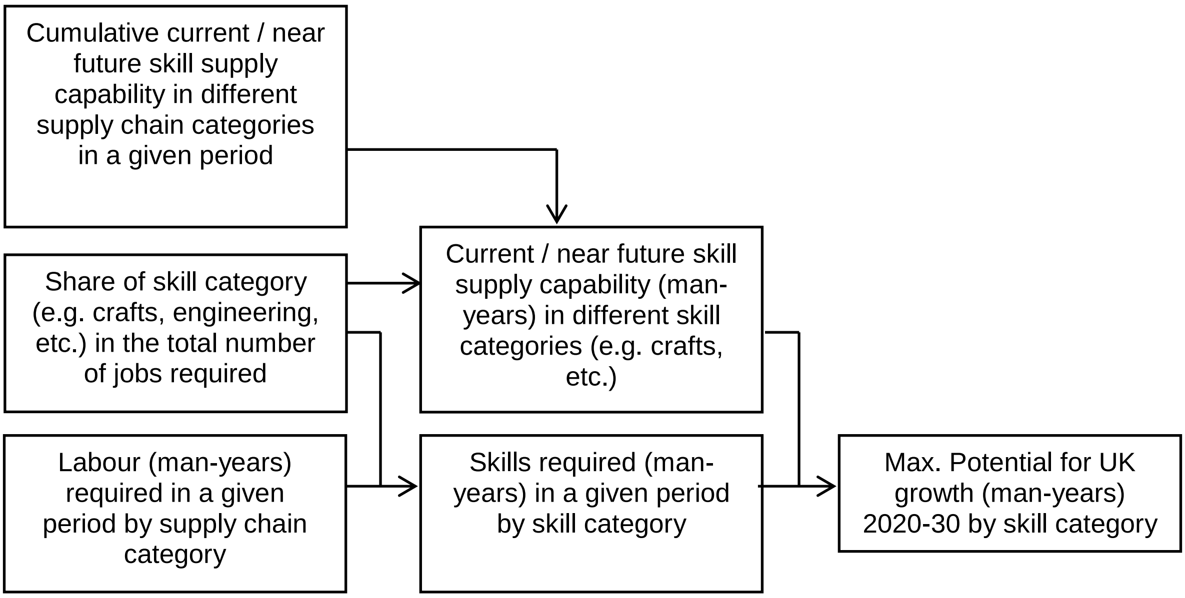
- The share (%) of each of the skill categories (e.g. number of mechanical engineers required as a percentage of the total jobs needed for project management) in the different business areas for the different components within a technology area were based on responses from the stakeholder consultation;

- These shares were used to split the total labour needed into specific skill category requirements (man-years). This was achieved by multiplying the skill percentage for a given category (e.g. the percentage for mechanical engineering) by the labour required (man-years) for a given business area to split the jobs into various skill category needs;

- The current / near future capability was estimated in each of the skill categories based on supply chain capabilities to deliver the demand to 2020. As discussed in Section 2.2.2., this was based on the assumption that the UK supply chain has the capability to deliver a proportion of the demand required by 2020. It is also assumed that the UK skills are available (in numbers as well as type of discipline) to achieve these early deployment targets.

- The maximum potentials for UK supply chain jobs growth (abstracting from export opportunities) were then estimated by subtracting the current / near future capability from the total skill demand in each of the skill categories.

Figure 7: Split of job demand and maximum potential for jobs growth (man-years) into different skill categories



If the UK supply chain does not grow fast enough to fulfil all these job/skill requirements in the 2020s, it is assumed that they will be filled by jobs in the global supply chain.

2.3 Data and assumptions

The data required to undertake the analysis is given in the Table 1 below with a brief description. The sections below provide additional information on the assumptions and data used for the analysis.

Table 1: Data requirements

Data	Use and/or assumptions	Source
Projections of CCS capacity (GW) and technology mix in the UK (**Section 2.3.1**)	The analysis was based on a base scenario of 10GW total CCS capacity in 2030. Assumptions were made for the capacity and technology mix during the period 2021-2030. Scenario and sensitivity analysis was undertaken on variations to the expected capacity and technology mix (see Section 6)	The base scenario was based on projections by the **Carbon Plan** and was agreed with DECC. The scenario analysis in Section 6 compared the base scenario to a lower and a higher deployment scenarios based on projections given in the CCSA Strategy (2011)
Technologies and associated components **(Section 2.3.2)**	Each of the technologies listed in Section 1.2 were broken down into components.	Component breakdown was based on input from in-house AEA experts
Capital cost (£/kW) data for CO_2 capture, transport and storage **(Section 2.3.3)**	This allowed the determination of the total required investment cost (£bn) for a given technology in a given year	Capital costs were obtained from the International Energy Agency (IEA) study (2011) and were cross-checked with cost data for the UK provided by DECC

The share (%) of the cost of individual components (e.g. turbine or boiler island) of a plant in the total capital cost **(Section 2.3.4)**	The total cost of a technology was broken down by component - thus allowing the determination of investment required in different areas of the plant	Previous studies (AEA, 2010) and verified through stakeholder consultation
The share (%) of the costs associated with each of the business areas (e.g. project management) in the total cost of delivering a given component (e.g. turbine island or CO_2 capture) from beginning to end **(Section 2.3.5)**	The cost of a given component within the plant was broken down by investment required in specific business areas.	Previous studies (AEA, 2010) and verified through stakeholder consultation
The share of the costs of different physical components (e.g. CO_2 absorbers) in the manufacturing costs **(Section 2.3.6)**	This allowed the split of the manufacturing market into demand (£bn) by physical component	Integrated Environmental Control Model (IECM) supported by a literature review
The share (%) of the UK supply chain in each of the business areas for various components and in the manufacture and supply of power / capture plant physical components **(Section 2.3.7)**	This allowed the estimation of the current and future UK supply chain capability. These shares refer to the proportion of the market associated in 2020 that the UK supply chain can capture based on the assumed deployment level of 2GW	Previous studies on strengths and weaknesses of the UK supply chain supported and followed by verification through stakeholder consultation
Average rates (£/year per employee) by business area **(Section 2.3.8)**	This allowed the conversion of investment costs (CCS market) into labour (man-years). The average rates (£/year per employee) take into account the proportion of labour in each of the different business areas. It was assumed these are constant.	UK National Accounts (Blue Book)
Breakdown (% by number) of skill needs (e.g. engineering discipline, legal & financial, crafts) in each of the business areas under various components **(Section 2.3.9)**	This allowed the breakdown of labour (man-years) required, UK current capability and UK growth potential into various discipline areas	Stakeholder consultation supported by reference to IPA study on skills (2010)

2.3.1 Deployment scenarios

A base scenario to assess the UK supply chain's ability to deliver the UK's future CCS needs was agreed with DECC. This base scenario was based on the following deployment levels**:**

Base scenario	2020	2025	2030
Cumulative CCS capacity, GW (gross)	2	3	10

This scenario assumed that:

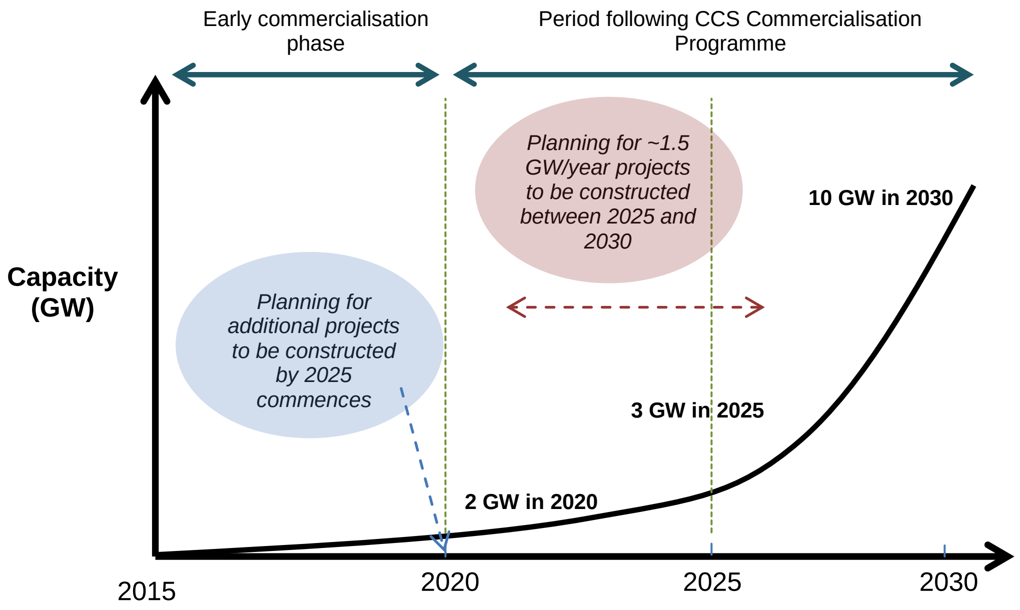
- CCS capacity will be 2 GW in 2020;
- A period of planning and preparation for a second wave of CCS plants will commence during the early 2020s as early commercial plants emerge;

- A total capacity of 1 GW will be added in the five years between 2021 and 2025; and
- A total capacity of just over 1 GW will be added in each of the years between 2026 and 2030

This is in agreement with DECC's Carbon Plan (2011) which shows that in order to meet its carbon budgets, the UK will need to have largely decarbonised its electricity system by the 2030s. Achieving this aim will involve large investment in low carbon generation, including CCS. The scenario above assumes that cost reductions in CCS following the early CCS projects makes CCS cost competitive with other low carbon generation sources, leading to a fairly rapid roll out of the technology in the second half of the 2020s.

It takes several years (4-6 years) of preparation before construction of a CCS power plant can commence; hence, planning for projects to be built by 2025 is expected to begin in the early 2020s while planning for the 7 GW expected between 2025 and 2030 is expected to take place in the period between 2022 and 2027. This means that CCS market demand between 2020 and 2025 will be greater than the 1GW of CCS constructed under the base scenario – as planning for the 7GW of capacity, due to be built between 2025 and 2030, will also get underway between 2020 and 2025.

Figure 8: Base scenario for the deployment of CCS in the UK to 2030



2.3.2 Technologies and components

The study considered both coal and gas power generation technologies (Section 1.2) and the associated CO_2 capture technologies which are being currently considered for the roll out of CCS in the UK. Three technologies are available for CO_2 capture at power plants.

- Post-combustion capture via amines is the most suitable for retrofitting as well as for installation on new PC and CCGT power plants.
- Pre-combustion capture utilising physical absorbents such as Selexol is the technology of choice for IGCC.
- Oxy-firing followed by post-treatment leads to a relatively pure stream of CO_2 which can then be compressed and transported for storage.

As discussed in Section 1.2, the coal-based technologies considered are PC with post-combustion capture, IGCC with pre-combustion capture, and oxyfuel firing. In addition, the analysis also covers CCGT with post-combustion capture.

Coal-based technologies

As evident from the planned projects worldwide, most of the early CCS projects are expected to be retrofits to coal power plants. In the longer term, however, the opportunity of retrofitting CCS to existing conventional coal power plants in the UK will largely depend on commercial operators' decisions on whether to extend the economic life of coal plants into the 2020s, while also meeting environmental legislation such as the Industrial Emissions Directive. This means that it is difficult to predict whether future coal generation is likely to be from retrofit or new build. As such, for simplicity (and following the more conservative approach), the study assumes that all CCS on coal in the period 2026-2030 is new build.

There are currently only four IGCC power plants (without CCS) worldwide. However, IGCC is viewed as a cleaner coal technology and pre-combustion, in comparison to post-combustion capture, requires less energy for solvent regeneration. As a result, the build of IGCC plants and the associated deployment of pre-combustion capture on these plants could accelerate in the second half of the 2020s if the technology is proven on a large scale.

Pulverised coal power plants with CCS may incorporate biomass co-firing. Biomass co-firing with coal in PC power plants offers the benefit of achieving negative emissions. Section 7, which presents sensitivity analysis, considers the effect on the supply chain of biomass co-firing with coal in PC power plants with CCS.

Natural gas based technologies

The majority of fossil fuel power plants which received Section 36 consents over the past few years in the UK were CCGT power plants[6]. All combustion plant at or over 300MWe[7] are required to be Carbon Capture Ready (CCR) before consent will be granted – that is, they must demonstrate the economic and technical feasibility of retrofitting CCS, that a suitable area of offshore storage exists and that sufficient space is available on or near the site. This is in addition to the requirement that new coal plant must have CCS on at least 300MW net of the proposed generating capacity. Therefore it is possible that CCS capacity on gas fired power plants between 2025 and 2030 will be retrofitted to existing CCGT power plants. However, in estimating the market and maximum potential supply chain growth for the current work, we are assuming that all CCS capacity between after 2025 will be on new CCGT plants.

Table 2: Components considered in the analysis under each of the technology options

Technology area			
PC	IGCC	Oxyfuel	CCGT
Boiler	Gasifier	Boiler	Gas turbine
Steam turbine	Gas turbine	Steam turbine	HRSG
Environmental controls	HRSG	Environmental controls	Steam turbine
Balance of plant	Steam turbine	Balance of plant	Balance of plant
CO_2 capture*	Balance of plant	CO_2 capture*	CO_2 capture*
CO_2 transport	CO_2 capture*	CO_2 transport	CO_2 transport
CO_2 storage	CO_2 transport	CO_2 storage	CO_2 storage
	CO_2 storage		

Note: In the analysis, CO_2 compression is considered as part of CO_2 capture. For IGCC and oxyfuel, the air separation unit (ASU) is covered under the capture component. The analysis does, however, separate the costs, market and maximum potentials for UK industry growth associated with physical components within the capture plant including ASU, CO_2 compressors, absorbers, etc.

The analysis considers the capital costs (section 2.3.3.) of the different technologies listed above and splits that overall cost into costs associated with individual components (Section 2.3.4). The components included under each of the technologies are summarised in Table 2.

[6] https://www.og.decc.gov.uk/EIP/pages/recent.htm
[7] Of a type covered by the Large Combustion Plant Directive

2.3.3 Technology capital cost data

CO_2 capture

Data on the capital costs (£/kW) of CO_2 capture in the UK were provided by DECC. These data, based on a model by Parsons Brinckerhoff (PB) (2011)[8], were considered first for the purposes of this study, as they are UK-focussed and are based on the most recent estimates. The CCS costs in this study were based on a review of many reports and investigations and covered PC, CCGT and IGCC with CCS. However, since for our analysis we are also considering oxyfuel, a complete dataset covering all four technologies based on the same set of assumptions was required for consistency.

Capital cost data ($/kW) for the four major power generation / capture technologies covered for this study were obtained from the recent International Energy Agency (IEA) study on cost and performance of CO_2 capture[9] (Table 3). The IEA study is based on several specific investigations undertaken between 2002 and 2010. The IEA report provides averages of the costs reported in the different studies investigated. For our analysis, costs were converted from $/kW to £/kW using an exchange rate of $1.49/£ - which is the 2010 year average.

It should be noted that CCS is a new technology which has not yet been proven at commercial scale. This means that the costs are subject to considerable uncertainty. Nevertheless, the costs shown in Table 3 (which are in 2010 prices) are based on a single study and so provide consistency. The major difference between the IEA and PB costs provided by DECC is that the IEA study provides much lower estimates of capital costs for IGCC with CCS. This is because the IEA studies average costs from new as well as older studies. While for PC and CCGT plants similar CCS costs are reported in new and old studies, the same does not apply for IGCC where recent studies have shown higher estimated capital costs.

For this study we assumed that the capital costs remain fixed (and at the 2010 levels) over the period of analysis to 2030. This was due to the fact that a reduction in capital costs will lead to reduction in the investment required for the same plant capacity, based on the estimation method used (as explained above in Section 2.2). In reality, CCS capital costs would be expected to fall – both through learning by doing and through research and development (R&D). These cost reductions would increase the commercial case for CCS, facilitating its commercial roll out.

Table 3: Capital costs for power plants with CO_2 capture (£/kW)[1]

Technology	Capital costs, £/kW
PC + CCS	2104
IGCC + CCS	2125
Oxyfuel	2116
CCGT + CCS	1034

Notes: (1) Based on IEA study on cost and performance of CO_2 capture from power generation (2011) and an exchange rate of $1.49/£ (the year average for 2010)
(2) The costs in this table do not include transport and storage costs

CO_2 transport and storage

Usually the capital costs of CO_2 transport and storage are reported as absolute costs (e.g. £bn) for a specific project. This is because the costs of transport and storage are project-specific and may vary considerably depending on pipeline specifications and route, CO_2 specifications, location and nature of the storage site relative to the power plant and on whether the pipeline is onshore or offshore. Some literature studies also report transport and storage costs on a £/t-CO_2 transported or stored basis.

In order to be used in the model described in Section 2.2, the capital costs of transport and storage need to be expressed in £/kW. The costs in Table 4 below were used for this study.

[8] http://www.pbworld.com/pdfs/regional/uk_europe/decc_2153-electricity-generation-cost-model-2011.pdf
[9] IEA, Cost and performance of carbon dioxide capture from power generation, 2011

A recent study by PB[10] produced low and high scenario estimates for CO_2 transport in the UK. The study reports a transport network cost of £2bn for the low scenario to £3.5bn for the high scenario. Assuming a total investment value of £2.5bn for the base deployment scenario (of 10 GW by 2030), the effective cost of transport is £250/kW. This is in agreement with the figure in Table 4, which is derived from a previous AEA study. The cost of CO_2 storage is assumed 60% of the total transport costs which is in agreement with recent estimates[11].

Table 4: Capital costs for power plants with CO_2 capture (£/Kw)

Technology	Capital costs, £/Kw
CO_2 transport	250
CO_2 storage	150

Source (AEA, 2010)

2.3.4 Cost split by plant component

Initial estimates of the split of costs associated with each main plant item are shown in Table 5. These estimates were used in a previous AEA study[12] in 2010 and were verified again with stakeholders for this study. The percentages reported are assumed constant over the period of analysis.

Table 5 shows that the cost of capture ranges from 30-40% of the total investment required for a *new* power plant. The cost of the CO_2 compression plant is included in the cost of capture.

Table 5: Capital cost split (%) for power /capture plant by component for new plants with CCS

Technology	Share of component cost in total technology cost, %							
	Boiler	Steam turbine	Gas turbine	Environmental control equipment[1]	Heat recovery steam generator (HRSG)	Gasifier	Balance of plant (BoP)[2]	Capture[3]
PC	30%	15%	-	10%	-	-	15%	30%
IGCC	-	5%	12%	10%	6%	30%	3%	34%
Oxyfuel	35%	15%	-	15%	-	-	10%	25%
CCGT	-	7%	30%	-	16%	-	7%	40%

[1] Environmental control equipment is that equipment which is required to remove emissions other than CO_2. In the case of PC plants, this consists of flue gas desulphurisation (FGD) for SO_2 removal, selective catalytic reduction (SCR) for NOx removal and electrostatic precipitation (ESP) for particulate matte removal. For IGCC, this consists of technologies for H_2S removal (i.e. the Claus Plant) other technologies while for oxyfuel this consists equipment required for the conditioning and dehydration of the CO_2 stream. In the case of CCGT, air emissions other than CO_2 are minimal and so environmental control is usually not required (unless the flue gas contains high concentration of NOx in which case SCR will be required).
[2] Balance of Plant (BoP) means all equipment, other than that mentioned in the table above, and which is necessary for the operation of the power plant. This could include cooling towers, water treatment systems, coal handling systems and other smaller units such as pumps, pipes, heat exchangers, tanks, etc.
[3] The cost of the CO_2 capture plant includes the cost of CO_2 compression. For IGCC and oxyfuel, the cost of 'Capture' also includes the cost of the air separation unit (ASU). For IGCC, this also includes the cost associated with the Selexol process (more details are in Table 7).
[4] Transport and storage capital costs (£/kW) are dealt with separately as described in Section 2.3.3 above.

2.3.5 Cost split by business area

Next, the capital costs associated with the delivery of each of the components for a given technology were split into costs by business area. The share that different business areas are likely to have as part of the total component investment was based on the AEA study mentioned above (AEA, 2010). These figures, shown in Table 6 below, were verified with stakeholders for this study.

Table 6 shows that for manufacturing the major part of the investment costs are associated with components. This means that the major contribution to the future CCS market and consequently to the value added will come from the manufacturing sector.

[10] Parsons Brinckerhoff, for DECC, Technical Analysis of Carbon Capture & Storage (CCS) Transportation Infrastructure, May 2009.
[11] http://www.decc.gov.uk/assets/decc/what%20we%20do/uk%20energy%20supply/energy%20mix/carbon%20capture%20and%20storage/1_20100317095408_e_@@_ccsbusinessclusters.pdf
[12] AEA Technology, Future Value of Carbon Abatement Technologies in Coal and Gas Power Generation to UK Industry, 2010

Based on the data above (given in Table 5), the CCS market was split into the following business areas:

(1) Project management,
(2) Design & engineering,
(3) Procurement,
(4) Component manufacturing,
(5) Construction,
(6) Commissioning, and
(7) Legal & financial

Table 6: Split of capital cost of components by business area*

Component	Share of cost associated with business area in total component cost, %					
	Project Management	Design & Engineering	Procurement	Manufacture	Construction	Commissioning
Boiler	5%	10%	5%	50%	25%	5%
Gas turbine	5%	15%	10%	50%	10%	10%
Steam turbine	5%	15%	10%	50%	10%	10%
Heat recovery steam generator	10%	10%	5%	45%	25%	5%
Gasifier	5%	15%	10%	50%	10%	10%
Environmental controls	5%	10%	5%	50%	25%	5%
Balance of plant	10%	15%	5%	45%	15%	10%
CO_2 Capture	10%	15%	5%	45%	15%	10%
CO_2 Transport	10%	10%	5%	40%**	30%	5%
CO_2 Storage	15%	10%	5%	45%**	15%	10%

* Source: Data based on AEA study in 2010 and verified by stakeholders for this study
** CO_2 transport manufacturing costs are those associated with the manufacture of the CO_2 pipeline and re-compression stations. For CO_2 storage, the manufacturing cost is that associated with injection platforms and wells.

The cost associated with legal & financial services was assumed to be 4% of the total investment costs (i.e. 4% of the figures in Table 3) for all technologies. As part of the analysis, the capital cost share of a given component was divided into areas 1-6 above (as in Table 6); an additional 4% was then added to the technology costs to account for legal and financial services.

2.3.6 Manufacturing cost split by component

The component manufacturing market (4 in the list above) was further split into supply chain components. This was done for CO_2 capture component manufacturing based on the figures provided in Table 7. The figures in Table 7 represent the share (%) that a given component within the capture plant makes out of the total capture manufacturing cost.

Table 7 shows how the total manufacturing costs of post-combustion capture on PC and CCGT power plants and pre-combustion capture on IGCC power plants can be broken down into their associated components. For the non-CCS components of the plant, the physical components listed in Table 2 were considered using the shares (%) shown under manufacturing in Table 6.

The oxyfuel combustion process does not require the installation of a separate capture plant (as with post-combustion and pre-combustion capture) because the process itself produces almost pure CO_2, which can be compressed and transported for storage. As a result, the physical components considered under the manufacturing area for oxyfuel are those listed in Table 2. It should be noted, as mentioned above, that the capture component of oxyfuel (as in Table 5) refers to the air separation unit.

The percentages in the tables below were obtained based on analysis using the Integrated Environmental Control Model (IECM) by Carnegie Mellon University. These figures can be used to split the investment costs of the manufacturing business area of CO_2 capture (post- and pre-combustion) into physical components within the supply chain.

Table 7: Capital cost breakdown by component of post-combustion CO_2 capture plant for PC and CCGT plants, and pre-combustion IGCC, with CCS (analysis using IECM)

Post-combustion capture			Pre-combustion capture (IGCC)	
Component	Share in total cost, %		Component	Share in total cost, %
	PC	CCGT		
Direct Contact Cooler	11%	16%	Air separation unit	49%
Flue Gas Blower	2%	3%	High Temperature Reactor	1%
CO_2 Absorber Vessel	32%	41%	Low Temperature Reactor	2%
Heat Exchangers	2%	2%	Heat Exchangers	26%
Circulation Pumps	5%	4%	Absorbers	8%
Sorbent Regenerator	18%	13%	Power Recovery Turbines	1%
Reboiler	9%	6%	Slump Tanks	1%
Steam Extractor	1%	1%	Recycle Compressors	2%
Sorbent Reclaimer	0.5%	0.5%	Flash Tanks	1%
Sorbent Processing	0.5%	0.5%	Selexol Pumps	1%
CO_2 Compressors	19%	15%	Refrigeration	2%
			CO_2 Compressors	6%
			Final Product Compressors	1%

Source: Data based on analysis using the Integrated Environmental Control Model (IECM)[13]

Notes:

(1) Components of oxyfuel are broken down as in Table 5 (boiler, steam turbine, environmental controls, balance of plant, capture). The capture component in the case of oxyfuel represents the air separation unit.

(2) The manufacturing costs of CO_2 transport and storage refer to the manufacturing of CO_2 pipelines, re-compression stations, and injection equipment. These are estimated from the manufacturing share in Table 6 (last two rows for CO_2 transport and storage) and are not broken down further in this study.

2.3.7 Share of the UK supply chain

The study assessed the ability of the UK supply chain to deliver CCS projections in the UK to 2030. Future projections were compared against current and near future capabilities to identify potential gaps and the maximum potential for UK supply chain growth (abstracting from exports). The current / near future capability was based on the UK's supply chain share of the UK CCS market in 2020.

Data on the share of UK companies in the CCS market was obtained from the AEA[14] report mentioned above and was verified with stakeholders for this study. Shares of the domestic market UK companies are projected to hold in 2020 in different business areas are shown in Table 8. These figures are best estimates by stakeholder/AEA experts on the UK market of the current / near future ability of UK companies to deliver projects in the UK, but are inherently subject to some uncertainty. It is recognised that the market share achievable by UK companies is also influenced by factors other than the strength and capacity of the UK supply chain. This includes, for example, pre-existing relationships and agreements with non-UK suppliers. However, this was the best estimate of UK supply chain capability available to this study; a more in-depth investigation of supply chain capability was beyond the scope of this study.

Based on Table 8, the UK is expected to capture about half of the UK carbon capture and transport market to 2020. In addition, the UK is expected to capture about a third of the UK market for the construction of CO_2 storage facilities. Considering CO_2 capture, there has been recent pilot scale plants in the UK testing post-combustion and oxyfuel technologies. This will help UK companies to develop the necessary expertise to supply these technologies in the near future. In terms of CO_2

[13] The Integrated Environmental Control Model (IECM) is a computer-modeling program which was developed for the U. S. Department of Energy's National Energy Technology Laboratory (NETL). It can be used for cost and performance analyses of emission control equipment at coal and gas power plants. The model can be used to analyse power plants with and without CCS. It is useful for preliminary design and analysis of electricity generation options. One of the capabilities of IECM is its ability to characterize performance and cost uncertainties explicitly.

[14] Future Value of Carbon Abatement Technologies in Coal and Gas Power Generation to UK Industry, 2010

transport, UK companies currently have the expertise required to design and build a large part of the required CO_2 transport pipeline.

In practice, post-combustion or pre-combustion plants will be delivered by a company which will manage and design the project. Many of the components required for a CO_2 capture project can be manufactured in the UK. The UK company share in the manufacturing of equipment used in the capture plant is shown for various components in Table 9 below. This is based on consultation with stakeholders and on the fact that UK-based companies have higher capability in post-combustion than in pre-combustion technology.

Table 9 shows that currently the UK has strengths in the manufacture of most equipment related to post combustion capture - aside from CO_2 absorbers, strippers, sorbent processing and CO_2 compressors. Table 9 also shows that UK companies lack expertise in the manufacture of equipment required for pre-combustion capture. The lower share figure for CO_2 compressors reflects the fact that this type of equipment is supplied by international rather than UK companies.

Table 8: UK companies' share (%) in meeting the investment needed (£m) in delivering CCS capacity in the UK

Component	Share of business area in component cost, %					
	Project Management	Design & Engineering	Procurement	Manufacture	Construction	Commissioning
Boiler	50%	50%	25%	25%	75%	75%
Gas turbine	20%	10%	5%	5%	20%	20%
Steam turbine	20%	10%	5%	5%	20%	20%
HRSG	25%	15%	15%	15%	25%	25%
Gasifier	20%	10%	5%	5%	20%	20%
Environmental controls	20%	20%	20%	20%	20%	20%
Balance of plant	50%	50%	40%	40%	50%	50%
CO_2 Capture	50%	50%	40%	40%	50%	50%
CO_2 Transport	50%	50%	50%	50%	50%	50%
CO_2 Storage	35%	35%	35%	35%	35%	35%

Source: Data based on AEA study in 2010 and verified by stakeholders for this study. In the original study in 2010, these data was obtained based on a comprehensive and detailed stakeholder consultation through a questionnaire prepared by AEA

Table 9: UK companies' share in the manufacture of CO_2 capture components

Post combustion capture		**Pre-combustion capture**	
Components	**Share of UK market, %**	**Components**	**Share of UK market, %**
Direct contact cooler	80%	Air separation unit	20%
Flue gas blower	80%	Water gas shift reactor	20%
CO_2 absorber	30%	Heat exchangers	80%
Heat exchanger	80%	Selexol absorbers	20%
Pumps	80%	Power recovery turbines	20%
Regenerator	30%	Tanks	20%
Reboiler	50%	Recycle compressors	20%
Steam extractor	50%	Selexol pumps	20%
Sorbent reclaimer	20%	Refrigeration	20%
Sorbent processing	20%	CO_2 compressor	20%
CO_2 compressor	20%		

Source: Data based on AEA consultation for this project
Notes:

(1) Oxyfuel is broken down by component as in Table 5,
(2) The manufacturing cost of transport and storage is that of the pipeline, re-compression stations, injection equipment, etc. and is calculated based on the manufacturing share in Table 6.

2.3.8 Average rates (£/year per employee)

Average rates (i.e. £/year per employee) were used to estimate the labour associated with the overall level of CCS investment. The rates in Table 10 take into account the labour content associated with each of the business areas. For example, while project management has a labour content of 100%, manufacturing (mostly material and equipment cost) has a much lower labour content. This allows the estimation of jobs associated with the investment required without double counting. The average rates in Table 10 are based on figures reported in Blue Book 2008 and converted into 2010 prices.

Table 10: Average rates by business area[15]

Business area	Average rate, £000
Project management	90
Design & Engineering	60
Procurement	60
Manufacturing	60
Construction	35
Commissioning	60
Legal & financial	90

These rates are assumed constant for purposes over the period of analysis

2.3.9 Labour breakdown by skill category

As described above, the labour required in the period 2021 to 2030 was estimated by dividing the investment required under the different business areas by the average rates (£/year per employee) for the given business area. This approach was applied to the categories listed in Section 2.3.5 using the average rates in Table 10.

The current capability in terms of UK skills was based on the investment required in 2020 in the different business areas. The difference between total skills required to service the UK CCS market and the current and near future UK skills capability was then estimated. This gives an indication of the scale of the opportunity available to the UK if it were to further develop and grow its CCS supply chain.

The total number of jobs required, current capability and maximum employment growth potential can be split into different skill category areas as described in Section 2.2.4. The nature of categories of skills involved in the construction of the CCS chain is based on a 2010 study undertaken by the Industrial and Power Association[16]. The breakdown of jobs by skill category is based on the questionnaire responses and feedback from stakeholders (Appendix C).

3 Estimation of market from the operation of CCS plants

3.1 Overall Approach

The CCS market has also been estimated for the operational phase. Both fixed (labour and material) and non-fuel variable costs (e.g. amine solvent) were considered. Data were obtained on the operational costs (£/MWh) of power plants with CCS. The annual market was then estimated as described on Section 3.2.

The categories considered for each of the technologies were:

- Fixed costs: labour and maintenance material; and

[15] ONS (2008), UK National Accounts (Blue Book) 2008
[16] Alan Young, Richard Catterson and Mike Farley, Carbon Capture and Storage Skills Study, 2010

- Variable costs: these were considered as non-CCS variable costs, CO_2 capture, CO_2 transport and CO_2 storage.

The CO_2 capture component was split into several categories depending on the technology. For post-combustion capture, the categories covered (under variable costs) included:

- Amine solvent;
- Other chemicals necessary for operating the capture plant (i.e. caustic soda and activated carbon); and
- Electricity for operating the compressor, flue gas blower and pumps.

For pre-combustion capture, the costs considered included solvent costs and electricity costs. For oxyfuel, the major non-fuel cost associated with CO_2 capture is the energy required for running the ASU. CO_2 transport and storage variable costs were considered as separate components each.

3.2 Methodology and Data

The operational CCS market was analysed as follows:

- The operating costs for the four main technologies (PC, IGCC, oxyfuel and CCGT) were obtained (Table 11)

Table 11: Technology operating costs[17]

Technology	Operating costs, £/MWh
PC + CCS	11.2
IGCC + CCS	8.1
Oxyfuel	8.0
CCGT + CCS	3.0

- The operating cost (£/MWh) was converted to £/year based on the deployment levels within the base scenario and using a load factor of 85% for all technologies
- The total O&M cost was split into fixed and variable costs.
- The fixed costs were then split into ‘labour’ and ‘maintenance material’ costs.
- Variable costs exclude fuel costs.
- The share of the different categories (as shown in Table 12) of the total operating costs was estimated based on the Integrated Environmental Control Model (IECM)[18] which provides estimates of the cost breakdown.
- The total O&M cost (£/year) was split into the different cost categories shown in Table 11 as follows. Starting with the total O&M cost for the whole plant (both CCS and non-CCS)
    - Column 1: is used to estimate the total fixed O&M costs (both CCS and non-CCS). The balance is the total (both CCS and non-CCS) variable costs of the plant.
    - Column 2: is used to estimate the fixed cost which is attributed to CCS only. The balance is fixed costs associated with the non-CCS part of the plant
    - Column 3: is used to split the total variable cost into CCS and non-CCS variable costs

[17] Machteld et. al., Effects of technological learning on future cost and performance of power plants with CO_2 capture, Progress in Energy and Combustion science 35 (2009) 457-480.
[18] http://www.cmu.edu/epp/iecm/

- Column 4: is used to estimate the labour costs associated with the non-CCS part of the plant. The balance is the cost attributed to material costs.

- Column 5: is used to estimate the labour costs associated with the CO_2 capture plant. The balance is the cost attributed to material costs.

Table 12: Breakdown of total O&M costs into fixed and variable costs

	Column 1	Column 2	Column 3	Column 4	Column 5
Technology	Share of fixed costs in O&M costs, %	Share of CCS fixed costs in total fixed costs, %	Share of CCS variable costs in total variable costs, %	Share of **labour costs** in Non-CCS fixed costs, %	Share of **labour costs** in CCS fixed costs, %
PC + CCS	35%	25%	70%	60%	50%
IGCC + CCS	45%	20%	60%	65%	55%
Oxyfuel	40%	25%	65%	60%	50%
CCGT + CCS	45%	45%	100%	65%	55%

Source: analysis using IECM

- The variable costs were further broken down into material costs based on the figures in Table 13.

- Under the base scenario, the operating costs were estimated for the period 2021-2030, for the different technologies. The results were then aggregated to yield O&M costs by category (e.g. amine solvent, Selexol, labour, etc.). The results are reported as value of the CCS market for operational phase (Section 4.1.2).

Table 13: Breakdown of CO_2 capture variable costs

Variable cost category	Share in total non-fuel variable OpEx, %
CO_2 capture - Amine and other chemicals	5%
CO_2 capture - Waste disposal	2%
Electricity	50%
CO_2 transport	15%
CO_2 storage	28%

Source: analysis using IECM

4 Model results

This section summarises the model results, including market demand, estimation of current / near future capability (to 2020), supply chain growth opportunities beyond 2020 and skill demand and jobs growth opportunities beyond 2020. For the operational phase, due to lack of data on the current and near future capability of the operational supply chain, only market demand was estimated - as presented in Section 4.1.2.

4.1 CCS Market in the UK

The CCS market was estimated for both the construction and operational phase.

4.1.1 Value of the CCS market for the construction phase

The total UK CCS market for the construction phase was evaluated for the base scenario described in Section 2.3.1. The results are shown in Table 14 for the period 2021-2030.

Table 14: Market demand (£m), UK capability (£m/year) and supply chain maximum growth potential (£m) for CCS market in the UK (2021-2030)

Supply chain component		Cumulative contribution of 2020 UK supply chain capability to meeting demand (2021 –2030), £m	Cumulative Market (2021 – 2030), £m	Cumulative max. potential market opportunity for UK supply chain (2021 – 2030), £m
Project management		438	1,246	808
Design & Engineering		600	1,907	1,307
Procurement		193	919	726
Manufacturing	Boiler	229	859	630
	Steam Turbine	25	612	587
	Environmental controls	2	311	309
	Gas Turbine	8	721	713
	HRSG	4	341	337
	Gasifier	217	446	229
	Balance of plant	141	514	373
	Direct contact cooler	102	170	68
	Flue gas blower	19	32	13
	CO_2 absorber	102	454	352
	Heat exchanger	105	143	38
	Pumps	30	50	20
	Regenerator	42	189	147
	Reboiler	38	101	63
	Steam extractor	5	13	8
	Sorbent reclaimer	1	6	5
	Sorbent processing	1	6	5
	Air separation unit	42	223	181
	Water gas shift reactor	3	14	11
	Selexol absorbers	7	36	29
	Power recovery turbines	1	5	4
	Tanks	2	9	7
	Recycle compressors	2	9	7
	Selexol pumps	1	5	4
	Refrigeration	2	9	7
	CO_2 compressor	38	242	204
	CO_2 transport	120	800	680
	CO_2 storage	225	540	315
	Manufacturing sub-	1,512	6,860	5,348
Construction		1,106	2,654	1,548
Commissioning		421	1,226	805
Legal & Financial		177	499	322
Total		4,448	15,312	10,864

The total market associated with CCS represents the total investment in the different business areas needed to achieve the required CCS deployment. This provides an indication of the scale of the total future UK CCS-related business opportunities available to UK (and overseas) companies.

Under the base scenario, the total cumulative CCS market in the UK to 2030 is £15.3bn, with the total UK market being around £2.7bn/year in 2030.

As discussed above, the manufacturing market is further split into markets for the different components. Table 14 shows that about 45% of the total CCS market to 2030 is related to manufacturing. This is followed by construction, design & engineering and project management.

Table 14 also suggests that UK companies have a substantial opportunity to develop their businesses several, specific supply chain categories, although there is a significant potential in all business areas (The highest value is under construction, followed by design & engineering, project management, commissioning, and procurement. For component manufacturing, areas with the highest potential in the 2020s are for gas turbines, boilers, CO_2 transport, steam turbines, CO_2 storage and gasifiers. Large markets for absorption columns, air separation units and CO_2 compressors are also expected, offering a significant business opportunity for these components, too.

4.1.2 Value of the CCS market for the operational phase

The market related to the operation of CCS plants in the period 2021-2030, based on the base scenario, is shown in Table 15. The operation and maintenance (O&M) costs used in the analysis exclude fuel costs. It show that the market value associated with operation of the plant is much lower than the market associated with the construction phase. The labour market makes up about 26-34% of the total O&M cost.

Table 15: Operational phase market

Category	Market (2021-2030)
Labour	87
Maintenance Material	55
Total fixed costs, £m	**142**
CO_2 capture	69
CO_2 transport	22
CO_2 storage	41
Total variable costs, £m	**132**
Total O&M over period, £m	**274**

4.2 Estimate of current and near future supply chain capability

The current and near future capability of the UK supply chain (in £m/year) is assessed as described in Section 2.2.2. This is based on the fact that UK companies have existing capability to deliver CCS projects in the short term. The potential share of UK companies in the 2020 CCS market was based on the 2010 AEA study and verified with stakeholders for this study.

This study assumes that there will be 2 GW of CCS by 2020. The share of the year 2020 of this cumulative market is about £1.2bn/year. The UK capability for the different components listed in Figure 1 is estimated based on the 2020 market. The results are shown in Table 14.

Table 14 shows that the total UK capability (£463m/year) is about 38% of the 2020 market.
The 2020 UK capability (£m/year) figures in Table 14 are held flat until 2030, because a detailed assessment of potential growth opportunities for the UK supply chain in the 2020s was beyond the scope of this project. The cumulative baseline capability level during the 2020 decade is then calculated by multiplying each of the supply chain capability figures by 10 (i.e. each of the years between 2021 and 2030). One can also see that the UK is expected to already have well established capabilities in key areas such as construction activities, design and engineering and project management by 2020.

4.3 Supply chain potential growth beyond 2020

Maximum potential growth in the UK supply chain from 2020 to 2030 was assessed as described in Section 2.2.3. This takes into consideration future demand in the different supply chain categories listed in Figure 1 and the current and near future capabilities in the UK. The annual deployment levels are in line with those described at the beginning of Section 2.3.1.

Table 14 above shows that opportunities for growth exist in most categories of the supply chain. This provides an opportunity for UK companies. It is also noted that UK companies have the capability to deliver several components as part of post-combustion plants (e.g. direct contact coolers, heat exchangers, pumps). There may be further potential for growth associated with export opportunities, as assessment of which was beyond the scope of this study. However, any UK CCS demand not satisfied by the UK supply chain is expected to be filled by the global supply chain.

4.4 Skill demand and maximum potential job growth

The total labour (man-years) required under the base scenario was estimated based on the approach described in Section 2.2.4. The results are summarised in Table 16. A similar trend is observed for labour demand as for the market demand discussed in Section 4.1. Most labour is required in the manufacturing and construction sectors.

Table 16 below also shows the opportunities for employment growth across the seven main business areas. Table 17 below shows the split of potential employment growth into different discipline categories based on the data provided in Appendix C. From the table, it can be seen that the largest potentials for employment growth are in the area of mechanical and process engineering.

It should be noted that the development, planning and construction of a power plant with CCS takes 5-6 years. Most of the engineering skills will be required during the planning and design phase (years 1-2 of a project) while jobs in the construction industry will mostly be required during the construction phase (year 3-5 of the project). There may be further potential for growth associated with export opportunities, as assessment of which was beyond the scope of this study.

Table 16: The total labour (1000 man-years) required

Supply chain component	Market (2021 – 2030)	Difference between UK 2020 capability and market demand (2021 – 2030)
Project management	13.8	9.0
Design & engineering	31.8	21.8
Procurement	15.3	12.1
Manufacturing	114.3	86.2
Construction	75.8	44.2
Commissioning	20.4	13.4
Legal & Financial	5.5	3.6
Total, 1000 man-years	277.1	190.3

The market demand figures reported here are calculated from investment based on average employee rates (£/year per employee) which account for the labour content of investment (Section 2.3.8)

It should also be noted that the analysis undertaken for this study does not account for people leaving other sectors (e.g. oil and gas) and joining the CCS sector, and so jobs shown in Tables 16 and 17 are not necessarily net new jobs. The figures provided below are the maximum additional level of employment (beyond the 2020 level) which can be captured by UK skills to 2030, not the total numbers of man-years deployed on activities related to the UK CCS market.

Table 17: Employment growth opportunities broken down by category (1000 man-years)

Skill category	Difference between UK 2020 capability and market demand (2021 – 2030), 1000 Man-years
Mechanical engineering	79.0
Process engineering	35.8
Civil engineering	16.6
I & CE engineering	24.7
Offshore engineering	6.4
Crafts	22.8
Geology	0.7
Legal & financial	5.6

There may be further potential for growth associated with export opportunities, as assessment of which was beyond the scope of this study. However, any UK CCS demand not satisfied by the UK supply chain is expected to be filled by the global supply chain.

5 The CCS supply chain in the UK

This section discusses the strengths and weaknesses of the CCS supply chain in the UK; it begins by outlining the results from the stakeholder questionnaire.

5.1 Stakeholder consultation

The analysis of the current UK supply chain capability is drawn from the views of a number of industry experts. These experts were consulted during the course of the project on the current UK capability in different areas of the supply chain. A stakeholder questionnaire (Appendix D) was developed and shared with UK stakeholders for views on the strengths and weaknesses of the UK supply chain compared to the global supply chain. The stakeholders responding to the questionnaire are listed in Appendix B. The questionnaire was followed by telephone conversation with the stakeholders to discuss the main issues related to the CCS supply chain.

Individual responses from the questionnaire were collated as shown in Figure 9, where industry experts rate UK and global capabilities as high, medium or low. The figures shown indicate the number of respondents who selected each of the categories as their answer. There was naturally a degree of variation between the views of those consulted, reflecting different opinions and differing degrees of familiarity with different aspects of the CCS supply chain. Where possible, the analysis gives greatest credence to the views of those with expertise in particular aspects of the supply chain.

The stakeholder responses show that the UK supply chain has moderate to high capability in most categories of the supply chain. Industry experts believe that the UK supply chain has a strong base from which to deliver CCS during the early commercialisation phase (i.e. early projects under the Commercialisation Programme), providing a good base for the supply chain in the decade that follows (i.e., the 2020s).

The different parts of the CCS chain (capture, transport and storage) have individually been in operation worldwide. The expertise required to construct and operate CCS plants within the power sector can be readily developed based on these existing experiences. UK companies have the capability to develop leading expertise in the different areas of the supply chain.

Careful examination of the questionnaire responses and the follow-up discussions with stakeholders show that the UK supply chain has a capability at the same level as the global capability in most categories. The low capability in 'oxyfuel' and 'CO_2 monitoring instrumentation' is a global rather than UK-specific feature. There is, however, a need for additional expertise in the UK in categories related to CO_2 capture, mainly in pre-combustion capture, air separation (where there are currently no centres of technical expertise or manufacturing sites in the UK) and CO_2 compression.

In the case of pre-combustion capture, industry experts consulted believe that the UK supply chain lags behind the global supply chain. In the case of environmental impact assessment (EIA), on the other hand, industry experts believe that the UK has a higher capability than other countries. This is attributed to the fact that one of the first EIA studies on a CCS plant was undertaken in the UK (for the previously planned plant at Peterhead by BP, which was cancelled in 2007).

Figure 9: Summary of stakeholder responses on the relative capability of the UK supply chain

Value chain category	UK Capability			Global capability		
	Low	Moderate	High	Low	Moderate	High
CO_2 Capture						
Post-combustion capture	0	3	4	0	1	6
Pre-combustion capture	2	5	0	0	2	4
Oxyfuel	3	3	1	1	5	1
Balance of plant	0	4	3	0	1	6
Design, build and commissioning	0	1	6	0	0	7
Operation and maintenance	0	2	5	0	2	5
Monitoring and testing	0	6	1	0	6	1
R&D	0	2	5	0	2	5
Consultancy	1	2	3	0	3	3
CO_2 transport						
Design, build and commission	1	1	4	0	2	4
Pipeline suppliers	1	1	4	0	1	5
Welding services	0	2	4	0	1	5
Pipeline risk assessment	1	1	4	0	2	4
Network management	2	0	4	0	2	4
R&D	0	2	4	0	1	5
Consultancy	0	2	4	0	1	5
CO_2 storage						
Injection well design, build and	0	3	3	0	2	4
Reservoir operations	0	2	4	0	1	5
Field services	1	1	4	0	2	4
CO_2 monitoring instrumentation	2	4	0	1	5	0
R&D	0	2	4	0	1	5
Consultancy	0	3	3	0	2	4
Related activities						
Legal services related to CCS	1	1	4	0	2	4
Financing and insurance services	5	0	2	3	2	2
Environmental impact assessment	1	1	5	1	3	3
Planning	2	1	4	0	3	4
GHG accounting and verification	1	3	2	0	4	2

* The figures in the table refer to the number of respondents

5.2 Strengths and weaknesses of the UK CCS supply chain

Based on experiences from the power, process and oil & gas industries, it can be said that the UK has existing capability to deliver many parts of the supply chain for the early CCS commercial plants. However, as the rate of deployment increases rapidly, the UK CCS supply chain needs to grow significantly. In addition, in order to remain competitive, the UK CCS supply chain will need to develop new expertise such as, for example, expertise in CO_2 capture technologies with lower energy consumption (Section 5.2).

The strengths and weaknesses identified for this study are discussed below. One should note that weaknesses per se are not evidence of a supply chain barrier - as barriers are construed as impediments that will not resolve themselves as CCS deployment grows. Indeed, UK expertise may well increase in areas of UK comparative weakness (discussed below) as the UK CCS market expands.

Some of the strengths offered by the UK supply chain include:

- Many areas related to CCS such as consulting, engineering design and equipment suppliers for both power and process plants and offshore engineering firms. UK businesses have the capability of supplying plant equipment such heat exchangers, pumps and pipes and fans;

- Many of the UK companies active in the development of CCS are members of the UK Carbon Capture and Storage Association (CCSA). The CCSA is one of the first CCS-focussed organisations worldwide and now has a membership of over 60 organisations[19]. The membership of the CCSA includes companies covering the whole supply chain - including academic institutions, consultant engineers, utility companies, insurance companies, process industries, oil and gas companies, law companies, engineering contractors and project developers;

- The skills and supply chain requirements for CO_2 capture are similar to the current practice in other industries in the UK. For example, post-combustion capture is currently being applied in natural gas sweetening to reduce the content of CO_2 in natural gas to levels below 2%[20];

- The skills and capabilities required for CO_2 storage and transport are similar to those in the oil and gas industry. First movers which have already emerged in the CCS supply chain are oil and gas companies which are looking to expand into new areas. The supply chain in the oil and gas industry is established and it is likely that the CCS supply chain will closely resemble it. Nevertheless, new supply chain needs such as storage site characterisation, storage site risk assessment and CO_2 shipping will emerge as part of the new CCS supply chain;

- There are already several thousand employees[21] working in the CCS area in the UK in academia, industry and Government;

- Several universities in the UK have already started MSc and PhD CCS programmes;

- Several UK consultant engineering companies are involved in CCS projects overseas;

- There are several large CCS pilots in the UK including CCPilot100+ and Oxycoal;

- Around twelve major companies and many other smaller companies in the UK are involved in collaborative R&D projects; and

- Many equipment suppliers for supplying pumps, heat exchangers, fans, control systems exist in the UK.

The sections below give more detail on the expertise and capability of the UK supply chain in different parts of the CCS chain.

5.2.1 CO_2 capture capability

Strengths
The UK has a strong power plant and process engineering capability. In addition, the UK has strong expertise in the design, build & commissioning, operation & maintenance (including solvent manufacturing) and R&D activities related to CO_2 capture. The current UK market for CO_2 capture in comprises several small scale projects ranging from pilot scale plants to feasibility and front end engineering design (FEED) studies. The integration of capture technologies into the power plant, where the UK has significant expertise[22], can provide a significant opportunity for UK businesses to develop as part of the supply chain.

The UK has strong capability in post-combustion capture and is developing expertise in oxyfuel combustion. The UK supply chain has the necessary technical expertise to design, build and operate post-combustion capture. Amine-based CO_2 capture is a mature technology which has been in application for many decades for the removal of carbon dioxide from hydrogen in ammonia plants and from natural gas. This technology, which is the technology of choice for post-combustion capture, has not yet been tested on a large scale for CO_2 capture from flue gas in power plants.

[19] http://www.ccsassociation.org/about-us/our-members/
[20] The prevailing technology for separating CO_2 from natural gas is amine-based chemical absorption. This technology has been in practice worldwide for many decades but at a smaller scale than would be experienced in fossil fuel power plants.
[21] This includes people working in all areas and activities related to CCS (consultancy, R&D, academia, engineering, etc.) and does not necessarily mean that their work is only related to CCS.
[22] P.Simmonds, J. Lonsdale and D. Musco, A study to explore the potential for CCS business clusters in the UK, DECC, 2010

Research is underway in the UK to develop new technologies (e.g. membranes, adsorption) for the removal and capture of CO_2. Research is also underway in the UK to develop the next generation of solvents exhibiting lower energy requirements and lower evaporation and degradation losses.

Weaknesses

Pre-combustion capture

Pre-combustion capture is an area of weakness in the UK supply chain compared to the global supply chain. Currently there are only four IGCC power plants in operation worldwide and none in the UK. Physical absorption, the CO_2 removal technology of choice for pre-combustion capture, has been in use worldwide for many decades. There are several commercially-available physical absorption processes (e.g. the Selexol and Rectisol processes) but these are owned by companies outside the UK. In addition, while tests have been undertaken in the UK on post-combustion capture (e.g. at Didcot and Longannet power stations and currently the pilot scale at Ferrybridge) and oxyfuel (e.g. Oxycoal), there have been none on pre-combustion capture to date.

Air separation

Air separation units are a major part of oxyfuel and IGCC power plants. The major manufacturers and suppliers of air separation units are German and U.S. companies. There is also a need to reduce the significant energy consumption associated with air separation (but this a global rather than UK specific issue).

CO_2 compression

One of the areas where the UK supply chain needs to develop is CO_2 compression. CO_2 compressors require very large engines and will consume a large proportion of the power plants. The cost of a compressor comprises about 5-10 % of the capture plant capital cost. The UK has no capability in the manufacturing of the major compressor package but UK companies have expertise in many of the components used in these compressors, such as intercoolers, valves and pipework, which can be sourced locally in the UK. As a result, the CO_2 compressor may be a future area of interest and target for research in the UK in order to improve capability of UK companies.

CO_2 monitoring

CO_2 monitoring is another area where supply chain expertise is required in the UK and globally. There is a need to develop instruments and expertise for CO_2 monitoring and for the accurate measurement of CO_2 flow rates. So far, monitoring has been tested at pilot scale plants and through research projects but it still needs to be tested on a large scale.

5.2.2 CO_2 transport capability

Strengths

The UK has strong capability in the construction and operation of transport pipelines. Currently there are thousands of miles of CO_2 pipeline in operation in the U.S. and so it is believed that operating CO_2 transport pipelines will not raise any major challenges. CO_2 streams from power plants will, however, contain impurities which are not currently experienced in gas transport, and so this will lead to changes in CO_2 flow properties. These issues can be easily dealt with proper design of the CO_2 pipeline.

The UK has high capability in pipe laying, both onshore and offshore. Aberdeen-based companies, for example, have sub-surface capabilities which are widely recognised by the oil and gas industry as one of the best in Europe. This is also combined with significant capability in support ancillary services. In addition many existing assets, such as pipelines, thermal plants and offshore platforms, can be reused, albeit with modifications. The UK also has good expertise in gas pipeline build and welding and in network management. Experience from the North Sea oil industry has led to the development of high standards of integrity and safety.

In conclusion, the UK has a competitive advantage over other countries because of its well-established oil and gas industry. The UK is currently well placed to develop the CO_2 transport infrastructure required for early CCS projects. The UK has the capability to meet future needs and this area is not likely to act as a barrier to future CCS deployment.

Weaknesses
UK companies may still have international competition in areas such as network management and pipeline risk assessment in addition to pipeline supply and consultancy and R&D.

5.2.3 CO_2 storage capability

Strengths
The UK has strong capability in all CO_2 storage activities including reservoir operations and field services due to existing expertise in the UK oil and gas industry.

The UK has existing expertise and capability in sub-surface analysis, exploration, and design. In addition, the UK has sufficient, accessible offshore storage in the North Sea. Furthermore, academia in the UK is at the forefront of CO_2 storage R&D (e.g. British Geological Survey and Scottish Centre for Carbon Storage).

The UK experience from the North Sea oil and gas industry combined with the abundance of offshore geological sites provide an important storage business opportunity of European significance. The oil and gas supply chain in the UK is well placed in terms of skills and capability to serve the CCS industry both for domestic projects and overseas.

Weaknesses
Some of the areas where expertise in the UK can be developed storage site characterisation, storage site risk assessment and CO_2 shipping.

5.2.4 Other CCS-related capability

The UK supply chain also has strong capability in ancillary services associated with CCS such as planning, environmental impact assessment, managing public perceptions, verification, financing, insurance and legal services.

5.2.5 Skills

The skills associated with CCS are similar to those currently encountered in the energy, process and oil and gas industries. As a result, the deployment of CCS will require expertise that is currently available in the UK. In addition, several universities throughout the UK are creating programmes for training CCS graduates. However, the number of skilled employees required to deliver CCS deployment levels seen in the base scenario are significant. A shortage of engineering skills and construction workers may also result due to competition with other industries within and outside the UK.

5.3 Supply Chain barriers to the deployment of CCS

This section outlines the potential supply chain barriers which could affect the development of the CCS supply chain in the UK.

5.3.1 The CCS supply chain

It is evident from the analysis that there is scope for the development and growth of the CCS supply chain in the UK, particularly where the UK is deemed relatively weak. However, some potential barriers to CCS deployment may exist.

Supply chain structure

One such potential barrier is uncertainty over the future CCS industry structure. This is because the deployment of CCS will require the creation of value chains across previously separate areas - such as power plants, capture plants, transport pipeline and storage site in addition to other cross-cutting services - and here uncertainty over the degree of integration across these areas could be important. For example, if companies in the power sector (who currently have their own established supply chains) were to expand their operations to cover CO2 transport and storage, it would require them to expand their supply chains into these areas as well.

Several possibilities exist for the shape that the CCS industry may take. Based on the current characteristics of the energy industry, it is expected that the power generation and capture plant will have some common skills, capability and business model requirements. As a result, it is likely that the power and capture plant value chains will be separate from those of transport and storage. The transport and storage value chains, on the other hand, may be joined together or they may be separated into two different industries. In addition, offshore and onshore storage or transport can have different business models as the case is currently for gas pipeline transport in the UK[23].

The traditional approach in the power generation industry is to contract one of the engineering and construction companies to design and build the power plant. For power plants with post-combustion or pre-combustion CO_2 capture using chemical solvents, the process engineering industry will have a major role to play. It is likely that a process engineering company will design and manage the construction of the capture plant and will contract some of the manufacture and installation to specialist component manufacturers.

Early deployment of CCS may be undertaken as single projects from beginning to end managed by the power plant owner or by a consulting engineering firm[24]. However, as the infrastructure for transport and CO_2 storage develops, the construction of the capture plant may be undertaken as a separate project integrated with the power plant construction while the transport and storage site development will be undertaken by a different supply chain.

Lack of clarity on the industry structure may present a barrier to UK or global companies as it introduces uncertainty which could hinder investment decisions.

Technology-specific barriers

Another potential barrier, the major technology-specific one which needs to be overcome, is developing the supply chain for air separation which will then allow for wider deployment of pre-combustion capture and oxyfuel. In addition, CO_2 compression and CO_2 monitoring instrumentation are two areas where additional know-how and expertise is required in the UK.

Uncertainty about investment in supply chain infrastructure

Another potential barrier is the concern that investment in CCS research and development and skills could be lost overseas. While this risk applies to many sectors, in the case of CCS, the door is wide open for new innovations such as the development of new solvents and new processes in several technology areas.[25]

5.3.2 Skills

Many of the CCS skills needed are common with other related industries including chemical and process engineering, pipelines, offshore engineering and geological exploration. However, some barriers related to skills may still exist, and these are discussed below.

[23] Senior CCS Solutions, CO_2 storage in the UK – Industry Potential, 2010
[24] Department of Energy and Climate Change, Clean Coal: an industrial strategy for the development of carbon capture and storage across the UK, March 2010
[25] World Energy Council, Carbon Capture and Storage, a WEC 'Interim Balance', http://www.worldenergy.org/documents/ccsbrochurefinal.pdf, 2007.

Replacement of skills

It has been estimated by Engineering UK that another 2.2 million engineers will be required in the next 5 to 10 years in the UK across all sectors of the economy. For every new opportunity that comes from economic growth over the next 10 years, it is estimated that 10 will come from replacement demand. The main contributor to the shortage of engineers is expected to be demographic trends, i.e. skilled engineers reaching retirement age before 2020. Many of the sectors with the same skills required by the CCS industry are already reporting shortages of skilled staff.

Training needs and requirements

There are already training programmes available in the UK for training CCS graduates. However, these post-graduate and doctorate training programmes will need to expand in order to meet future demand. In addition there will be a need for short specialist courses to retrain people who transfer into CCS.

As a result, investment in new training programmes will be required. For companies to invest in training, they need to be assured that they will be able to retain these skills and that they will not be lost to other countries. The need to address education and training provision should continue such that capacity is built up in line with the needs of the UK's CCS requirements. This will need to be considered alongside other concerns regarding the potential shortage of skills at technical, graduate and post-graduate level.

Competition with other industries

It is recognised that many CCS jobs will be filled by skilled personnel transferring from other industries (e.g. oil and gas) for involvement in the UK CCS Commercialisation Programme. The success of this will, however, depend on the relative financial rewards available. For example the offshore renewables industry has found that the oil and gas industry can afford to pay considerably higher wages than they can, making it more difficult to transfer skilled staff (including contractors). It is likely that there will be a similar disparity in staff remuneration between the oil and gas (on the one hand), and CCS industry (on the other) - making it equally difficult to transfer staff.

The capacity of the supply chain can be expected to grow if there is sufficient market demand, as greater demand will allow Industry to invest in a financially viable way. The process will be "top down" with each tier reacting to the plans of the tier above.

There is currently high availability of offshore engineers, geology experts and financial expertise in the UK. This consultation showed that skills availability in engineering disciplines (mechanical, chemical, civil engineers, etc.) is moderate due to the large numbers required and because of the competition with other industries. The stakeholder consultation also revealed that, as the deployment of CCS increases, there could be a shortage of construction workers (although this is true for power plants in general - including nuclear and wind).

In addition to the available skills which can be utilised in the implementation of CCS projects, other skills will need to be developed:

- There is a need to develop skills for the commercial operation of CCS plants;
- There is also a need to develop skills required for the understanding the full environmental impact of CCS plant and designing monitoring and regulatory requirements;
- Furthermore, there is demand for skills required to oversee integration issues related to planning & permitting; and
- Finally, expertise is also required in communication in order to create public awareness of the advantages and benefits of CCS, particularly at the local, project level.

6 Sensitivity Analysis

This section discusses the effect of varying certain parameters on the ability of the supply chain to deliver the requirements in 2030. The following sensitivities are considered:

- Varying deployment levels
- Varying the fuel mix
- Increasing the deployment levels of IGCC
- Growth of the supply chain as opposed to a fixed supply chain capability

Sensitivities 1 and 2 (S-1 and S-2): Varying deployment level

A higher deployment scenario (Sensitivity 1) and a lower deployment scenario (Sensitivity 2) were considered and compared to the base scenario, as shown below.

CCS capacity, GW (gross)	2020	2025	2030
Lower deployment – S-1	2	3	5
Base scenario	2	3	10
Higher deployment – S-2	2	5	20

For both deployment sensitivities, the 2020 level of deployment was kept the same as under the base scenario (2GW). The technology mix was also kept the same as the base scenario throughout. All the installed capacity between 2025 and 2030 was assumed new capacity - as in the base scenario. The supply chain and employment maximum growth potentials are compared in Figure 10.

It is observed that the market demand increases proportionally with deployment levels. The maximum potential for UK supply chain growth in the 2020s reduces to £1.2bn for the lower deployment scenario and increases to £29.9bn for the higher deployment scenario.

Sensitivity 3 and 4 (S-3 and S-4): Variation of the fuel mix between 2020 and 2030

The sensitivity of changing the fuel mix in the period 2026-2030 was investigated by looking at the two extremes: Sensitivity 3 (S-3) considers a case where all CCS in the second half of the 2020s is installed on new CCGT plants, while sensitivity 4 (S-4) considers a scenario where all CCS installed over the same period is on new coal plants. For S-4, the technology mix for PC, IGCC and oxyfuel is kept the same as for the base scenario; these results are also shown in Figure 10.

Sensitivity 4 shows a higher market demand due to the higher investment associated with coal power plants[26]. In comparison to the base scenario, the maximum potential for UK supply chain growth in the 2020s as a percentage of total market demand reduces when more CCS is installed on gas power plants. This is due to the decreasing market demand and to higher UK capability associated with post-combustion capture (the technology of choice for CCGTs).

Sensitivity 5 (S-5): All CCS on coal is IGCC with pre-combustion capture

This sensitivity investigates the effect of all CCS-on-new coal in the period 2026-2030 is on IGCC plants - with no new PC or oxyfuel plants. The share of CCGTs is the same as under the base scenario.

Again, the results are shown in Figure 10. These show that the change in the UK CCS market and UK supply chain maximum potential for UK supply chain growth in the 2020s relative to the base scenario

[26] The costs associated with CCGT are approximately one half of those associated with coal power plants as evident from Table 3 and so the value of the market and consequently the gap are expected to be at the low end. It should be noted that the figures in Table 3 are assumed fixed and so the costs used here do not take account of learning.

is minor. This is because, as seen from Table 3, the costs associated with constructing PC, IGCC and oxyfuel power plants are similar.

Table 7 shows that the current / near future UK capability in pre-combustion capture is lower than for post-combustion capture. This, however, does not affect the size of the maximum potential for UK supply chain growth in the 2020s significantly when all coal power plants between 2025 and 2030 are IGCC (with pre-combustion capture). This is because the demand in CCS services and components is significant in comparison to the current / near future capability.

Sensitivity 6 (S-6a and S-6b): Growth in the CCS supply chain after 2020

This was considered in order to investigate the difference that a growing supply chain would have on the overall level of UK supply chain activity in the 2020s and the difference between that and total UK CCS market demand. Two sensitivities were considered. In sensitivity S6-a, a growth rate of 4.5% per annum was used, and in sensitivity S-6b, a growth rate of 1% per annum was used.

We believe that the ranges tested here (1 – 4.5% per annum) represent conservative assumptions of future CCS supply chain growth (providing a cumulative growth by 10-60% between 2020 and 2030) and therefore provide an illustration of how the UK supply chain may grow. It should be emphasised that these growth rates are for illustrative purposes only and do not represent our view of how the supply chain will actually grow in the future (as detailed analyses of the scope of the supply chain growth was beyond the scope of this study). We also acknowledge that there may be some heterogeneity in the growth rates of different parts of the supply chain within these aggregate supply chain growth figures. This heterogeneity was also not examined, being beyond the scope of this study.

The analysis shows that even with the higher growth rate of 4.5% per annum, the UK supply chain would not grow fast enough to meet all of UK CCS demand. With the lower growth rate, the difference between UK CCS market demand and UK supply chain sales reduces by 3% relative to the base case (flat UK capability from 2020) while for the higher growth rate the difference reduces by 29% relative to the base case. It would be expected that the difference would be able to be met by the global supply chain.

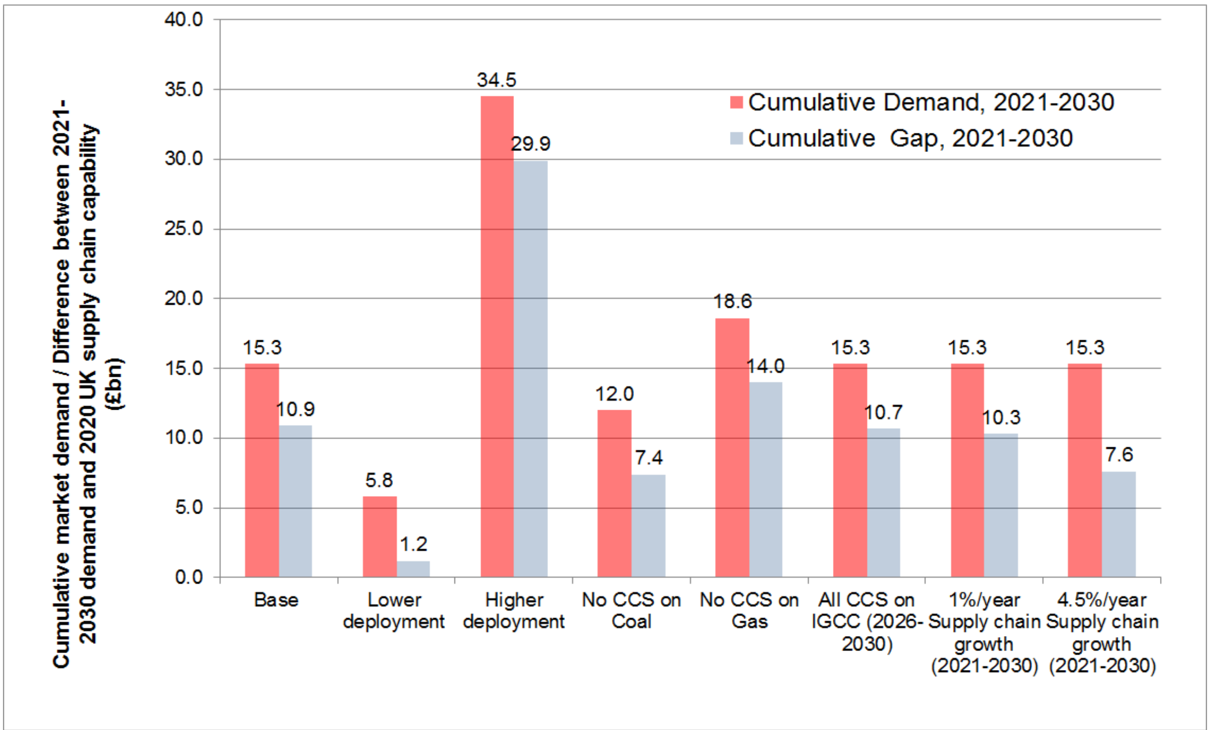


Figure 10: Sensitivity analysis

7 Conclusions

Our analysis found that there are currently no significant supply chain barriers that could inhibit the commercial roll out of CCS within the UK power sector in the 2020s. However it also found that some CCS related potential barriers may still exist.

One such potential barrier is uncertainty over the future CCS industry structure. This is because the deployment of CCS will require the creation of value chains across previously separate areas - such as power plants, capture plants, transport pipeline and storage site in addition to other cross-cutting services - and uncertainty over the degree of integration across these areas could be important. For example, if companies in the power sector (who currently have their own established supply chains) were to expand their operations to cover CO2 transport and storage, it would require them to expand their supply chains into these areas as well. Lack of clarity on the industry structure may present a barrier to UK or global companies as it introduces uncertainty which could hinder investment decisions.

Several possibilities exist for the shape that the CCS industry may take. Based on the current characteristics of the energy industry, it is expected that the power generation and capture plant will have some common skills, capability and business model requirements. As a result, it is likely that the power and capture plant value chains will be separate from those of transport and storage. The transport and storage value chains, on the other hand, may be joined together or they may be separated into two different industries. In addition, on- and offshore CO2 transport could have different business models as the case is currently for gas pipeline transport in the UK[27].

The traditional approach in the power generation industry is to contract one of the engineering and construction companies to design and build the power plant. For power plants with post-combustion or pre-combustion CO_2 capture using chemical solvents, the process engineering industry will have a major role to play. It is likely that a process engineering company will design and manage the construction of the capture plant and will contract some of the manufacture and installation to specialist component manufacturers.

Early deployment of CCS may be undertaken as single projects from beginning to end managed by the power plant owner or by a consulting engineering firm[28]. However, as the infrastructure for transport and CO_2 storage develops, the construction of the capture plant may be undertaken as a separate project integrated with the power plant construction while the transport and storage site development will be undertaken by a different supply chain.

Another potential barrier is the concern that the returns from investment in CCS research and development and skills could be lost to overseas. While this risk applies to many sectors, in the case of CCS, the door is wide open for new innovations such as the development of new solvents and new processes in several technology areas.

Another potential barrier, the major technology-specific one which needs to be overcome, is developing the supply chain for air separation which will then allow for wider deployment of pre-combustion capture and oxyfuel. In addition, CO_2 compression and CO_2 monitoring instrumentation are two areas where additional know-how and expertise is required in the UK.

The study also found that there are some potential barriers around skills. This skill barrier is likely to be primarily a numerical supply issue rather than an issue of expertise (i.e. one where demand outstrips supply). One of the issues which emerged from this study is that the significant demand in the CCS industry could lead to low availability of engineering skills and construction force as a result of competition with other industries, such as wind and nuclear.

Training programmes are currently available in the UK for training CCS graduates. However, these post-graduate and doctorate training programmes will need to expand in order to meet demand. In addition there will be a need for short specialist courses to retrain people who transfer into CCS. The

[27] Senior CCS Solutions, CO_2 storage in the UK – Industry Potential, 2010
[28] Department of Energy and Climate Change, Clean Coal: an industrial strategy for the development of carbon capture and storage across the UK, March 2010

need for education and training provision will continue to build in line with UK CCS demand. This will need to be borne in mind alongside the potential shortages of skills at the technical, graduate and post-graduate levels.

A related potential barrier is that competition for skills (particularly related to construction and engineering) between the renewable, nuclear and CCS industries in the late 2020s could limit the availability of the required skill labour for the UK supply chain.

Finally, there are some categories where the UK is currently behind in terms of expertise, and these could become important in the 2020s. Expertise in areas related to CO_2 capture technologies, such as pre-combustion capture, air separation (where there are currently no centres of technical expertise or manufacturing sites in the UK), CO_2 compression and CO_2 monitoring instrumentation needs further development in the UK over the next decade.

Regarding the scope for growth of UK CCS supply chain in the 2020s, our analysis showed that, under the base scenario (based on DECC's Carbon Plan), the cumulative market for CCS in the UK to 2030 is valued at £15.3bn with an annual market of approximately £2.7bn/year in 2030. UK companies and businesses are currently involved in the delivery of activities related to the pilot scales being planned. It is expected that the CCS Commercialisation Programme will help the UK supply chain develop expertise and skills further. The study showed that by 2020, following the UK CCS Commercialisation Programme, the UK supply chain will be able to access 35-40% of the available UK market . The current / near future capability (based on 2020 levels) was estimated at about £0.46bn/year.

The study also estimated the difference under the base scenario during the 2020s. It found that the overall cumulative difference between market demand (between 2021 and 2030) and fixed UK supply chain capability (at 2020 levels) was around 70% of CCS market demand (or around £10.9bn). This shows the significant opportunity available for UK companies to expand their business, expertise and skill base. This assessment helped determine areas of the supply chain with high demand in the 2020s and where investment is required to develop expertise and skills over the next decade.

It was also estimated that about 280,000 man-years will be required for the deployment of CCS in the UK between 2021 and 2030 under the base scenario. The maximum potential for UK supply chain employment growth in the 2020s follows a similar trend to the maximum potential for UK supply chain growth in the 2020s. Most of the skills required are mechanical, process engineering jobs and crafts. In some areas, skills could be transferred from other sectors such as the oil and gas industry. However, the decline in numbers of experienced engineers (due to retirement) and the competition for skills with other emerging low carbon technology sectors poses a challenge to the CCS industry. In addition, the large scale of CCS deployment and competition with other sectors in the future may lead to shortage in the construction workforce.

Finally, the study found that the level of CCS deployment in the UK was likely to influence the scope for growth for the UK CCS supply chain. However, it also found that the fuel mix also matters, with coal plants requiring more investment relative to gas plants. In contrast, the type of technology used for capture (IGCC, PC, oxyfuel) did not have much bearing on the potential scope for growth in the supply chain

Appendices

Appendix A: References
Appendix B Stakeholders responses
Appendix C: Breakdown of the number of jobs for different components by skill category
Appendix D: Questionnaire

Appendix A: References

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Appendix B: Stakeholders responses

Contributions to the questionnaire were received from

The Carbon Capture and Storage Association
CCS TLM
CO_2 Sense
Doosan Babcock
Drax Power Limited
Nottingham Centre for CCS
Peel Energy
Petrofac (CO2DeepStore Ltd)
Progressive Energy
Schlumberger Carbon Services
Scottish and Southern Energy

Appendix C: Breakdown of the proportion of jobs for different components by skill categories

CO_2 Capture	Mechanical Engineer	Chemical Engineer	Civil Engineer	Electrical Engineer	Offshore Engineer	Construction Workers	Geology
Project	30%	30%	20%	20%	0%	0%	0%
Design	30%	30%	20%	20%	0%	0%	0%
Procurement	30%	30%	30%	10%	0%	0%	0%
Manufacturing	30%	30%	30%	10%	0%	0%	0%
Construction	10%	0%	10%	0%	0%	80%	0%
Commissioning	30%	40%	20%	10%	0%	0%	0%

CO_2 Transport	Mechanical Engineer	Chemical Engineer	Civil Engineer	Electrical Engineer	Offshore Engineer	Construction Workers	Geology
Project	30%	30%	10%	0%	20%	0%	10%
Design	30%	30%	10%	0%	20%	0%	10%
Procurement	30%	30%	10%	0%	20%	0%	10%
Manufacturing	50%	20%	10%	0%	20%	0%	0%
Construction	20%	20%	0%	0%	30%	20%	10%
Commissioning	-	-	-	-	-	-	-

CO_2 Storage	Mechanical Engineer	Chemical Engineer	Civil Engineer	Electrical Engineer	Offshore Engineer	Construction Workers	Geology
Project	20%	30%	0%	10%	30%	0%	10%
Design	20%	30%	0%	10%	30%	0%	10%
Procurement	40%	30%	0%	10%	20%	0%	0%
Manufacturing	50%	30%	0%	10%	10%	0%	0%
Construction	20%	10%	0%	10%	30%	30%	0%
Commissioning	20%	40%	0%	10%	20%	0%	10%

Boiler	Mechanical Engineer	Chemical Engineer	Civil Engineer	Electrical Engineer	Offshore Engineer	Construction Workers	Geology
Project	40%	30%	10%	10%	0%	10%	0%
Design	40%	30%	10%	10%	0%	10%	0%
Procurement	50%	30%	10%	10%	0%	0%	0%
Manufacturing	50%	30%	10%	10%	0%	0%	0%
Construction	20%	20%	10%	20%	0%	30%	0%
Commissioning	20%	30%	10%	20%	0%	20%	0%

Steam Turbine	Mechanical Engineer	Chemical Engineer	Civil Engineer	Electrical Engineer	Offshore Engineer	Construction Workers	Geology
Project	30%	20%	10%	30%	0%	10%	0%
Design	30%	20%	10%	30%	0%	10%	0%
Procurement	50%	10%	10%	30%	0%	0%	0%
Manufacturing	50%	10%	10%	30%	0%	0%	0%
Construction	30%	20%	10%	20%	0%	20%	0%
Commissioning	20%	20%	10%	30%	0%	20%	0%

Heat Recovery Steam Generator	Mechanical Engineer	Chemical Engineer	Civil Engineer	Electrical Engineer	Offshore Engineer	Construction Workers	Geology
Project	40%	30%	10%	10%	0%	10%	0%
Design	40%	30%	10%	10%	0%	10%	0%
Procurement	50%	30%	10%	10%	0%	0%	0%
Manufacturing	50%	30%	10%	10%	0%	0%	0%
Construction	20%	20%	10%	20%	0%	30%	0%
Commissioning	20%	30%	10%	20%	0%	20%	0%

Gas Turbine	Mechanical Engineer	Chemical Engineer	Civil Engineer	Electrical Engineer	Offshore Engineer	Construction Workers	Geology
Project	30%	20%	10%	30%	0%	10%	0%
Design	30%	20%	10%	30%	0%	10%	0%
Procurement	50%	10%	10%	30%	0%	0%	0%
Manufacturing	50%	10%	10%	30%	0%	0%	0%
Construction	30%	20%	10%	20%	0%	20%	0%
Commissioning	20%	20%	10%	30%	0%	20%	0%

Gasifier	Mechanical Engineer	Chemical Engineer	Civil Engineer	Electrical Engineer	Offshore Engineer	Construction Workers	Geology
Project	70%	30%	0%	0%	0%	0%	0%
Design	70%	30%	0%	0%	0%	0%	0%
Procurement	80%	20%	0%	0%	0%	0%	0%
Manufacturing	80%	20%	0%	0%	0%	0%	0%
Construction	10%	0%	0%	0%	0%	90%	0%
Commissioning	80%	20%	0%	0%	0%	0%	0%

Air Separation Units	Mechanical Engineer	Chemical Engineer	Civil Engineer	Electrical Engineer	Offshore Engineer	Construction Workers	Geology
Project	80%	0%	0%	20%	0%	0%	0%
Design	70%	0%	0%	30%	0%	0%	0%
Procurement	80%	0%	0%	20%	0%	0%	0%
Manufacturing	80%	0%	0%	20%	0%	0%	0%
Construction	10%	0%	0%	0%	0%	90%	0%
Commissioning	80%	0%	0%	20%	0%	0%	0%

Balance Of Plant	Mechanical Engineer	Chemical Engineer	Civil Engineer	Electrical Engineer	Offshore Engineer	Construction Workers	Geology
Project	40%	20%	20%	20%	0%	0%	0%
Design	40%	20%	20%	20%	0%	0%	0%
Procurement	40%	20%	20%	20%	0%	0%	0%
Manufacturing	40%	20%	20%	20%	0%	0%	0%
Construction	10%	0%	0%	0%	0%	90%	0%
Commissioning	40%	20%	20%	20%	0%	0%	0%

Operation	Mechanical Engineer	Chemical Engineer	Civil Engineer	Electrical Engineer	Offshore Engineer	Construction Workers	Geology	Legal
Power	35%	30%	0%	30%	0%	0%	0%	5%
Capture	50%	40%	0%	10%	0%	0%	0%	0%
Transport	20%	0%	0%	20%	60%	0%	0%	0%
Storage	0%	0%	0%	0%	80%	0%	20%	0%

Environmental Controls	Mechanical Engineer	Chemical Engineer	Civil Engineer	Electrical Engineer	Offshore Engineer	Construction Workers	Geology
Project	40%	30%	10%	10%	0%	10%	0%
Design	40%	30%	10%	10%	0%	10%	0%
Procurement	50%	30%	10%	10%	0%	0%	0%
Manufacturing	50%	30%	10%	10%	0%	0%	0%
Construction	20%	20%	10%	20%	0%	30%	0%
Commissioning	20%	30%	10%	20%	0%	20%	0%

Appendix D: Questionnaire

Part A: Current status

The table below provides a list of the different categories of the value chain required for the commercial deployment of CCS projects on coal and gas power plants. Can you please indicate using a tick (√) whether you think the capability of the global and UK industry to deliver the required CCS capacity, in each of the areas below, is

- currently, and will still in the near future be, non-existent requiring significant development (**Low**)
- currently, and considering the near future, existent but requires specific development for CCS applications (**Moderate**), or
- currently, and considering the near future, existent and ready for wide-scale deployment of CCS (**High**)

Value chain category	UK Capability			Global capability		
	Low	Moderate	High	Low	Moderate	High
CO_2 Capture						
Post-combustion capture						
Pre-combustion capture						
Oxyfuel						
Balance of plant						
Design, build and commissioning						
Operation and maintenance						
Monitoring and testing						
R&D						
Consultancy						
CO_2 transport						
Design, build and commission						
Pipeline suppliers						
Welding services						
Pipeline risk assessment						
Network management						
R&D						
Consultancy						
CO_2 storage						
Injection well design, build and						
Reservoir operations						
Field services						
CO_2 monitoring instrumentation						
R&D						
Consultancy						
Related activities						
Legal services related to CCS						
Financing and insurance services						
Environmental impact assessment						
Planning						
GHG accounting and verification						
Additional comments would be appreciated						

What do you think the strengths and weaknesses of the CCS supply chain in the UK are and why?

Strengths	Weaknesses

Considering what is required globally under the global scenario described above, what do you think the strengths and weaknesses of the global CCS supply chain are and why?

Strengths	Weaknesses

In circumstances and areas where the UK supply chain is not well-prepared to provide for the commercial deployment of CCS in the UK, the global supply chain will be utilised. Can you please comment on the ability of the global supply chain to complement the UK supply chain in low and moderate UK capability areas?

We think that, for the construction and development of CCS projects, skills are required in the following categories

- Engineering: mechanical, chemical, civil, electrical, and offshore
- Construction work
- Geology
- Legal and financial advisers

Please indicate using a tick (√) in the table below whether you think the UK and global capability in the different skill areas is

- **Low: does not exist,**
- **Moderate (exists but requires training for CCS), or**
- **High: exists and ready for CCS**

Current status of skills in the UK

	Capability		
	Low	**Moderate**	**High**
Mechanical engineers			
Chemical engineers			
Civil engineers			
Electrical engineers			
Offshore engineers			
Geology			
Construction force			
Legal services			
Financial services			

Current status of skills globally

	Capability		
	Low	**Moderate**	**High**
Mechanical engineers			
Chemical engineers			
Civil engineers			
Electrical engineers			
Offshore engineers			
Geology			
Construction force			
Legal services			
Financial services			

What other skills do you think are required for the commercial deployment of CCS on power plants?

Part B: Estimation of future needs

We will estimate future needs of the supply chain based on the investment required to achieve the CCS deployment targets. We will split the supply chain needs into different activity areas using information on the share of different components and activity areas in the total cost of different coal and gas power generation technologies with CCS. Please indicate your best estimate for the % of the skills required in each of the activity areas listed under each of the components below

CO_2 Capture	Mechanical Engineers	Chemical Engineers	Civil Engineers	Electrical Engineers	Offshore engineers	Construction workers	Geology
Project management							
Design and engineering							
Procurement							
Manufacturing							
Construction							
Commissioning							

CO_2 Transport	Mechanical Engineers	Chemical Engineers	Civil Engineers	Electrical Engineers	Offshore engineers	Construction workers	Geology
Project management							
Design and engineering							
Procurement							
Manufacturing							
Construction							
Commissioning							

CO_2 storage	Mechanical Engineers	Chemical Engineers	Civil Engineers	Electrical Engineers	Offshore engineers	Construction workers	Geology
Project management							
Design and engineering							
Procurement							
Manufacturing							
Construction							
Commissioning							

Boiler	Mechanical	Chemical	Civil	Electrical	Construction workers	**Steam Turbine**	Mechanical	Chemical	Civil	Electrical	Construction workers
Project						Project					
Design and						Design and					
Procurement						Procurement					
Manufacturing						Manufacturing					
Construction						Construction					
Commissioning						Commissioning					

Heat Recovery Steam Generator	Mechanical	Chemical	Civil	Electrical	Construction workers	**Gas Turbine**	Mechanical	Chemical	Civil	Electrical	Construction workers
Project						Project					
Design and						Design and					
Procurement						Procurement					
Manufacturing						Manufacturing					
Construction						Construction					
Commissioning						Commissioning					

Gasifier	Mechanical	Chemical	Civil	Electrical	Construction workers	**Air separation units**	Mechanical	Chemical	Civil	Electrical	Construction workers
Project						Project					
Design and						Design and					
Procurement						Procurement					
Manufacturing						Manufacturing					
Construction						Construction					
Commissioning						Commissioning					

Balance of plant	Mechanical	Chemical	Civil	Electrical	Construction workers
Project management					
Design and engineering					
Procurement					
Manufacturing					
Construction					
Commissioning					

Operation	Mechanical	Chemical	Civil	Electrical	Offshore	Construction workers	Geology	Legal	Financial
Power plant operation									
Capture plant									
Transport pipeline									
Storage site									

Costs

The table below lists different power plant components with corresponding activity areas. The share of the different activities in the total investment required in delivering each of the components is shown as a %. Do you agree with the figures stated below and if not, can you please provide best estimates in the adjacent blank cells.

% of activity area in the total investment cost of the component	**Activity area**									
	Project management		Design & Engineering		Procurement & Manufacturing		Construction		Commissioning	
Power plant component										
Boiler		5%		10%		55%		25%		5%
Steam turbine		5%		15%		60%		10%		10%
Gasifier (for IGCC)		5%		15%		60%		10%		10%
Gas Turbine (IGCC)		5%		15%		60%		10%		10%
ASU (for IGCC or		5%		10%		60%		15%		10%
Shift reactor (for IGCC)		5%		15%		60%		10%		10%
HRSG (CCGT or IGCC)		10%		10%		50%		25%		5%
Balance of plant		10%		15%		50%		15%		10%
CO_2 capture		10%		15%		50%		15%		10%
CO_2 transport		10%		10%		45%		30%		5%
CO_2 storage		15%		10%		50%		15%		10%
Comments										

We will estimate the investment costs associated with each of the components within a technology based on the total technology cost (£/kW) and the share of each of the components in the total cost. The table below lists the share (%) of total investment cost of a technology (with CCS) attributable to a given component. Do you agree with the figures stated and if not, can you please provide best estimated in the adjacent blank cells.

Technology	**Component**	**% of total technology cost**	
		Estimates based on previous study by AEA (2010)	**New estimate (if same, please leave blank)**
Pulverised coal	Boiler	15%	
	Steam turbine	15%	
	Capture	40%	
	Balance of plant	30%	
IGCC	Gasifier	20%	
	Air separation unit	15%	
	Steam turbine	20%	
	Gas turbine	20%	
	Shift reactor & capture	20%	
	Balance of plant	5%	
Oxyfuel	Boiler	25%	
	Air separation unit	10%	
	Steam turbine	25%	
	Clean up compression	5%	
	Balance of plant	30%	
CCGT	Gas turbine	10%	
	HRSG	10%	
	Steam turbine	10%	
	Capture	50%	
	Balance of plant	20%	

In the table below, legal & financial services required during the construction of different technologies are expressed as a % of the total investment costs. Do you agree with the figures stated and if not, can you please provide best estimated in the adjacent blank cells.

	Financial & legal services	
Conventional PC		2%
PC with CCS		4%
IGCC		4%
IGCC with CCS		6%
Oxyfuel		6%
CCGT		2%
CCGT with CCS		4%
CO2 capture retrofit		8%
CO_2 storage facility		8%

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