CBI Economics

Capturing the carbon opportunity

Making carbon capture and storage a reality for UK businesses

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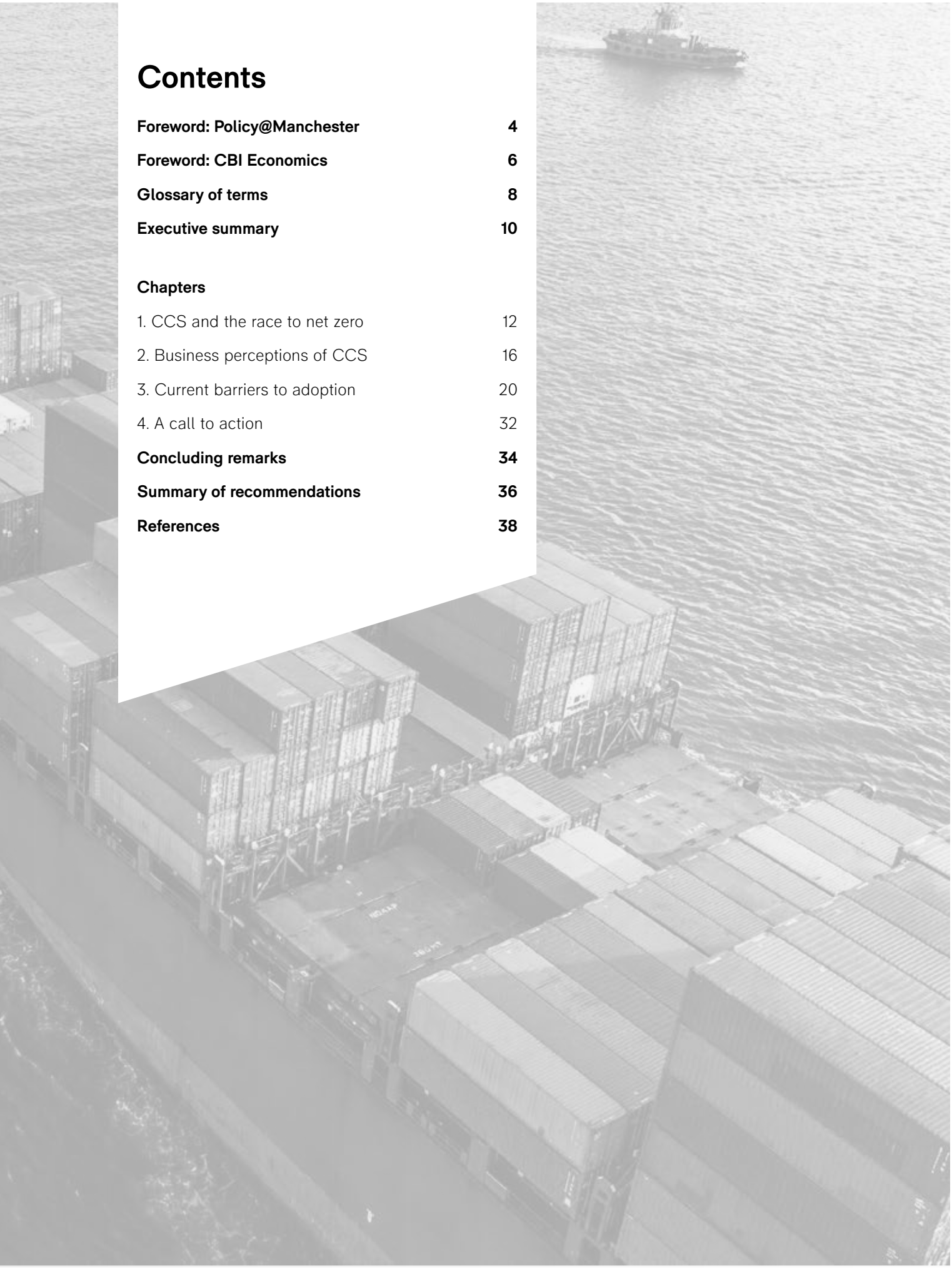
Contents



Foreword Policy@Manchester

The importance of research cannot be overstated; without it, there would be no progress. The backbone of research and development is the same questioning instinct that pushed our human ancestors to explore, to invent and to craft. Now, the research of academics can help guide the future of our society.

In my time as The University of Manchester's Vice-President for Research, I have had the pleasure of witnessing the many contributions our academics have made to policymaking. The impact of the work of the Policy@Manchester team and The University of Manchester's researchers and academics is felt in areas of government ranging from social care to heavy industry.

Research has the potential to provide policymakers with a strategic advantage, to anticipate barriers and challenges to their goals, and to effectively stimulate private industry into aligning with public sector objectives. It is my hope that this report will join the ranks of publications that will inform economic and industrial policy on CCS for many years to come.

I am pleased to introduce this joint report with CBI Economics, the economic consultancy team at the Confederation of British Industry (CBI), examining the role that carbon capture and storage can play in the UK's goal to reach net zero by 2050. As the technology develops, CCS has the potential to dramatically assist in the UK's decarbonisation ambitions.

In collaboration with CBI Economics, this report presents our findings on the potential impact of CCS, as well as the barriers to its effective implementation. Our goal is to convey these findings in an informative and relevant way to government, leaders and policymakers of all kinds, so that steps can be taken to deliver CCS as we catalyse our transition towards a low-carbon economy.

The UK has the capability to lead the global drive towards a more sustainable future, especially in CCS. We have a wealth of research at our fingertips, which, with the assistance and support of policymakers, can be utilised to scale up investment in CCS infrastructure for UK businesses.

By combining research from The University of Manchester's academics with the voices of industry, this report presents a unique perspective on the strengths, weaknesses, opportunities and threats to CCS. As climate change becomes an even more present reality of our lives, CCS has the potential to become an essential component in our aims to propel the UK closer to a sustainable future. However, that vision of the future will remain out of reach without the correct intervention of policymakers guided by expert research.

Professor Colette Fagan

Vice-President for Research,
The University of Manchester

Foreword CBI Economics

Achieving net zero greenhouse gas emissions by 2050 across the UK is a task that increases in urgency with each passing year. It is an ambitious target, but one that is achievable provided policymakers, businesses, academics and other relevant actors work together and consider the full range of approaches available.

Notable progress has been made in the last decade. The legislation of a net zero target has marked a step change in the way we view emissions reduction and the role of business in achieving this. At COP26 we saw, for the first time, government, business and civil society come together to mark this turning point. Recent years have also seen considerable innovation in decarbonisation technologies. Global industries such as carbon capture and storage (CCS) have scaled up to create jobs and new opportunities for businesses to innovate and grow. However, there is more work to be done.

This report, commissioned by Policy@Manchester, a policy engagement unit at The University of Manchester connecting researchers with policymakers, and delivered by CBI Economics, clearly highlights areas for policymakers to act on to enable businesses to grasp the potential of CCS. Through in-depth interviews with organisations throughout the CCS supply chain, CBI Economics has uncovered key barriers and challenges to making CCS a reality. Economic barriers are inhibiting the scaling up of CCS. Various uncertainties, including around the effectiveness of CCS technologies and long-term policy direction, are disincentivising investment. Limited access to vital infrastructure that enables the transport and subsurface storage of carbon, is also slowing progress.

These barriers can be overcome. In this report, CBI Economics and The University of Manchester academics have developed important policy proposals to unleash the potential of CCS. UK businesses are rightly committed to decarbonising, but if policymakers do not act soon to create the conditions for businesses to do so effectively, we will fall short of our goals.

The climate challenge is an era-defining one, and policymakers must continue to be agile in the face of evolving business needs. A continuing conversation between policymakers, academics, businesses and other organisations across the CCS supply chain is a necessity. My special thanks goes to Policy@Manchester for commissioning this report, which contributes to the conversation, and acts as a timely reminder of the challenges we still face.

Rain Newton-Smith
Chief Economist, CBI

Glossary of terms

Blue hydrogen: Hydrogen produced from natural gas and supposed by CCS.

Green hydrogen: Hydrogen produced from renewable energy sources.

CCS: Carbon capture and storage.

CCUS: Carbon capture, utilisation and storage. This differs from CCS as the captured carbon is also used in other industrial processes such as fuel and fertilisers.

BECCS: Bioenergy with carbon capture and storage. A negative emissions technology where bioenergy is paired with carbon capture and storage.

Megatonne (Mt): A unit equivalent to 1 million tonnes.

Carbon sink: A place that absorbs more carbon than it releases such as plants and the ocean.

Cluster sequencing process: The government funding process for determining the order of CCS projects for industry.

Phase-1 process: The government selection process to determine the two industrial clusters that will be taken forward by the mid-2020s.

Phase-2 process: The second phase of the government selection process to determine the next four CCS clusters, by 2030 at the latest.

Scope 1 emissions: Greenhouse gas emissions that come directly from operations that are owned or controlled by the reporting company.

Scope 2 emissions: Indirect greenhouse gas emissions that come from the generation of purchased or acquired electricity, steam, heating, or cooling consumed by the reporting company.

Scope 3 emissions: All indirect emissions (not included in scope 2) that occur in the value chain of the reporting company, including both upstream and downstream emissions.

Executive Summary

The UK government has a target to reach net zero greenhouse gas emissions across the UK by 2050. This ambitious target will necessitate a range of approaches to carbon reduction, and it is increasingly clear that carbon capture and storage (CCS) will play an important role. Businesses, as key drivers of economic growth, are also emitters, and so need to urgently adapt their business models and pivot their operations to decarbonise.

CCS is at an earlier stage of commercialisation than other decarbonisation approaches. As such, there may be barriers to the adoption of CCS by businesses, whether they be policy, regulatory, socioeconomic, or technology-related. CBI Economics was commissioned by Policy@Manchester to interview organisations across the CCS supply chain to understand perceptions of CCS, barriers to adoption, and what can be done to reduce barriers. 18 interviews were conducted in July and August 2022, including international energy companies, power generation companies, manufacturers, infrastructure and machinery companies, stakeholder groups, and businesses across various sectors. Businesses at different stages in their CCS journey were included, with some located in a CCS cluster. This report presents interview insights, case studies reflecting the views of specific organisations, and policy recommendations developed in collaboration with academics from The University of Manchester, to help make CCS a reality for UK businesses.

Findings from a literature review and subsequent organisation interviews, uncovered the following key findings around **CCS perceptions** and **key barriers to adoption:**

- There is general agreement that CCS will play a vital role in the transition to net zero, but that it must be part of a portfolio approach with other technologies
- CCS technology is generally perceived to be proven, and commercially-viable with government support. Recent momentum in CCS adoption is perceived to be strong, but with more transport and storage infrastructure required to spur further progress
- Uncertainties may be inhibiting the buy-in of CCS amongst employees, the general public and other stakeholders, and therefore the overall scale of CCS investment

- Economic barriers, including cost, skills availability, and access to transport and storage infrastructure are generally viewed as more severe than technical barriers
- There is a perception amongst stakeholders across the CCS supply chain that there is a lack of funding from government, contributing to investment hesitancy

With these findings in mind, CBI Economics and Policy@Manchester **developed key themes which require government action to address.** Government should:

- Stimulate stakeholder engagement to mobilise action and change perceptions, including building on recent engagement with industry, and expanding channels with non-governmental organisations (NGOs), the educational sector and specific sectors that need further guidance
- Improve awareness of work that has been carried out regarding the future direction of CCS, including timelines, and review funding levels to stimulate investment
- Consider legislative and policy changes to stimulate adoption of CCS, including steps to ensure sign-off for important projects is given as quickly as possible

The report outlines **policy recommendations** under each of these thematic areas.

CCS and the race to net zero

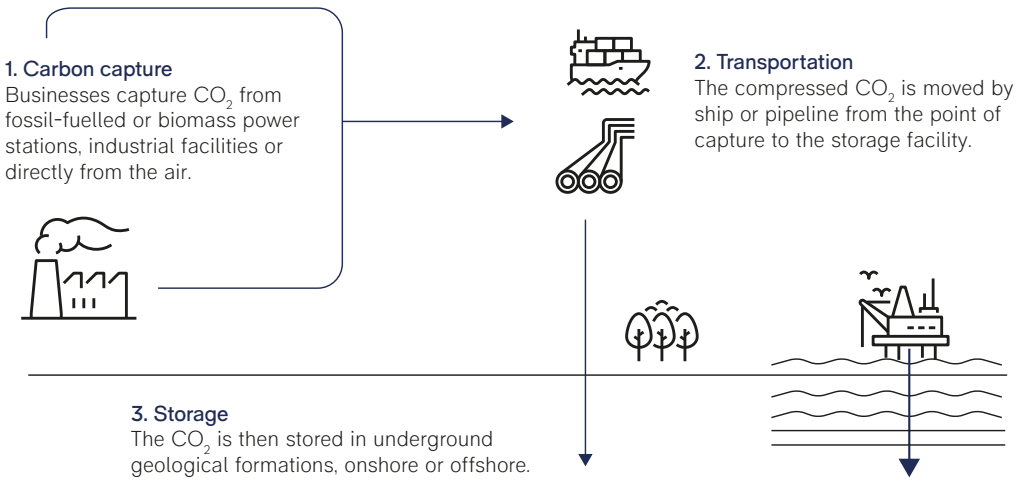
In 2019, the UK government set out its bold ambitions to reduce carbon emissions. It legislated a target to reach net zero greenhouse gas emissions across the UK by 2050. This means that any such emissions that continue to be produced must use a form of greenhouse gas removal (GGR) such as offsetting by the planting of trees, or technology which utilises carbon capture and storage (CCS), such as bioenergy with CCS. The focus of this report is the role of CCS in delivering the UK's net zero objectives, through both emissions reduction as well as carbon removal.

What is Carbon Capture and Storage?

CCS takes place in three key phases: the first phase involves the capture of carbon from an industrial facility or directly from the air; the second phase is the transportation of the captured carbon to a final storage point; and the third phase is the storage of the compressed CO_2 underground as shown in **Figure 1.**

CCS has a critical role to play in the race to net zero. For carbon-intensive industries such as fertiliser production and chemical manufacturing, reducing carbon emissions must happen at speed, but also at scale.[1] This means capturing carbon that may otherwise be hard to reduce or abate from the source of production of the CO_2. Therefore, while the energy sector can reduce carbon emissions through renewables such as solar and wind technologies, for many industries CCS is the only technology available.

Figure 1 Overview of CCS in practice



In some cases, captured carbon is utilised in industrial processes such as fuel and fertilisers. This utilisation stage is sometimes referred to in the wider term carbon, capture, utilisation and storage (CCUS).

Current UK objectives for CCS and delivery

The Climate Change Committee (CCC) has long stated that developing a CCS industry is essential to decarbonising the UK industrial sector and enabling the UK to meet its net zero target.[2] Crucially, to meet this national objective, CCS infrastructure needs to be in place by the late 2020s. Infrastructure needs that are delivered in the next few months and years will define the success of the UK's national climate effort.

The UK is well-positioned to be a world leader in CCS. Academic research into the technology is extensive in the UK, business expertise and skills through industrial clusters is strong, and government policy development has been wide-reaching. In its Net Zero Strategy, the government set out its ambitions to deliver four carbon capture usage and storage (CCUS) clusters capturing 20-30 $MtCO_2$ across the economy per year by 2030, including 6 $MtCO_2$ of industrial emissions.[3] This is aligned with the CCC's pathway of a 22 $MtCO_2$ per year capture by 2030.[4] Taken together, the UK has made strong progress in thought leadership, research and policy to kickstart the delivery of CCS in this decade.

The importance of CCS for business

To meet the UK's net zero targets, businesses must work now to adapt their business models and pivot their operations. In the literature, multiple forward-looking scenarios demonstrate the necessity of CCS in order for the UK to transition to net zero.[5] Many heavy-emitting industries are difficult to decarbonise and will therefore take more time. This includes industrial processes which, through their production process, produce CO_2 such as with steel and cement.[6,7] For aviation, difficulties in decarbonising stem from slow fleet turnover and limited retrofitting opportunities, highlighting the importance of developing negative emissions technologies. Establishing bioenergy with carbon capture and storage (BECCS) is critical in delivering carbon removal.[8] This will require the development of both sustainable biomass energy resources, as well as CCS facilities. Indeed, whilst the majority (65%) of carbon reductions are estimated to come from sustainable aviation fuels, it is estimated that 19% of emissions reduction in the race to net zero within the aviation sector will need to come from offsets and carbon capture.[9] As a result, CCS must play a role in decarbonising sectors such as these, where alternatives are currently technically limited.[10]

The use of CCS becomes particularly important within industries where it is relatively low-cost to capture the CO_2, for example brewing and distilling where the CO_2 emerges at a high concentration, and where methods such as biogas upgrading and industrial hydrogen production can be used.[11,12]

Literature also demonstrates the case for government to have CCS development and deployment to sit alongside a detailed strategy for improving efficiency and reducing material consumption in manufacturing and construction.[13]

Along with being a global leader in deployment, carbon storage also presents a sizeable export opportunity to the UK economy. The UK is fortunate to have 26% of European storage sites – the second highest in Europe – with offshore locations that have existing pipeline infrastructure in place.[14] Capturing this storage export opportunity could establish the UK's position as a global leader in CCS.

Business perceptions of CCS

CBI Economics interviewed 18 businesses across the CCS value chain, including potential end users of the technology, to understand what is needed to make CCS a reality in the UK.

CCS will play a vital role in the transition to net zero

It was noted by the majority of businesses in the interviews conducted, including a large energy intensive manufacturer, that it will be difficult to reach net zero carbon emissions by 2050 without CCS. Further to this, a large international energy company stated that CCS will also help to protect the UK's industries which find it costly to abate carbon. A power generation business stated that CCS is essential to reach net zero within the legislated timeframe.

However, multiple businesses also stated in the interviews that CCS should be used alongside other decarbonisation strategies as it is not a panacea. This was emphasised by an industry and government alliance to reduce industrial carbon emissions who stated that CCS is not a silver bullet in the transition to net zero, but that it is still critical and that the UK cannot reach net zero without it.

Interestingly, multiple businesses, including a power generator, stated the importance of CCS in the short to medium-term and for the 'transition' to net zero, but with some indication that eventually the reliance on it will be reduced in the long-term. For example, a regeneration business said that electrification will take an increasingly significant role. Meanwhile, a power generation company highlighted spillover benefits from developing CCS technology, including that the breadth of applications of the technology are varied and can enable additional industries to grow, such as low-carbon hydrogen generation.

Impressive momentum is perceived to have been made regarding CCS adoption, but with greater access to infrastructure required to fully grasp opportunities

Whilst in the past, some carbon capture and offsetting technologies were not seen as commercially-viable and were not well understood, it was the view of an airports group that they are now being proven and are becoming potentially commercial, yet government support remains important. In fact, it was the view of a partnership organisation between the community, industry, and investors that the UK wasn't overly active in the widespread application of CCS even five years ago, but that major efforts are being made now.

The view was that the industry has a lot of momentum, especially given the wide range of potential methods in capturing carbon, and the government should capitalise on this momentum amongst project developers.

A large international energy company mentioned that a large part of the value chain around CCS are technologies that have been developed and deployed for decades, which is a reason why it is emerging as an important and credible technology for net zero. However, the company mentioned that areas which are less developed, such as subsurface storage, are heavily dependent on government support.

Recent momentum paves the way for the UK to take an internationally leading role and develop export opportunities worth billions of pounds. Estimates indicate that the UK could benefit from an additional £4.3bn a year from CCUS exports by 2050.[15] A specialist CCS technology and infrastructure business highlighted that the UK is on the doorstep to the biggest industrial sectors in Northern Europe, including neighbours such as Norway, but that government should wake up to and support this opportunity (see case study). As the supply chain and skills around CCS are developed, these will also be in high demand as further countries adopt CCS.

Case Study: CCS infrastructure business

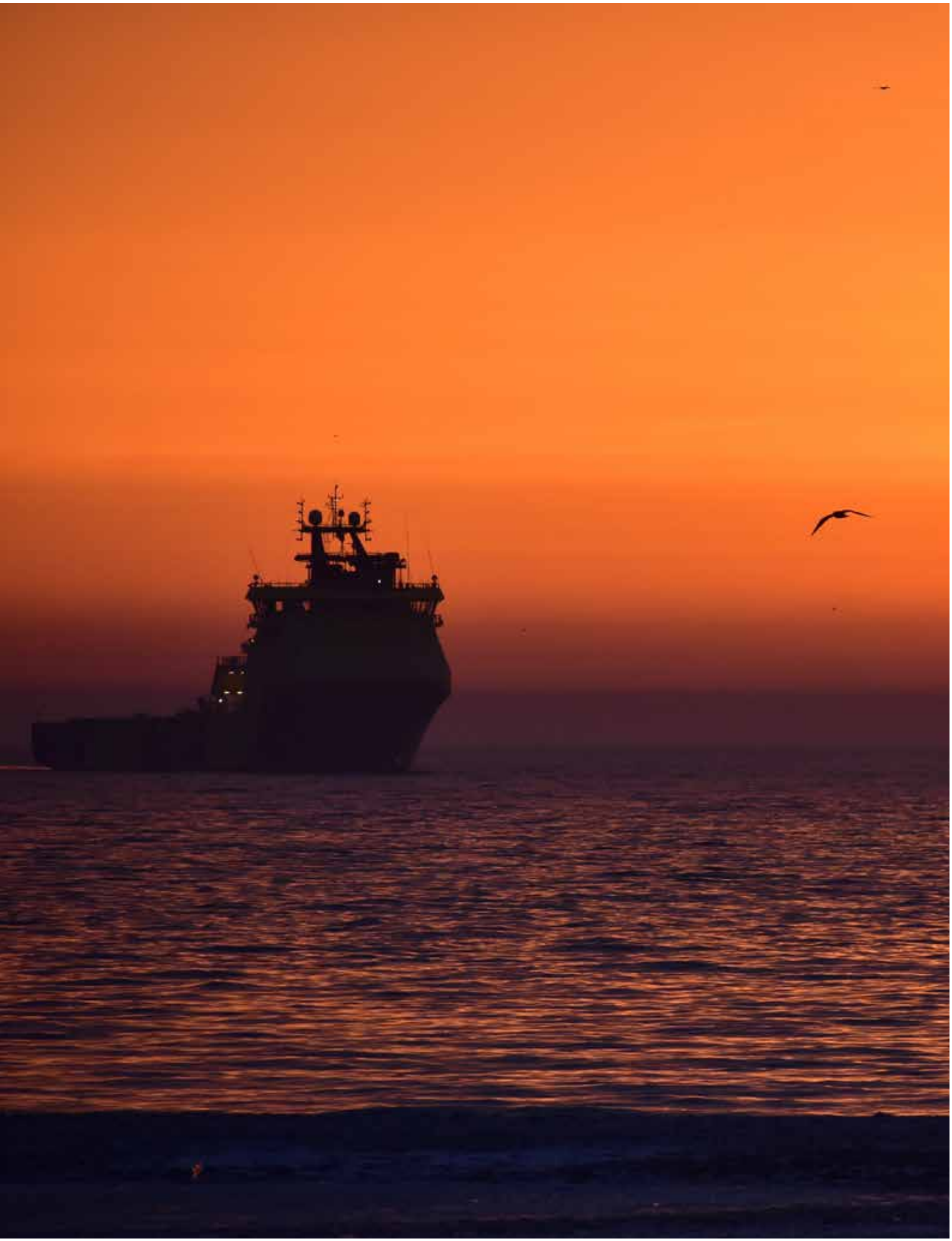
An infrastructure developer believes that CCS opens up a big trade opportunity for the UK potentially worth billions annually, but that government should wake up to and support this opportunity

A business developing infrastructure across the entire carbon ecosystem, including capture, transport and permanent deep geological storage stated that their transport and storage solutions for CO2 enable other opportunities, such as low-carbon hydrogen generation and direct air capture. They told CBI Economics that they feel the government should get behind this significant export opportunity for the UK.

The business mentioned that the UK is standing on the doorstep to one of the world's biggest industrial areas in Northern Europe. They believe this area has aspirations for roughly 400 million tonnes of carbon storage requirement every year until 2050. However, they mentioned that there is a lack of transport and storage infrastructure available, as infrastructure cannot be developed until an operating license has been granted by the government. Their view is that the door is not yet open to building a UK export industry worth potentially billions of pounds (also see footnote 17 for BEIS research indicating £4.3 billion of annual CCS export potential). For Scotland, they estimate that this would be more than the huge malt whisky industry.

The CCS developer believes that this export opportunity is being grasped by European neighbours, rather than the UK, and that action is required to ensure we don't miss out further.

Overall, whilst there was a clear perception of momentum with regards to CCS, it was generally the view that there is still far to go with regards to scaling up and grasping CCS opportunities, in part due to a lack of transport and storage infrastructure.



Current barriers to adoption

A number of barriers to the adoption of CCS were raised through the business interviews, that largely corroborated those identified in the existing literature.

Uncertainties may inhibit the Social License to Operate and scale of investment

The literature highlights the importance of companies ensuring that they have a Social License to Operate (SLO) to fulfil the potential of CCS. SLO refers to the level of support or opposition granted to a project, technology or industry by the project's stakeholders. A strong SLO requires the project, and those who support it, to be seen as being legitimate, credible and trustworthy.[16,17] Without one, a technology may fail to properly take off.

A SLO is important for any technology, but perhaps particularly in the case of CCS, given evidence that public attitudes to CCS vary. There is some evidence of negative perceptions stemming from a lack of understanding or a 'not in my backyard' attitude.[18] Participants in online workshops have raised concerns about potential risks in both the construction and operation stages, including environmental risks and safety risks.[19] On the other hand, workshops have highlighted that participants in certain areas feel that CCS will have a positive impact on local employment, revitalise the local economy, and even help redefine regional identity after a period of industrial decline.[20]

Addressing misconceptions and improving awareness is important to developing a SLO and ensuring CCS reaches its potential. A renewable energy company discussed in an interview the importance of engagement with the general public on the wider benefits of CCS, such as delivering negative emissions and permanent carbon removal through BECCS (see case study).

Case Study: Power generation company

An energy company discussed the importance of engagement with the general public on the wider benefits of CCS and how it can enable other industries

An energy company engaged in renewable power generation and the production of sustainable biomass discussed the importance in engaging with the general public on the benefits that CCS creates.

The company emphasised that, in addition to capturing carbon, the technology to deliver negative emissions and permanent carbon removal through BECCS is one of the additional benefits that have resulted from developing CCS technologies. Further to this, the breadth of applications of CCS is varied, including enabling other technologies to scale up; for example, capturing the emissions from the production of hydrogen from natural gas.

They also mentioned that, as a new heavy industrial sector, CCS is not well understood by the public and more information is needed in the public domain. They believe it is important for public perception to be aware of these spillover effects and how CCS is an enabler for other industries.

Credible solutions and concrete, detailed plans are required to develop trust and confidence, and ultimately attract investment and encourage innovation.[21] However, the literature highlights uncertainties that may undermine a SLO. For example, it is argued that there remain uncertainties around carbon removal effectiveness, technical efficiency, scale, risks, and interactions with other policy objectives.[22] Uncertainty of the feasibility of deploying at scale still exists.[23]

The business interviews highlighted important technological uncertainties as well. A power generation company mentioned that, whilst the technologies are generally proven, they have uncertainties around the capacity to scale, and that more understanding and data on the logistics needed to scale is required (see case study).

Case Study: Power generation company

An energy company shared the opportunities of CCS to grow, but also the scaling challenges ahead

The energy company mentioned that the technology behind CCS is proven but there are some uncertainties on the operational side as it scales up. They feel the technology is credible, with significant research happening within the UK despite the current relatively small size of the industry. However, it is the first time it is being deployed at this scale.

Better understanding and large-scale data of the operational performance is needed, which does not yet exist for the UK. Getting more CCS sites operational will provide the needed data on this.

As the industry scales, the supply chain will also need to scale. This would provide an opportunity for the UK to become an exporter of cost-effective materials and specialist skills for CCS.

An industry and government alliance to reduce industrial carbon emissions felt that some uncertainty and initial inefficiencies are to be expected at this early stage of scaling in the UK, whilst a combined heat and power plant felt that the technology cannot be seen as 'credible' until it can be used without the necessity of government support, but that a high degree of such support is currently required in the UK.

There is also some uncertainty over the future direction of CCS. A membership organisation highlighted uncertainties over timelines to access transport and storage infrastructure and when Contracts for Difference contracts will be allocated to help developers with costs. Furthermore, an energy company said that, given the time to build CCS projects (4-5 years), a long-term sight on policy is needed, including around the understanding of storage availability, which needs to be developed and de-risked before carbon capture projects commence (see case study).

Case Study: Power generation company

An energy company stressed the importance of long-term policy guidance to develop CCS at the scale it is required

The power generation company mentioned that for the industry to scale, there needs to be long-term policy positioning on CCS. They felt that uncertainties around the seriousness and future direction of CCS policy can constrain investment, especially given the time to develop CCS projects (4-5 years). In particular, they believe that greater clarity is required regarding the processes around storage availability, including how to develop this storage and how to ensure that any associated storage risks are mitigated. Clarity around these details is necessary before any CCS project can commence.

The power company felt that long-term policy guidance is improving, for example with the cluster sequencing process which provides a contracts-based approach in funding for the next set of projects. However, additional policy direction on CCS sites beyond that is needed.

Barriers around transport and storage infrastructure remain

The importance of shared access to transport and storage infrastructure for emitters across multiple sectors is emphasised in the literature.[24,25,26] It is noted that industry clusters provide a solution for those located within a cluster, offering integrated transport and storage networks that enable the cutting of emissions from a multitude of industrial point sources, including hard-to-abate sectors.[27] However, both the literature and business interviews emphasised that infrastructural barriers remain.

On storage specifically, the literature notes that more work is required to enable safe and efficient sub-surface storage. It has been suggested that the UK should implement a nationwide pilot programme to identify additional CCS sites and help boost the UK's skills and infrastructure in relation to sub-surface storage.[28] Storage specifically being an area requiring more work was corroborated through the business interviews, with a regeneration business noting that questions remain over liability and indemnity in the case of carbon leakage, and how long one can store carbon. A membership organisation raised that storage risks, whilst low, include reservoirs not performing to the required level, and potential leakage. The organisation mentioned the need for mitigation plans to be put in place, whilst acknowledging that work is being carried out in this area.

Logistics and capacity of shipping carbon to storage sites was also raised as an area requiring further attention. A large energy intensive manufacturer noted that shipping was not included in the Phase-1 CCS deployment process, but that more work was required to work out the detail around points such as buffer storage and turnaround times. It was mentioned by the company that the fact that most carbon is not next to a carbon store necessitates further work on shipping, a point that the interviewee felt has been neglected by policymakers. Indeed, it is the case that some companies in Phase-2 of the cluster sequencing process are not located in either of the clusters, and so will likely have to ship CO_2.[29]

With regards to infrastructure generally, a large international energy company held the view that transport and storage infrastructure is generally lacking (see case study), whilst a membership organisation emphasised the need for further investment in options to transport carbon via approaches other than pipeline, of which one is shipping.

Case Study: Global energy company

A global energy company highlighted progress the UK government has made in deploying CCS, but also the need to get the infrastructure in place without delay

A multinational energy company emphasised that a crucial element of CCS technology is to have functioning and reliable storage and transport infrastructure for the carbon that is captured in an industrial process. The company raised that, for many sectors, access to infrastructure is a key barrier to abating their carbon emissions as there is currently a lack of infrastructure for transport and storage of captured carbon.

The energy company's view however is that the UK has the perfect combination of independent advisors, legally binding targets, geology, government process and evolving business models to get the technology off the ground and the infrastructure in place – we just need action. They also highlighted the UK can benefit from attracting inward investment as businesses look to the UK, as one of the first countries to deploy a T&S system.

Their view is that another important factor in ensuring the success of CCS infrastructure is public engagement. They noted that infrastructure needs of CCS technology are huge, and having a well-informed public will demonstrate how CCS will help to meet the UK's net zero objectives and the crucial role it will play.

A leading infrastructure developer noted that a lack of infrastructure can give carbon-intensive or hard-to-abate businesses an excuse as to why they aren't reducing their carbon intensity sooner.

It was also noted that location matters. A membership organisation raised how much easier it is for those that are part of a cluster to access the necessary infrastructure, whilst a regeneration business noted that businesses can experience incremental costs if not located near a carbon sink.

Economic barriers are generally viewed as greater than technological barriers

In the business interviews, economic barriers including cost, availability of skills and technology, and the integration of particular sectors were mentioned. Generally, whilst interviewees raised good progress that has been made in areas such as business models, economic barriers were still more likely to be raised than technological barriers.

From a cost perspective, a paper mill company stated that they are unaware of any companies in their industry using CCS technologies, mentioning their perception that it is very capital-intensive and hard to justify for industries with a lower level of emissions. Their perception was that benefits of using the technology would only outweigh costs at a certain scale. An architectural firm mentioned that net zero is mandated for the construction of hospitals, and therefore that CCS must play a role in the low-carbon solution. However, the firm held the view that if net zero was not mandated, CCS would be excluded on cost grounds as is often the case (see case study). It was raised by a large energy intensive manufacturer that there is a current inability to pass costs on to the customer due to the worry of being undercut by imported products. The company suggested that a carbon border adjustment mechanism would tackle this issue and that, without these mechanisms, one may not be able to justify large investment.

Case Study: Architectural firm

An architectural firm holds the view that, without adequate incentive, CCS will often be ignored on cost grounds

An international architectural firm that primarily works in healthcare, education, commercial and residential sectors told CBI Economics that CCS technologies will generally not be used unless there are increased incentives.

They mentioned that net zero is mandated in the construction of hospitals, which necessitates the use of CCS as part of a portfolio of approaches to decarbonise. However they noted that, in many construction cases, net zero is not included as part of building regulations and is not a planning requirement with local authorities, which often leads to it being excluded on cost grounds.

Their view is that action is required if the private sector is to fully grasp the potential of CCS. They feel that mandating net zero in construction, across a wider range of sectors, could be one effective approach. Another could be allowing lower carbon buildings to benefit from lower rates or further tax benefits. Without such incentives, they feel that CCS uptake may be limited.

A lack of suppliers of the technology or necessary skills in the marketplace were raised as risks. The architectural firm noted that the general shortage of labour in the construction industry limits the supply of necessary equipment from sub-contractors. A large multinational energy company noted the importance of government, industry and the educational sector working together to ensure a whole generation of people is developed that can work in the area in order for CCS to fulfil its potential (see case study). A large power generator noted that the UK supply chain around CCS is still developing, explaining in part why not all projects have the necessary availability of skills and materials, whilst also raising Norway and the US as areas with better availability.

Case Study: International oil and gas company

An international oil and gas company feels that government should work with the educational sector to ensure a ready supply of necessary skills, given the scale of the investment and growth opportunity available

An international oil and gas company emphasised the importance of collaboration between government, the education sector and industry on skills, given the potential for the creation of new and highly skilled jobs related to CCS.

The company mentioned that "a whole generation of people that want to work in this area" will be needed, and therefore that the government, industry and educational sectors will need to take a long-term view, anticipating what skills requirements might arise.

One area in which the company feels that government and the educational sector should collaborate more is on apprenticeship programmes. They feel that more of a focus on technical schemes such as these, and other efforts to incentivise people to pursue certain careers, will be necessary if CCS is going to contribute significantly in the race to net zero.

An important point raised in the interviews was that there is not enough thought on how to enable CCS for specific sectors. A large airport operator noted that there is not enough information on how carbon removal technology will be used within aviation, and whether it will be integrated with existing frameworks like the UK Emissions Trading Scheme which could help to speed up deployment (see case study). An architectural firm noted that there is a general tendency for risk aversion with regards to new technologies in the construction industry, highlighting that different approaches may be required for different industries. A paper company raised that they don't have clarity on whether or not CCS will need to be important for their industry as they are waiting on further policy direction of whether or not biomass will change from being defined as a renewable energy source to a non-renewable which, if it were to go ahead, would necessitate a much greater degree of decarbonisation in the industry.

Case Study: Airport operator

A large airport operator suggests that CCS could be a vital tool for businesses within the industry, but more detail is needed

An airport group that operates multiple UK airports as well as having an international business stated that as CCS infrastructure is developed and its commercial viability demonstrated, carbon-intensive sectors such as aviation will need to be brought along on this journey. Their view is that there is a lack of thought on how to integrate aviation into the broader roadmap on CCS.

The group highlighted that more information is needed to demonstrate how carbon removal technology will be used to support aviation decarbonisation. This includes information about whether it will be integrated with existing frameworks like the UK Emissions Trading Scheme (ETS), which could help to speed up deployment.

The sector has already decoupled growth in passenger numbers from carbon emissions, and is highly focused on decarbonisation through operational efficiencies, sustainable fuels and the development of alternatively fuelled aircraft. However, it is widely recognised that tools such as carbon credits and CCS will need to play a role in net zero aviation. Aviation and other sectors which are difficult to decarbonise should be front and centre of the development of sector-specific detail to reduce climate impacts and develop a successful CCS industry in the UK.

There is a perception of a lack of funding from government, contributing to investment hesitancy

Recent progress on business models and industrial clusters was praised by multiple interviewees, with a large energy intensive manufacturer praising the Department for Business, Energy and Industrial Strategy's engagement with industry. Despite this, the interviews showed that there remains a perception of a lack of funding for CCS.

A perception that the Treasury is too hesitant to provide the necessary financial support required for CCS to fulfil its decarbonisation potential and meet the scale of the challenge we face was raised multiple times. A large international energy company called for funding to be ringfenced and secured, whilst a construction and machinery company highlighted the difficulty of securing the match-funding required for most projects. A regeneration business called for government to provide more financial support to support co-investment between business and government. A non-profit private-sector led organisation held the view that additional government funding will be required over time (see case study).

Case Study: Non-profit organisation

A non-profit private-sector led organisation spelling out that additional government funding will be required over time

A non-profit organisation helping the UK and Scotland achieve energy security and net zero through developing a globally integrated energy cluster discussed the importance in continuing the good progress between industry and government. Funding as part of the cluster sequencing process has been provably beneficial, yet additional funding will be needed and the organisation shared concern at the pace of progress. The transition to net zero within the timeframes required will need carbon capture and storage, and the UK has an advantage here with existing knowledge and experience in oil and gas.

The organisation also believe that hydrogen has become extraordinarily important through significant technological improvements. This has allowed hydrogen to be produced from natural gas with CCS to capture the emissions, and government funding is crucial in accelerating the development of technologies such as these.

This perceived lack of funding may exacerbate existing worries that are constraining investment. A large energy intensive manufacturer and a regeneration business felt that past stop/start activity from government has made people hesitant to invest, even now. A specialist CCS technology and infrastructure organisation expressed a concern that the government may take their foot off the pedal which would allow other countries to overtake the UK and would put the UK at the back of the queue for various materials and support.

The business interviews also highlighted a perception that government is often not agile enough with regards to project delivery or development of approach. A large international energy company held the view that the government is too slow to give the go-ahead for vital projects. A large multinational energy company raised the issue of decarbonisation beyond industrial clusters, which they felt has been neglected to some extent.

A call to action

When it came to what should be done, the general perception amongst interviewees was that government is the actor that has the most potential to influence the future success of CCS, given the various policy levers at its disposal. Based on the findings from both the literature review and businesses interviews, there are various areas for government to act in order to reduce barriers and drive forward progress.

Stimulate stakeholder engagement to mobilise action and change perceptions

In order to safeguard and enhance the Social License to Operate, as well as accelerate progress, the government should take steps to stimulate engagement between relevant stakeholders, and with the general public. Not only would such engagement foster learning and enable the solving of current and future barriers, but it would also help build trust and confidence between developers, public bodies and civil society.[30] Specifically, the government should:

- **Continue to engage closely with industry to build on recent progress made in areas such as business models and industrial clusters.** Close engagement will allow government to react quickly as new barriers appear and better understand which sectors may need specialised support.
- **Seek further engagement with relevant NGOs, including those well-known by the general public, to improve awareness and perceptions of CCS.** Working with organisations that have a voice can enable the addressing of misconceptions that act against CCS adoption, and champions the benefits of CCS.
- **Review current stakeholder engagement to ensure that the right stakeholders are talking to each other and ensure that they are aligned on important processes and timelines.** Different stakeholders across the supply chain communicating and engaging with each other on a regular basis can help tackle existing and new barriers, and stimulate investment.
- **Engage closely with the educational sector, and industry, to ensure that there will be a ready supply of the necessary skills over the next years and decades.** A forward-looking approach to skills will help ensure CCS fulfills its potential, and industry can and should communicate their current and future needs to the educational sector.

- **Engage with and provide targeted support, such as additional government funding, to particular sectors such as aviation that have limited adoption of CCS, but will need to utilise it.** Certain sectors may need support whether it be because of a lack of sector-specific information or other sector-specific barriers. The level of support provided to a sector should also depend on its current CCS adoption level, as well as the need for it to adopt CCS to decarbonise.

Improve awareness of the future direction of CCS and review funding levels to stimulate investment

In order to reduce uncertainties, build the Social License to Operate, and stimulate investment, government should provide more clarity on and improve awareness of certain aspects of the future direction of CCS. Specifically, the government should:

- **Clarify and improve awareness of full CCS timelines to remove business uncertainties, including around the development, location and access to vital infrastructure. Specifically, provide clarity on long-term carbon storage availability.** More clarity and awareness of plans should stimulate investment.
- **Review the current total level of funding going towards CCS to determine if it is fit-for-purpose and sufficient given the scale of the decarbonisation challenge. In particular, review if funding is sufficient with regards to sub-surface storage skills and infrastructure, and investment in non-pipeline transport options such as shipping.** Without adequate funding, the immense potential of CCS simply cannot be realised.

Consider certain legislative and policy changes to stimulate adoption of CCS

There are a few other policy changes that the government should consider to drive adoption of CCS, including:

- **Consider mandating net zero in the construction of buildings across a wide range of sectors, just as in the health sector, to ensure CCS plays a larger part in construction.** Without mandates it is likely that adoption of CCS will be limited compared to what it needs to be.
- **Review processes to ensure that sign-off for important CCS projects is given as quickly as possible.** Not only will this directly drive quicker adoption of CCS, but it will also enable learning-by-doing and improve the efficiency of subsequent projects
- **Review cost mechanisms to reduce the burden on businesses of adopting CCS. For example, the introduction of a carbon border adjustment mechanism could facilitate greater cost pass-on from businesses to customers.** There needs to be a sharing of the cost burden of CCS to drive adoption.

Concluding remarks

Given the scale of the decarbonisation challenge, and the increasing urgency of action, this research has provided a timely reminder that there is still much work to be done to overcome barriers to CCS adoption and scale it up to the point that CCS becomes a reality for UK businesses.

Whilst businesses will need to adapt their business models and pivot their operations to decarbonise, it is clear from both the literature and interviews carried out as part of this project that government with its various policy levers, extensive networks, and significant funding potential, must act quickly to help enable businesses to grasp the immense opportunity.

Government must provide clarity and improve awareness of the future direction of CCS, including around the development, location and access to vital infrastructure. This is one of the most effective ways to stimulate investment. Similarly, government should work together with relevant organisations such as NGOs to improve the awareness and perception of CCS amongst the general public, addressing any misconceptions. Without this effort, CCS may not achieve the Social License to Operate that is so important for a technology to properly take off.

Government must also stimulate engagement between various stakeholders, not only to mobilise action and improve efficiency, but also to develop widespread buy-in. Recent engagement with industry on areas such as business models is laudable, and the government must not take the foot off the pedal given the further work to be done. Government should expand existing channels of engagement as well as develop new channels, including with relevant NGOs, the educational sector, and specific sectors that have until now failed to grasp the CCS opportunity to the extent they should have.

Perhaps most importantly, the government needs to provide adequate funding to meet the scale of the predicament faced. Adequate funding, coupled with greater agility for project sign-off, can drive forward CCS adoption, allowing us to learn from mistakes and improve efficiency of further projects. Without sufficient funding, we will certainly fail to grasp the immense potential of CCS.

Summary of recommendations

Exhibit 1 Summary of recommendations by thematic area

Theme	Recommendation
Stimulate stakeholder engagement to mobilise action and change perceptions	• Continue to **engage closely with industry** to build on recent progress made in areas such as business models and industrial clusters. • Seek further **engagement with relevant NGOs**, including those well-known by the general public, to improve awareness and perception of CCS. • **Review current stakeholder engagement channels** to ensure that the right stakeholders are talking to each other and ensure that they are aligned on important processes and timelines. • **Engage closely with the educational sector,** and industry, to ensure that there will be a ready supply of the necessary skills over the next years and decades. • Engage with and **provide targeted support,** such as additional government funding, **to particular sectors** such as aviation that have limited adoption of CCS, but will need to utilise it.
Improve awareness of the future direction of CCS and review funding levels to stimulate investment	• **Clarify and improve awareness of full CCS timelines** to remove business uncertainties, including around the development, location and access to vital infrastructure. Specifically, provide **clarity on long-term carbon storage availability.** • **Review the current total level of funding** going towards CCS to determine if it is fit-for-purpose and sufficient given the scale of the decarbonisation challenge. In particular, review if funding is sufficient with regards to sub-surface storage skills and infrastructure, and investment in non-pipeline transport options such as shipping.

Theme	Recommendation
Consider certain legislative and policy changes to stimulate adoption of CCS	• **Consider mandating net zero in the construction of buildings** across a wide range of sectors, just as in the health sector, to ensure CCS plays a larger part in construction. • Review processes to **ensure that sign-off for important CCS projects is given as quickly as possible,** driving quicker adoption of CCS and enabling learning-by-doing. • **Review cost mechanisms** to reduce the burden on businesses of adopting CCS. For example, the introduction of a carbon border adjustment mechanism could facilitate greater cost pass-on from businesses to customers.

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For more information about Policy@Manchester:

policy@manchester.ac.uk
policy.manchester.ac.uk

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