HM Government

Clean Growth

The UK Carbon Capture Usage and Storage deployment pathway

An Action Plan

INDUSTRIAL STRATEGY

Cover image: Aerial view of Port Talbot steelworks. Tata Steel is exploring the potential for CCUS to reduce the carbon footprint at its Port Talbot site. Image courtesy of Tata Steel.

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Foreword

As the Prime Minister said in her foreword to the Clean Growth Strategy, "Clean growth is not an option, but a duty we owe to the next generation".

To demonstrate this commitment, the Government has placed Clean Growth at the heart of our modern Industrial Strategy and it has become a great British success story; we have demonstrated that growth of our national income can go hand in hand with cutting greenhouse emissions.

Integral to our modern Industrial Strategy is the determination to seize the opportunities that drive productivity, and to foster emerging sectors that have the potential to create new high-value jobs, industries and companies. Innovation in decarbonisation technologies drives Clean Growth, meaning that not only are we rapidly decarbonising parts of the domestic economy, but we are successfully exporting goods and services around the world. This progress now means there are more than 390,000 jobs in low carbon businesses and their supply chains, employing people in locations right across the country.

I believe that carbon capture, usage and storage (CCUS) represents a huge opportunity for the UK to become a global leader in a technology which will have a key role to play in tackling climate change – one of the most pressing global challenges. And we share in the broad international consensus that CCUS will be essential to meet the ambitions set out in the Paris Agreement, reinforced by the IPCC's recent 1.5 degree Special Report.

CCUS deployment has the potential to support decarbonisation in several ways. Firstly, for countries such as the UK who have made great progress in decarbonising power, we know that flexible gas generation still has a role to play in generation as we transition to the inexpensive but intermittent world of renewables; CCUS technologies can help to take the carbon out of this valuable service. Secondly, I believe that if we are to enjoy the benefits of a broad and thriving industrial base in the second half of the century, CCUS gives us credible routes to decarbonise the processes that underpin many of these sectors. In the coming decades CCUS has the potential to be an

essential component of thriving low carbon industrial centres. Finally, CCUS could play a pivotal role in the huge challenge of decarbonising heat, through the development of the hydrogen economy, especially in countries with advanced gas networks.

The main barriers now are not technological: rather, government and the sector need to work together to build the frameworks to enable CCUS to deploy at scale. This is a partnership, but one in which we must be clear that government can only be expected to bear the irreducible risks, and where market mechanisms must come to bear to deliver best value solutions for taxpayers. The companies involved, many of whom rely on fossil fuels for the bulk of their revenues, must see finding routes to deploying CCUS solutions as an essential to their license to operate, as well as a chance to share in the economic rewards of leading in this burgeoning sector. This report delivers a plan to work with them to deliver on this opportunity.

The Rt Hon Claire Perry MP
Minister of State for Energy and Clean Growth

Executive Summary

We are committed to playing a leading role in supporting the development of the technologies of the future. Carbon capture usage and storage (CCUS) is one of the most promising technologies.

CCUS has economy-wide qualities which could be very valuable to delivering clean industrial growth. It could deliver tangible results in tackling some of the biggest challenges we face in decarbonising our economy, contributing to industrial competitiveness and generating new economic opportunities – a key part of our modern Industrial Strategy.

Our vision is to become a global leader in CCUS, unlocking the potential of the technology and securing the added value which it can bring to our industrial centres and businesses all across the UK.

Our ambition is that the UK should have the option to deploy CCUS at scale during the 2030s, subject to the costs coming down sufficiently.

Our Industrial Strategy set out four Grand Challenges to put the UK at the forefront of the industries of the future. The Clean Growth Grand Challenge seeks to maximise the advantages for UK industry from the global shift to clean growth. CCUS can be an important part of achieving these objectives.

However, no technology can proceed at any price. We will look to ensure that the CCUS industry can operate within a supportive business environment that delivers a cost reduction trajectory, and in return we expect that industry will play the leading role in delivering CCUS. Our CCUS innovation programmes will continue to support cost reduction and position the UK as a leader in CCUS technologies and enabling infrastructure.

In parallel, we will shift our approach to focus on domestic deployment by continuing to work with industry, building on the CCUS Cost Challenge Taskforce report, to identify cost effective private sector-led ways of developing, financing and delivering CCUS. Central to this will be the conclusion of our review of CCUS Delivery and Investment Frameworks in 2019, which, working with industry, will seek to identify investable commercial models and establish market-based frameworks for bringing forward CCUS. In addition, our new Industrial Energy Transformation Fund will provide funding for a range of transformative decarbonisation investments potentially including fuel switching and carbon capture.

Key messages

- This Action Plan is designed to enable the development of the first CCUS facility in the UK, commissioning from the mid-2020s.
- Commissioning of the first CCUS facility from the mid-2020s would help the UK to meet our ambition of having the option to deploy CCUS at scale during the 2030s, subject to costs coming down sufficiently.

Through our Clean Growth Strategy we re-affirmed our commitment to the domestic deployment of CCUS subject to cost reduction. This Plan sets out our next steps to progress this commitment.

We are committed to the UK having the option to deploy CCUS at scale during the 2030s subject to the costs coming down sufficiently. To realise our ambition, our Action Plan is designed to enable the development of the first CCUS facility in the UK, commissioning from the mid-2020s.

We will not deploy CCUS at any price, however, and the first CCUS facility will need to demonstrate that it will be cost effective. In 2019 we will commence detailed engagement with industry on the critical challenges to delivering CCUS in the UK, in particular the cost structures, risk sharing arrangements and the necessary market mechanisms which take full advantage of innovation and competition. This work will support the review of delivery and investment frameworks, described in more detail in this document. This engagement will be an important further step in assessing whether CCUS can be sustainably financed in the UK and credibly demonstrate value for money for consumers, businesses and taxpayers.

Our vision and ambition can only be achieved through close Government and industry partnership, and our commitment is contingent on industry joining us in meeting the challenge of delivery.

CCUS can help to deliver Clean Growth as part of the UK's Industrial Strategy

This year marks 10 years since the passage of the Climate Change Act 2008, a world first.

In this time we have shown that we can tackle climate change while delivering real economic growth – reducing emissions by more than 40% since 1990 while growing the economy by more than two thirds.

Our Clean Growth Grand Challenge seeks to maximise the advantages for UK industry that the global shift to clean growth presents. Through its potential role across the economy, coupled with the UK's strengths in the technology, CCUS could play a central role in the transition to a low carbon economy and provide new markets for UK business.

Through our modern Industrial Strategy we are dedicated to creating an economy that works for everyone. That means putting more money into research, development and innovation, investing in skills throughout the country and working with businesses to encourage growth in the areas where the UK has an advantage. It also means identifying and capturing the economic and industrial opportunities of the future. CCUS has the potential to play an important role in supporting our Industrial Strategy.

CCUS could reduce emissions from our industrial centres, protecting existing industries and jobs, improving productivity and presenting opportunities for direct, low carbon investment. It is why our industrial centres in Scotland, South Wales, Humberside, Merseyside, and Teesside all see CCUS as central to their long-term competitiveness.

We see an opportunity for the UK to be a global technology leader in CCUS, and we are putting in place the foundations to achieve this and grasp the opportunities a growing global CCUS market presents. We are already well placed: innovative companies across the UK are developing cutting edge CCUS technologies; we have world leading academic institutions focused on solving key questions to reduce the costs of CCUS deployment; we have one of the largest potential carbon dioxide storage capacities in Europe; our existing industries have the skills and capability required to deploy CCUS at scale; and we are exploring investable commercial models to ensure a supportive business environment for those wishing to develop CCUS.

Enabling the UK's first CCUS facility from the mid-2020s

Our Action Plan is aimed at establishing a cost-effective, investable, and sustainable pathway for CCUS that supports cost reduction and enables commercial deployment in the UK.

We will seek to develop a new partnership between Government and industry to secure the benefits of CCUS to the UK. This joined up, integrated approach lies at the heart of our Action Plan.

Delivering this will require significant collaboration with industry, academia and industrial centres. It will require collaborative effort to move beyond supporting CCUS through innovation to establishing CCUS infrastructure in the UK.

This will ensure that the business environment works for all involved in CCUS through developing the appropriate commercial frameworks to enable investment, innovation and cost reduction. Should the costs come down sufficiently this may enable the deployment of CCUS at scale in the 2030s.

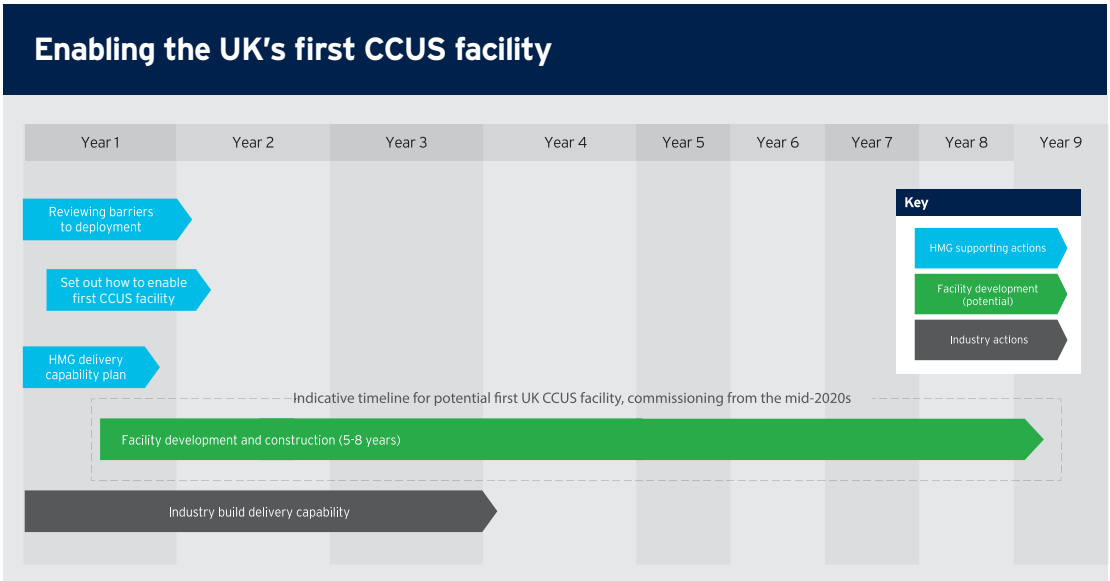


Figure 2 Indicative timeline for a first CCUS facility and carbon dioxide infrastructure network.

CCUS has the potential to support strong local economies, creating high value jobs for people across the UK. The majority of our industrial centres have all identified that CCUS has an important role in supporting their competitiveness and creating low carbon industrial clusters. Our Action Plan aims, under the right circumstances, to enable the establishment of the first CCUS facility in the UK, operating commercially from the mid-2020s. Deployment would be subject to the value for money case being made and we envisage development being primarily led and financed by the private sector.

We will work to position the UK as a global leader in CCUS through our leadership of multilateral organisations, working with our international partners to accelerate the global deployment of CCUS and support global cost reductions. An important element of this will be to continue to support our innovators to lead the way. We are committed to positioning the UK as a global leader in tackling the issues that have prevented the deployment of CCUS previously in the UK as well as globally. This Action Plan seeks to start a process of working in partnership with industry to address the commercial challenges while providing clarity on how we intend to meet our 2030s ambition.

Figure 1 Diagram to summarise actions and commitments necessary in order to achieve our stated ambition of having the option to deploy CCUS at scale during the 2030s, subject to costs coming down sufficiently.

The carbon capture pilot plant at Imperial College London, used to provide tuition for chemical engineering students and industry practitioners, and in research trials in to carbon capture methodologies. Image taken by Dave Gutteridge, courtesy of Imperial College London. © Imperial College London.

Our Vision for Carbon Capture, Usage and Storage

We see an opportunity to become a global leader in CCUS.

To achieve our vision, we are determined to grasp this opportunity, identified in our Clean Growth Strategy, to unlock the potential of CCUS and to secure the added value CCUS can bring to our industrial centres and businesses across the UK. Our ambition is that the UK should have the option to deploy CCUS at scale during the 2030s, subject to the costs coming down sufficiently.

Our vision and ambition can only be achieved through close Government and industry partnership, and our commitment is contingent on industry joining us in meeting the challenge of delivery.

Successful delivery of our vision and ambition will mean joint industry and Government action and a growing CCUS industry committed to its development in the UK. It will mean we will know whether we have a scalable, cost-competitive decarbonisation pathway that supports clean economic growth and the delivery of our carbon budgets, putting us at the forefront of a growing global CCUS market. An initial phase of deployment will be required if we are to know that this pathway is achievable.

It will also mean that we have secured the benefits laid out in the Industrial Strategy[1] through:

- **Ideas:** Being an innovation leader across the CCUS value chain, with new technologies being pulled through as a result of our initial deployment phase, driving further cost reductions and securing an increasing share of a global market as well as stimulating new products, markets and services.
- **People:** Having the necessary skills base to support a domestic supply chain, extending the longevity of our offshore oil and gas and chemicals industries, securing high value jobs in key industrial sectors such as iron and steel, cement and chemicals and building an export opportunity.
- **Infrastructure:** Developing a carbon dioxide infrastructure network to support decarbonisation across the economy, in particular those parts of the economy that are hardest to decarbonise.

Key messages

- **Our vision** is to become a global leader in CCUS, unlocking the potential of CCUS and securing the added value CCUS can bring to our industrial centres and businesses all across the UK.
- **Our ambition** is that the UK should have the option to deploy CCUS at scale during the 2030s, subject to the costs coming down sufficiently.
- **Our Action Plan** aims to enable the establishment of the first CCUS facility in the UK, operating from the mid-2020s. This can only be achieved through close Government and industry partnership.

- **Business Environment:** Developing a sustainable and investable commercial model for CCUS in the UK, supporting public-private partnerships and private sector investment, underpinned by appropriate risk sharing arrangements between Government and the private sector.
- **Places:** Supporting local industrial competitiveness, supporting our industrial centres and attracting new high tech companies to their areas.

CCUS is thought to be central to a least cost energy system decarbonisation pathway to 2050. The Committee on Climate Change (CCC) stresses the importance of CCUS to "achieving an 80% emissions reduction at lowest cost, as well as its crucial role in enabling deeper emissions reduction beyond that"[2].

Modelling by the Energy Systems Catapult (ESC) for the Energy Technologies Institute (ETI)[3] supports the conclusion by the CCC that energy system decarbonisation could be up to fifty per cent cheaper by 2050 if CCUS is deployed at scale[4], and conclude that delaying deployment beyond the 2020s will increase the risks of decarbonising the UK's energy system[5]. Both the CCC and ETI analysis concludes that initial deployment is required during the 2020s in order to have the option of deploying at scale during the 2030s, and in particular to keep open the option of UK CCUS deployment towards the levels both state are required in 2050. This timeline was endorsed by the CCUS Cost Challenge Taskforce[6], and the conclusion was also reached by the Parliamentary Advisory Group on CCS[7]. A key message from all these independent bodies is that deployment of CCUS during the 2020s is essential to unlock the greatest opportunities for cost reduction.

The definition of the 'scale' in these reports which may be required between 2030 and 2050 varies widely, depending on application. For example, the CCC state that the scale of CCUS required by 2050 may be between 60-180 $MtCO_2$/ year[8,9], whilst ESC modelling shows capacity of ~80 $MtCO_2$/ year by 2045[10]. At an individual facility level, according to the Global CCS Institute, a large-scale facility is defined as "involving the capture, transport and storage of carbon dioxide at a scale of at least 400,000 tonnes of CO_2 annually"[11].

BEIS' industrial decarbonisation and energy efficiency action plans highlighted the importance of CCUS for industrial decarbonisation across our energy intensive sectors[12]. Two of the three indicative pathways in the Clean Growth Strategy showed that CCUS could play a key role in decarbonisation of heat, power, and in providing negative emissions[13].

As we set out in the Industrial Strategy, the role of Government is not to pick winners and subsidise or protect them. The Strategy's Grand Challenges advocate taking a mission-based approach to innovation[14], an approach that we have followed in progressing CCUS. This means that we set ambitious goals and make decisions focused on achieving these. **Our ambition to develop CCUS at scale during the 2030s, subject to costs coming down sufficiently, is one such goal.**

A CCUS project, incorporating capture, transport and storage infrastructure, takes between five and eight years from commencing detailed engineering work to operation[15]. Therefore to support meeting our ambition of having the option of deploying CCUS at scale during the 2030s, subject to costs coming down sufficiently, we can use the 2020s to test and develop CCUS in the UK context.

We recognise that this also needs to be supported by market mechanisms that bring in private investment and enable a clear cost reduction pathway, by taking full advantage of innovation and competition. To achieve this, we will seek to progress CCUS in the UK through a staged approach, to allow us, and industry, to develop and test commercial and regulatory concepts incrementally during the 2020s, including through initial deployment. The aim of this approach is to allow lessons to be learned and applied, to identify, test and then secure initial cost reductions with the ultimate goal of enabling commercial deployment of CCUS in the UK should it be cost effective and value for money to do so.

A staged approach will enable us to assess progress against our ambition of having the option to deliver CCUS at scale during the 2030s, whilst monitoring costs and industry's commitment to deploying CCUS in the UK and for all parties to learn by doing.

CCUS and the Five Foundations of the Industrial Strategy

Key

- **Ideas**
- **People**
- **Infrastructure**
- **Business Environment**
- **Places**

- **St. Fergus** Key North Sea gas terminal and potential access point for CO^2 storage
- **Grangemouth** Industrial centre focused on chemicals and source of majority of Scottish CO_2 emissions
- **Teesside** Chemicals focused industrial centre with access to Southern North Sea storage
- **Humberside** Industrial centre with refining, steelmaking and biomass-fired power generation
- **Merseyside** Refining, chemicals, and fertiliser production with potential for storage in the East Irish Sea
- **South Wales** Industrial centre focused around steelmaking and refining

1 **Carbon Capture Machine**
Novel CCU technology development and Carbon X-Prize finalist

2 **University of Strathclyde**
World-leading research in to economic impacts of CCUS

3 **University of Edinburgh**
World-leading carbon dioxide storage research activity

4 **Drax**
C-Capture and Drax collaborating on Europe's first BECCS Pilot

5 **University of Sheffield**
Home of the UK CCS Research Centre and PACT research facility

6 **University of Cambridge**
Working with BHP and Harvard and Melbourne Universities to improve long-term CO_2 storage

7 **Imperial College London**
Carbon capture pilot plant and research activity

8 **Aberdeen**
World-leading offshore oil and gas workforce and Oil and Gas Technology Centre

9 **Econic Technologies**
Novel processes creating polyols from CO_2

10 **Goodwin Steel Castings**
Key supply chain partner of NET Power

11 **Johnson Matthey**
Developing low-cost hydrogen production technologies

12 **FLEXIS**
Energy systems partnership between universities and businesses

13 **Carbon8 Systems**
Developing technology use CO_2 in building aggregate

14 **Carbon Clean Solutions**
Implementing commercial CO_2 capture technology worldwide

15 **Central North Sea**
Potential opportunity for oil and gas infrastructure re-use

16 **East Irish Sea**
Potential opportunity for oil and gas infrastructure re-use

17 **Teesside Collective**
Collaboration between local business and public sector to advance CCUS

18 **Linklaters LLP**
Lead the CCUS Cost Challenge Taskforce

19 **OGCI Climate Investments**
Funding innovative CCUS technology and project development

Figure 3 : Map of the UK highlighting key companies, opportunities, or locations, and their relationship to the five foundations of the Industrial Strategy.

Developing CCUS will also support and contribute to the development of evidence to support decisions on the long term decarbonisation of heat, potential for the large scale use of hydrogen and the deployment of GGRs in the UK.

In doing this, we recognise the need for continued cost reduction and are encouraged by recent evidence suggesting that the costs of capturing carbon dioxide are falling. Value for money and the cost of energy for consumers, businesses, and taxpayers will remain central to our consideration and we will monitor this on an ongoing basis.

Action

- In 2019 we will commence detailed engagement with industry on the critical challenges to delivering CCUS in the UK, in particular the cost structures, risk sharing arrangements and the necessary market-based frameworks.

Aerial view of Grangemouth port facility. Photograph reproduced with permission from INEOS.

Action since the publication of the Clean Growth Strategy

The Government published its approach to CCUS in the Clean Growth Strategy in October 2017[16].

This confirmed that we see CCUS as having the potential to support decarbonisation of the economy, subject to its costs coming down sufficiently. The approach confirmed that we see a new opportunity for the UK to become a global technology leader for CCUS. Working domestically and internationally with industry and other governments to accelerate global deployment and bring about global cost reductions, we will seek to progress CCUS through three themes.

Re-affirming our commitment to deploying CCUS in the UK, subject to cost reduction

- **Established CCUS Council:** Our CCUS Council[17], co-chaired by the Minister for Energy and Clean Growth and James Smith, former Chair of Shell UK and the Carbon Trust, has been set up to advise us on progress and priorities as set out in the Clean Growth Strategy, and to monitor costs and deployment potential.
- **Received CCUS Cost Challenge Taskforce report:** The CCUS Cost Challenge Taskforce, established by the Minister for Energy and Clean Growth in January 2018, comprised forty-five leading experts from the CCUS, oil and gas, energy, finance, academic, and NGO sectors. The Taskforce published their report in July 2018[18], setting out their view on how to reduce the costs of deploying CCUS at scale in the UK. We set out the Government's response to those recommendations in this Action Plan.
- **Reviewing CCUS Delivery and Investment Frameworks:** We have started a review of CCUS Delivery and Investment Frameworks in industry, power and carbon dioxide infrastructure, in order to understand and develop options for addressing the commercial barriers to deploying CCUS in the UK through market based frameworks. In parallel, we have continued to engage with CCUS project developers and potential CCUS industrial clusters around the UK.

Key messages

- We are acting to advance the deployment of CCUS in the UK, and have established the CCUS Council, received and considered the CCUS Cost Challenge Taskforce's report, and started a review of CCUS Delivery and Investment Frameworks.
- We are collaborating with international partners to drive down the cost and accelerate deployment of CCUS, including hosting our global Accelerating CCUS Summit with the International Energy Agency.
- We have announced CCUS innovation programmes worth £45 million.

International collaboration to drive down the cost and accelerate deployment of CCUS

The Intergovernmental Panel on Climate Change (IPCC) has said that CCUS will need to become a globally significant technology in order to address the challenge of reducing our emissions. Increasingly countries are looking at CCUS to support the decarbonisation of their economies. We will continue to work with other governments and industry to accelerate global deployment and drive down the costs of CCUS. We are playing a leading role in this.

- **Accelerating CCUS Summit:** Our global Accelerating CCUS Summit, co-hosted with the International Energy Agency (IEA), and conference with the Global CCS Institute, brought together governments, industry and others to discuss and agree concrete actions to accelerate deployment.
- **Mission Innovation:** We have confirmed that we are, with Saudi Arabia and Mexico, leading the Mission Innovation CCUS Challenge[19] and are also co-leading the Clean Energy Ministerial CCUS Initiative, with the United States, Norway, and Saudi Arabia[20].
- **International CCUS Programme:** We are continuing to support developing countries and emerging economies to develop their technical and institutional knowledge of CCUS through our £70 million international CCUS programme.

Investing in innovation to support deployment and bring through technologies to reduce the cost of CCUS

Supporting CCUS Innovation: We are continuing to invest in supporting innovation in CCUS to support cost reduction, supporting innovative new technologies and deployment. This year we have announced three new CCUS innovation programmes[21]:

- A £20 million CCU Demonstration Programme to fund design and construction of CCU demonstration plants in the UK.
- A £15 million CCUS Call for Innovation to fund innovation projects that lead to significant cost reduction in, or quicker, more widespread deployment of CCUS technology.
- £6.5 million of UK funding to the second international call of the Accelerating Carbon Technologies (ACT) research programme, a €30 million fund supporting CCUS research across 11 countries that can lead to safe and cost effective development of CCUS technology[22]. This is in addition to funding to support the first call of the ACT research programme.This is in addition to funding to support the first call of the ACT research programme.

View from the top of the biomass storage silos at Drax Power Station. Image courtesy of Drax Group plc.

Canada/ US 1

Finalists of the NRG Cosia Carbon Xprize are testing innovative CCU technology at two test sites in North America.

Netherlands 2

The Port of Rotterdam is assessing the feasibility of a large scale industrial CCUS network.

Norway 3

Sleipner CCUS project has been storing CO_2 in a saline aquifer under the North Sea since 1996.

China 4

The UK-China (Guangdong) CCUS Research Centre brings together UK and Chinese expertise

Japan 5

CCUS demonstration plant at Tomakomai capturing and storing CO_2 from hydrogen production

US 6

NET Power are demonstrating their ground-breaking 'Allam Cycle' technology in Texas

US 7

The 45Q tax credit could stimulate investment in CCUS projects for EOR and CO_2 storage

India 8

Carbon Clean Solutions, based in the UK, installed carbon capture at an industrial site in Tuticorin

UK 9

Drax and C-Capture are piloting Europe's first BECCS facility

Key

- Clean Energy Ministerial CCUS Initiative and Mission Innovation CCUS Challenge Member
- Mission Innovation CCUS Challenge Member
- Clean Energy Ministerial CCUS Initiative Member
- Large-scale operational CCUS facility
- Large-scale CCUS facility under construction
- Innovative technology development
- UK Official Development Assistance CCUS funding
- New policy development

Multilateral Agreement	Members and participants
Clean Energy Ministerial CCUS Initiative Member	Canada, China, Japan, Mexico, Norway, Saudi Arabia, South Africa, United Arab Emirates, United Kingdom, United States of America
Mission Innovation CCUS Challenge Member	Saudi Arabia, Mexico, United Kingdom, Australia, Canada, China, European Commission, France, Germany, Norway, Netherlands, United States of America, Denmark, Finland, India, Indonesia, Italy, Japan, Korea, Sweden
ERA-NET Accelerating CCS Technologies second call participant	France, Germany, Netherlands, Norway, Romania, Spain, Switzerland, Turkey, USA, UK

The Tees Valley, possible site for CCUS in an industrial centre.
Image courtesy of Tees Valley Combined Authority.

Delivering our 2030s ambition

The Government has put achieving clean growth, while ensuring value for money for businesses and consumers, at the heart of our Industrial Strategy.

We have been among the most successful countries in growing our economy while reducing emissions. Since 1990, we have cut emissions by 43 per cent[23] while our economy has grown by over two thirds[24].

CCUS has a potentially significant role in supporting the UK to meet our legally binding target of reducing emissions by at least 80% compared to 1990 levels[25]. This is because CCUS could help the UK meet the challenges remaining in decarbonising our economy, primarily in how we provide low carbon heat and cut emissions from industry and transport, as well as supporting low carbon gas use. Our ambition for CCUS is consistent with our Industrial Strategy ambition of positioning the UK as "a leader in clean and efficient power, transport and heat through an integrated approach to decarbonising these increasingly connected systems"[26].

Through our Clean Growth Grand Challenge, we aim to maximise the advantages for UK industry from the global shift to clean growth. The role that CCUS could play in the transition to a low carbon economy, coupled with the UK's strengths in CCUS, means that development of CCUS technologies could strengthen local economies across the UK. It is why our industrial centres in Scotland, South Wales, Humberside, Merseyside, and Teesside all see CCUS as central to their long-term competitiveness.

That is why working with the UK's industrial centres, the private sector, including energy intensive industries, oil and gas companies, the investment community and academia is central to progressing CCUS and achieving our 2030s ambition.

Key messages

- CCUS has a potentially significant role in supporting UK emissions reductions across several sectors, and in driving clean growth.
- We will complete our review of CCUS Delivery and Investment Frameworks, considering how to deliver a supportive business environment.
- We will work with stakeholders to identify existing infrastructure that could be re-used to support CCUS projects and will develop a policy on re-use of infrastructure for the purpose of CCUS.

A scientist researching and developing sustainable technologies at Johnson Matthey's UK laboratories. Image courtesy of Johnson Matthey.

Development of CCUS in clusters

The CCUS Cost Challenge Taskforce[27] and Lord Oxburgh's Parliamentary Advisory Group on CCS[28] recommended the deployment of CCUS in industrial centres.

Both highlighted the opportunities to maximise economies of scale to lower the unit costs of developing a carbon dioxide infrastructure network in an industrial centre where costs across a number of users can be shared, if the right business model for carbon dioxide infrastructure is put in place.

Deploying CCUS in industrial centres has the potential to allow a number of carbon capture applications – from industry, to hydrogen, to low carbon gas in power – to connect to shared carbon dioxide infrastructure, improving resilience of carbon dioxide supply, availability of carbon dioxide storage (if multiple pipelines and stores are used), and mitigating potential cross-chain risk. We will examine and report, during 2019, on the opportunity of maximising economies of scale by developing shared carbon dioxide infrastructure network in an industrial centre, and the potential for cost effective deployment that provides value for money.

Deploying CCUS in industrial centres is considered to have the added benefit of helping protect existing industry, increase productivity and encourage inward investment[29].

At a local and regional level, direct high value jobs in capital intensive industries, such as oil and gas, chemicals, and other energy intensive industries have been shown to support up to four jobs in indirect employment[30]. Decarbonising these industries, potentially through deployment of CCUS, allows their sustained contribution to economic growth both nationally and in the regions in which the industry is concentrated. This is a key reason why CCUS is being progressed in other European industrial centres such as the Port of Rotterdam[31]. Furthermore, skills and supply chains from the oil and gas and chemicals industries could transition to service a growing CCUS industry, allowing the retention and creation of further high value jobs.

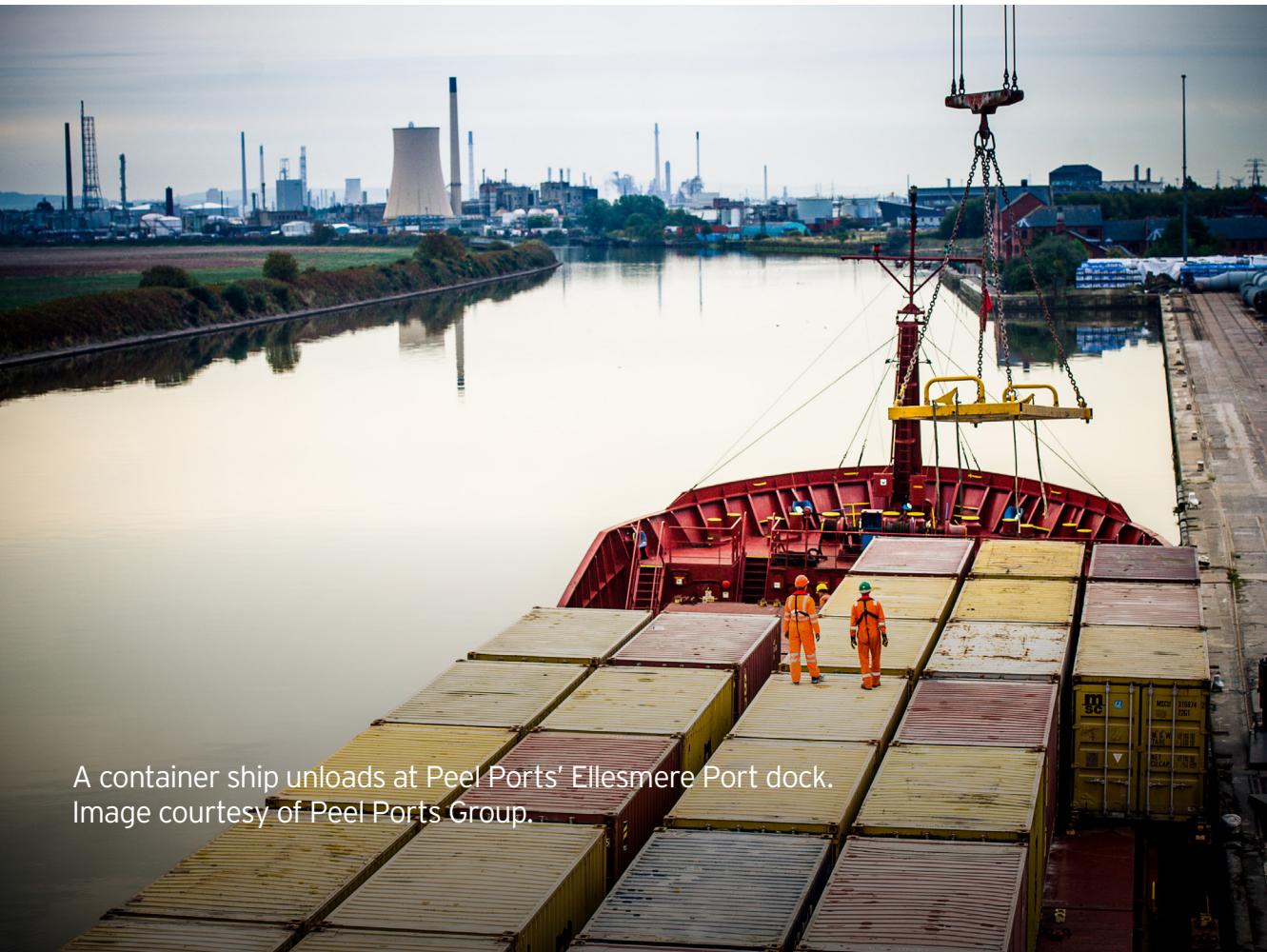
At this stage we recognise that a successful proposition for a CCUS facility and carbon dioxide infrastructure network could enable innovation, bring economies of scale and provide an integrated decarbonisation solution for a diverse range of industries, including the potential of using the carbon dioxide to create new products and services, stimulating clean growth within a defined place.

A successful proposition will be one that is supported by local and regional communities, authorities and businesses. It will need to be consistent with the market based framework set out by Government and include the wider industrial and economic benefits of establishing CCUS in the place.

Action: We will examine in detail the scope of the opportunity for maximising economies of scale by developing a shared carbon dioxide infrastructure network in an industrial centre, and will report in the first half of 2019.

Action

We will examine in detail the scope of the opportunity for maximising economies of scale by developing a shared carbon dioxide infrastructure network in an industrial centre, and will report by the end of 2019.



A container ship unloads at Peel Ports' Ellesmere Port dock. Image courtesy of Peel Ports Group.

Creating market mechanisms for CCUS

The barriers to deploying CCUS projects in the UK, and globally, are said to be primarily commercial, rather than technical[32].

These commercial barriers can increase the cost of financing projects, adding a "risk premium" to projects, and may prevent project developers from taking investment decisions. Our review of the delivery and investment frameworks for CCUS is seeking to understand these barriers and to identify potential ways to address them across CCUS in power generation and industry, and carbon dioxide transport and storage infrastructure. We are keen to see CCUS facilities brought forward through market mechanisms which take full advantage of innovation and competition, and the review, working with industry, will identify how this can best be established.

This review is underway and we will consult on our findings in 2019, announcing the outcome of the review by the end of 2019. This outcome will include possible market-based frameworks for power CCUS and for industrial CCUS, and possible commercial models for carbon dioxide transport and storage.

We will work with the CCUS industry and investors to gather their views on the proposed frameworks and enable detailed project development work to progress in parallel. The aim of proposing viable delivery and investment frameworks is to reduce the cost of financing CCUS projects, and, potentially, to allow project developers to take final investment decisions during the 2020s.

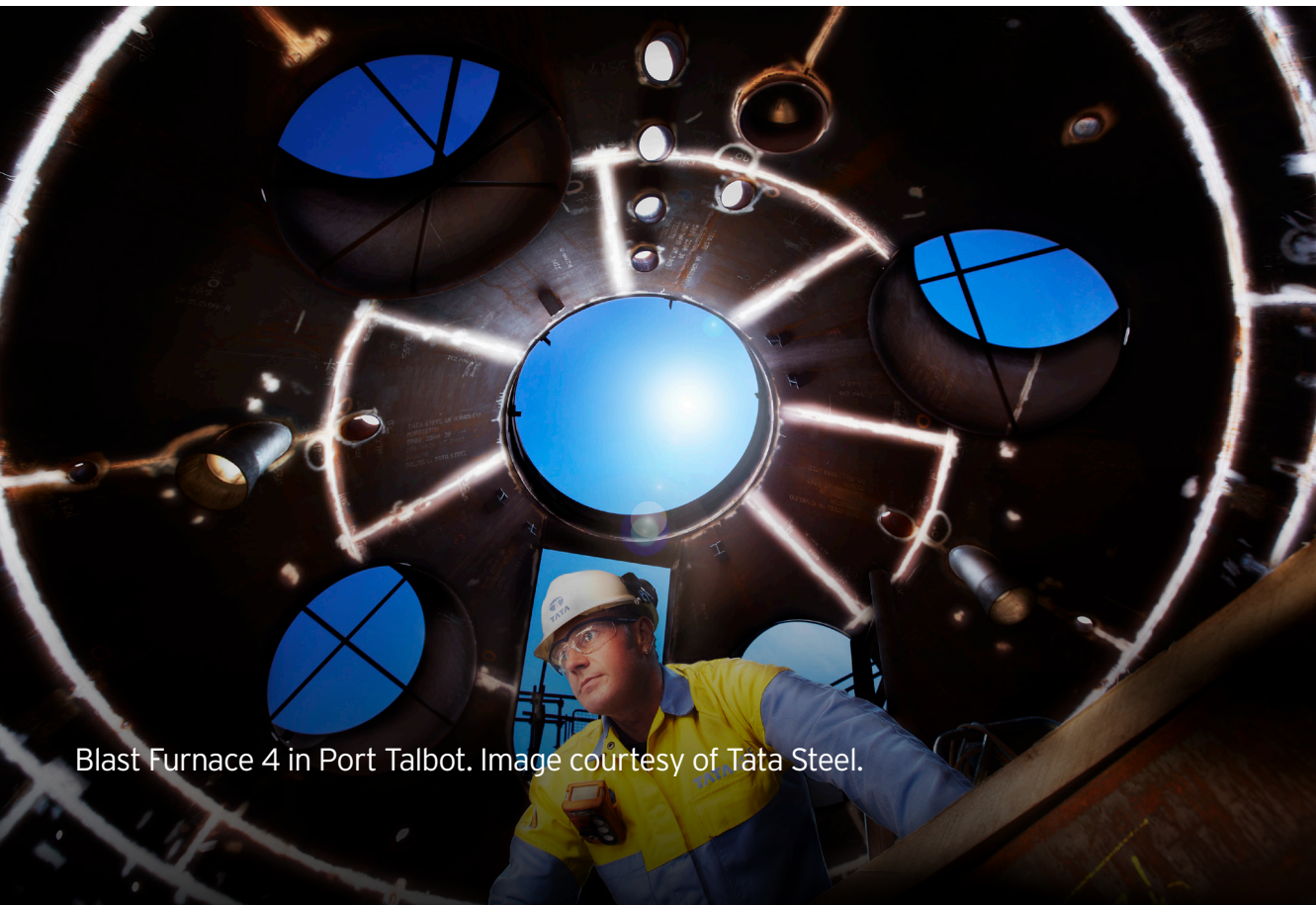
Actions

We will complete, and publish the outcome of, the review of delivery and investment frameworks by the end of 2019.

Industrial decarbonisation with CCUS

CCUS could be an important technology for decarbonising energy intensive industries (EIIs), including iron and steel, cement, chemicals, and oil refining[33]. Some of these industries produce volumes of emissions from chemical processes, in addition to combustion of fossil fuels, for example, up to 70% of emissions from cement production are from the process of producing cement, rather than from energy use[34]. These emissions cannot be abated by fuel switching or electrification.

Overall, CCUS could provide 37% of the total abatement potential in EIIs by 2050[35]. A recent study by McKinsey on decarbonising EIIs showed that where carbon dioxide storage sites are accessible, CCUS is the lowest-cost decarbonisation option at current commodity prices[36]. CCUS also enables the large-scale use of hydrogen as an industrial fuel, which the recent CCC and Element Energy reports have indicated could be one cost-effective pathway to industrial decarbonisation[37,38].



Blast Furnace 4 in Port Talbot. Image courtesy of Tata Steel.

EIIs such as these and others employ approximately 1.5 million people across the UK, and contribute just over 8% UK GVA[39]. They are often important employers to local economies and tend to pay above the median wage[40]. The international competitiveness of our key industrial regions could be supported by early adoption of disruptive technologies such as CCUS, which could also drive inward investment, and create and protect jobs for a low carbon global economy.

CCUS in industry presents challenges, particularly commercially, due to the globally traded nature of the products and heterogeneity of the sector. Industrial emissions arise from a broad range of processes and industrial subsectors, each with their own challenges and requirements.

CCUS in industry also has unique economic and market related risks. Industry has more flexibility in technology and location and relatively short investment timeframes of less than ten years. Carbon leakage[41] is thought to be a risk for industries with globally traded commodities, as industry may seek to operate in the jurisdiction in which it is cheapest to emit greenhouse gases, rather than decarbonise, if they are not supported to do so. Suitable business models that incentivise carbon capture in industry will need to address these issues and be broadly applicable to a range of subsectors.

There are nevertheless potential low cost capture opportunities. Recent analysis by the IEA estimated costs of carbon capture at around $28 per tonne for ammonia production, and $30 per tonne for ethanol production[42].

To help industry decarbonise, we have launched an Industrial Energy Transformation Fund, worth up to £315 million. This will provide funding for transformative decarbonisation investments, potentially including fuel switching and carbon capture. We will consult on the Fund's design during 2019.

We are reviewing the barriers to the deployment of industrial carbon capture and we will consult on emerging findings, including on the market-based frameworks for industrial carbon capture, in the first half of 2019. So far, we have:

- Commissioned Element Energy to review the commercial barriers to deployment and operation of industrial carbon capture infrastructure and identify a wide range of business models which could tackle these barriers to enable the cost-effective deployment of industrial carbon capture in the UK[43].
- Received Element Energy's assessment of the identified models according to a broad set of criteria that they developed, such as their commercial performance, cost-effectiveness, ability to drive cost-reductions, and sector-specific implications in order to identify those which are the most promising (see Table 1).
- Used the outputs from this study to inform further development of an industrial carbon capture business model.

Option	Description
Contract for Difference on CO_2 abatement strike price	Strike price per tonne of CO_2 abated on CO_2 certificate value, contractually agreed in advance to cover expected industrial carbon capture costs relative to business as usual.
Cost-plus open book	Emitter is directly compensated for all properly incurred operational costs through Government grant funding.
Regulated Asset Base (Hydrogen only)	Product price (Hydrogen) regulated to recover capital and operational costs.
Tradeable tax credits	Reductions in tax liability of energy intensive industries with industrial carbon capture, in £/tCO_2 abated. The tax credits may be fixed or may taper down over time. Tradeable to allow realisation of their full value.
Tradeable CCUS certificates, plus obligation	CCUS certificates are awarded per tonne of CO_2 abated and can be sold to other obligated emitters. There are obligations on emitters and/or fuel suppliers to present the required number of certificates.
Low carbon market creation	Creation of a low-carbon market through certification, public procurement and end-use regulations, allowing a price premium for low carbon goods.

Actions

- We have announced an Industrial Energy Transformation Fund, worth up to £315 million, which will help businesses with high energy use to cut their bills and transition to a low carbon future. This includes transformative decarbonisation investments potentially including fuel switching and carbon capture. We will consult on the Fund's design, including eligibility criteria, during 2019.
- We are reviewing the barriers to the deployment of industrial carbon capture and we will consult on emerging findings, including the options for establishing a market-based industrial carbon capture framework, in 2019.

Pipeline welding taking place on Lot 1 of the TANAP pipeline construction, in the province of Kars in Turkey. The Trans Anatolian Natural Gas Pipeline (TANAP) is a central part of the Southern Gas Corridor pipeline system. Image courtesy of BP plc.

Decarbonising electricity generation with CCUS

The Government has set out four principles to guide future strategy for the power sector[44].

These are:

I. We must, wherever possible, use market mechanisms that take full advantage of innovation and competition;

II. Government must be prepared to intervene to provide insurance and preserve optionality;

III. Energy regulation must be agile and responsive to opportunities; and

IV. Consumers of all types should pay a fair share of system costs.

In reviewing the role of power CCUS, we are considering these four principles and how we use them in our approach to this technology.

CCUS can support decarbonisation of electricity generation, with gas, or biomass, fired generation with CCUS able to provide firm low carbon baseload and potentially mid merit power on a flexible basis[44,45]. It is important that if CCUS is to have a role, it will need to show it is a cost effective part of power sector decarbonisation.

There is consensus, including through electricity system modelling done by BEIS, the ESC and National Grid[47], that there is a potential role for CCUS in decarbonising the electricity system, alongside an expansion of other forms of low- and zero-carbon generation. In particular, analysis has recognised the importance of firm, flexible low carbon power generation to achieve deep decarbonisation of the UK power sector[48,49]. CCUS could potentially provide this capability. Further analysis from the FlexEVAL project "shows the particular value of CCS to the UK's electricity system and quantifies that flexible CCS allows the integration of a greater amount of renewable energy than would be otherwise possible"[50].

BEIS analysis shows that the levelised cost of electricity (LCOE) for a first-of-a-kind combined cycle gas turbine (CCGT) with post-combustion carbon capture and storage could be around £75/MWh[51], for a plant commissioning in 2025. The LCOE of a plant of this type was previously estimated to be £110/MWh[52]. These updated figures drew on recent work, including a report by Wood Group for BEIS[53].

A recent feasibility study by Summit Power, which was conducted with funding from the UK and Scottish Governments, of the Caledonia Clean Energy Project, a potential CCUS power plant based in Grangemouth, Scotland, showed that the plant could generate power at a strike price of around £80 to £90/MWh, subject to some commercial changes. The feasibility study also confirmed that the plant would be able to dispatch flexibly, with maximum ramp rates of 88MW/minute[54].

CCUS in power has been the focus of previous efforts to deploy and commercialise CCUS in the UK. Lessons learned from these efforts[55] have shown that challenges facing the technology include the lack of a generic, investable mechanism for power CCUS.

In addition, recent research has shown that the flexibility of power CCUS could be a key component of the value which the technology can provide to the electricity system[56]. It is therefore

Technology	Commissioning year	
	2025	2030
CCGT + CCUS Post Combustion FOAK	£75 (£81)	£76 (£83)

Table 2: Estimated Levelised Cost of Electricity (LCOE) for First of a Kind (FOAK) combined cycle gas turbine (CCGT) plants with post-combustion CCUS. LCOEs in 2012 (and 2017 prices).

important that we understand, working with industry, the role CCUS has in the power sector and how best to ensure it is investable, including consideration of how to incentivise flexible operation of CCUS and other low carbon facilities.

We have:

- Commissioned Uniper Technologies Ltd. to provide updated technical and cost assumption data on power CCUS technologies[57]. We have used these updated assumptions to revise BEIS Levelised Cost of Electricity (LCOE) figures (see Table 2).
- Updated our internal modelling to assess the value which CCUS can potentially provide to the electricity system. For example, considering the place of CCUS in the merit order and the nature of dispatch, including the ability of CCUS to provide electricity system services.
- Commenced work with Energy UK and the CCS Association to examine what an investable proposition for power CCUS could look like.
- Started further work to assess viable mechanisms for power CCUS, including testing whether a Contract for Difference is the most appropriate mechanism.
- Begun engagement with work led by BEIS considering the option of a regulated asset base model as a sustainable funding model for nuclear power projects. We will consider the implications of this work for potential future CCUS power projects..

Action

We will, through joint working with industry, keep under review the role power CCUS has, and examine how it can provide the greatest value to the electricity system and support wider decarbonisation. We will consult on our emerging findings for a market based framework for power CCUS in 2019.

Carbon dioxide transport and storage infrastructure can support decarbonisation of our industrial centres

Carbon dioxide transport and storage infrastructure in the UK, incorporating pipelines and/ or shipping, is likely to be essential to support the decarbonisation of our industrial centres and deployment of CCUS at scale.

It will offIt will offer options to provide low carbon heat and electricity and enable the deployment of what are currently considered the most scalable GGR technologies – bioenergy with CCS (BECCS) and direct air capture[58].

The UK has a world-leading offshore oil and gas industry and strong domestic supply chain. It has an established skills base which is well-placed to develop a domestic carbon dioxide infrastructure network and export its expertise world-wide. With the potential to store more than 78 billion tonnes of carbon dioxide[59], the UK can be a world leader in carbon dioxide storage services, providing new economic opportunities by providing carbon dioxide storage for UK and European emissions for over a hundred years[60]. A number of UK carbon dioxide storage sites are already well appraised, an advantage over other nations, and information on potential storage is available through the world-leading CO_2 Stored database[61].

Transport and storage infrastructure for carbon dioxide has previously been considered in the UK only in the context of 'full-chain' projects, where a single developer would build and operate the carbon capture, transport and storage infrastructure with subsequent projects linking in to this infrastructure. This model meant that the initial full chain project was incentivised through one mechanism with the lead organisation then sharing payments across the chain (capture, transport, and storage). For those projects that included a different carbon dioxide transport and storage operator this increased cross chain risk and in turn increased the price of potential CCUS projects. In response, the Review of Delivery and Investment Frameworks for CCUS is exploring whether a separate, investable business model for the transport and storage element of the CCUS chain would reduce risk and support a sustainable commercial model for CCUS in the UK.

Our aim is to review the potential models that could best support the development of a commercial model to enable investment in, and deployment of carbon dioxide transport and storage infrastructure in the UK.

To take this forward we have:

- Published work by Pale Blue Dot Energy Ltd. which identifies the key challenges which might constrain the development of carbon dioxide transport and storage infrastructure[62]. It defines the range of possible delivery and operating business models for carbon dioxide transport and storage infrastructure, and considers how these models can differently address the challenges identified. The work identified as groups of models including full public ownership, majority public ownership, a public private entity and a fully private venture. As part of the Review we will undertake further analysis to test their suitability in a UK context.
- Published work by Element Energy exploring the potential role that shipping, as a mode of transporting carbon dioxide to offshore geological storage sites, could play in reducing the cost of deploying CCUS in the UK[63].
- The study includes consideration both of shipping between sites within the UK, and from the UK to a third country. The work will improve the evidence base on the costings of carbon dioxide shipping and identify the circumstances in which shipping may represent value for money in the UK, relative to fixed pipelines.
- Scoped a study to provide detailed advice on five potential delivery and investment models (see Table 3) for carbon dioxide infrastructure in the UK, building on the findings of the study by Pale Blue Dot Energy Ltd. This includes assessing the commercial performance of each model, and their associated costs, lead times, and set-up considerations. It will also consider specific carbon dioxide storage risks identified as a key issue by the Parliamentary Advisory Group on CCS and the CCUS Cost Challenge Taskforce.

Option	Commercial structure	Revenue
Fully private **Majority private** **50:50 Joint Venture**	Structured as a PPP or regulated asset business [or hybrid]	Revenue from a regulated return, (potentially contingent on performance).
Majority public **Fully public**	Structured as a regulated asset business.	Revenue from a regulated return.

Table 3: Potential delivery and investment models for carbon dioxide infrastructure in the UK.

There is potential for cost savings in initial CCUS projects which can re-use existing oil and gas infrastructure, an opportunity which has been identified by some project developers and the CCUS Cost Challenge Taskforce. Government will coordinate a process, in collaboration with project developers, owners of existing assets, and relevant regulators, to identify assets with potential for re-use. Government expects that regulators, developers and owners of existing assets will work closely together, where assets are identified with potential for re-use, in order to maximise the potential economic life of those assets.

As part of our work to build a business environment that is supportive of deployment and cost reduction in CCUS, we will work with industry, the OGA, the Crown Estate, and Crown Estate Scotland over the first half of 2019 to provide further clarity on this issue by developing a policy on re-use of infrastructure for the purposes of transporting and/or storing carbon dioxide.

Actions

- We will complete a process, with the OGA, industry and The Crown Estate and The Crown Estate Scotland, in the first half of 2019, which identifies existing oil and gas infrastructure that has the potential for re-use to support the development of CCUS in the UK.
- We will, in consultation with the OGA, Health and Safety Executive (HSE), Marine Management Organisation (MMO), Ofgem, industry, The Crown Estate, and The Crown Estate Scotland, develop a policy on re-use of infrastructure for CCUS in the first half of 2019.
- We are reviewing the potential market-based frameworks that could best support investment in, and deployment of carbon dioxide transport and storage infrastructure in the UK, and will consult on emerging findings in the first half of 2019.

CCUS can enable new industrial markets

CCUS can create new industries and markets through the use of carbon dioxide, such as chemicals, plastics, and building materials, with potential to use around 7GtCO$_2$/year globally by 2030[64].

Utilising carbon dioxide can also help improve the economics of CCUS projects and some uses, such as in cement and aggregate production, can support decarbonisation through permanent sequestration of carbon dioxide. Recent work by Carbon180 states that CCU products could access a multi trillion dollar market[65]. Implementing CCU to manufacture these innovative new low carbon products could contribute to cutting UK emissions, support the development of new carbon capture technologies, create new jobs, investment, and export opportunities for UK industries and SMEs.

Action

We will deliver our £20 million CCU Demonstration programme by March 2021 supporting the construction of CCU technologies at industrial sites across the UK. In total, we will deliver CCUS innovation programmes worth £45 million.

A tanker unloads at Carbon8 Aggregates' APCr treatment plant in Brandon, Suffolk. Image courtesy of Carbon8 Aggregates.

Low carbon hydrogen with CCUS

Low carbon hydrogen's flexibility as an energy vector could enable it to play a complementary and enabling role, alongside electricity, in the decarbonisation of a range of sectors, including domestic and industrial heat, transport, and power[66].

If the decision is taken to deploy low carbon hydrogen at scale, CCUS is likely to be required, as it is currently thought that the most cost-effective method of producing low carbon hydrogen at scale is through reformation of methane with CCUS[67]. The Government's £20 million Hydrogen Supply programme aims to accelerate the development of low carbon bulk hydrogen supply solutions[68], specifically including methane reformation with CCUS, alongside other methods (such as electrolysis and import infrastructure).

The scale of low carbon hydrogen that might be required in the UK is currently uncertain. For example, hydrogen is one potential option for decarbonising heat, alongside biogas, heat pumps and heat networks. Government is laying the groundwork to set up decisions in the first half of the next decade on the long-term future of heat.[69]Hydrogen could also provide a cost-effective decarbonisation option in transport, particularly in heavy goods road transport, trains, and shipping, as highlighted by the CCUS Cost Challenge Taskforce. As mentioned above, recent reports have suggested that hydrogen could represent a cost-effective pathway to decarbonising industry; and it could also play a role in addressing the challenges of intermittency and long-term storage in the power sector.

There is also the potential for carbon dioxide captured from the production of low carbon bio-hydrogen, as well as of biomethane, to be stored, leading to negative emissions.[70]Low carbon gas from biomass is one of the potential routes to decarbonise homes, businesses and industry currently served by the gas grid[71]. The CCC's recent report on bioenergy suggested that producing negative emissions could be the most valuable use of biomass by 2050[72].

Greenhouse Gas Removal technologies

The Paris Agreement includes an aim of achieving net zero global greenhouse gas emissions in the second half of the century.

In their initial consideration of potential domestic action following the Agreement, the CCC concluded that GGR options will be required alongside widespread decarbonisation in order to reach net zero emissions[73]. This work is supported by the recent IPCC report on global warming of 1.5°C[74]. The report concluded that limiting global warming to this level would require reaching net zero carbon dioxide emissions around 2050, and highlighted the importance of CCUS in achieving this. It also noted that all pathways with limited or no overshoot above 1.5°C project the use of carbon dioxide removal (i.e. GGR).

Two of the most scalable GGR technologies, BECCS and direct air capture, will both require carbon dioxide infrastructure. As we set out in the Clean Growth Strategy, GGR technologies are likely to have an important role to play in offsetting difficult-to-cut emissions, by removing greenhouse gases from the air.

Action

We will publish work during 2019 setting out policy options for responsibly developing GGRs.

Royal Society and Royal Academy of Engineering report on GGRs

The Royal Society and Royal Academy of Engineering have advised Government that even with very stringent emissions reductions across all sectors of the economy, around 130MtCO$_2$/year would need to be accounted for by negative emissions technologies if the UK were to reach net zero emissions in 2050. To achieve this, they concluded that BECCS and Direct Air Capture at a significant scale – over 50% of the total amount of negative emissions – would be required[75].

Central to the report's recommendations was to build carbon dioxide infrastructure, in order for permanent storage of carbon dioxide from BECCS and DACCS to occur.

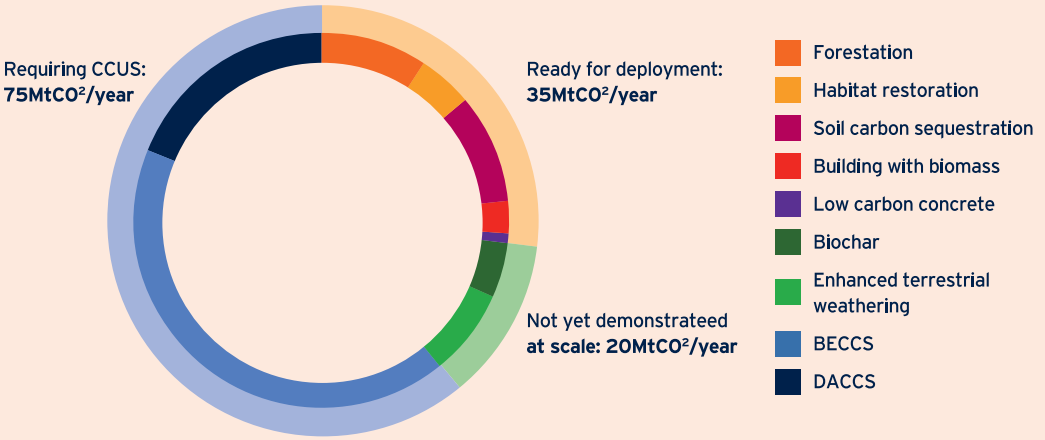


Figure 5: Chart to show the potential of technologies to provide Greenhouse Gas Removal services in 2050. Adapted from Carbon Brief[76]. Source: Royal Society and Royal Academy of Engineering Greenhouse Gas Removal report

The St Fergus Gas Terminal, possible site for the Acorn CCS Project.
Image credit North Sea Midstream Partners (NSMP).

The UK is leading innovation and global collaboration to accelerate CCUS

International collaboration is vital to accelerate CCUS globally.

From the IPCC to the IEA there is international consensus that CCUS is vital to meeting the ambitions of the Paris Agreement[77]. In the IEA's 'below two degrees' scenario, CCUS accounts for over one fifth of the total emissions reductions[78].

The recent IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels shows the significant importance of CCUS in industrial decarbonisation, electricity generation and carbon dioxide removal. The majority of the IPCC's pathways include CCUS as a critical enabling tool for greenhouse gas removal (achievable through bioenergy with CCUS and direct air capture with CCUS, for instance) which can offset residual emissions from "harder to reach" sectors such as agriculture and aviation. Global cumulative capture through CCUS may need to reach between 348 to 1218 billion tonnes of carbon dioxide by the end of the century. If this CCUS infrastructure does not become available at scale, much more rapid global cuts in emissions are required by 2030. The Government has asked the CCC to advise on the implications of the Paris Agreement for UK ambition. This advice is expected in March 2019.

Globally, CCUS is being deployed now: there are now eighteen[79] operational large scale[80] facilities ranging from applications in chemicals, iron and steel, gas processing and power generation. There are also hundreds of smaller scale CCUS projects and research centres operating around the world[81]. CCUS is proven, but it is estimated that global deployment of CCUS needs to increase significantly from the eighteen operational today to thousands of large-scale facilities by 2060[82].

Accelerating CCUS globally is complex but increasingly important and urgent. The challenge is to find cost effective, investable and sustainable pathways to enable commercial deployment of CCUS technologies. This challenge is compounded by an investment gap from both the public and private sectors. Of the $850 billion invested in low carbon energy worldwide in 2016, only 0.1% was invested in CCUS[83]. Putting in place a sustainable commercial pathway for CCUS can help unlock this investment and is an opportunity for those leading on CCUS.

Key messages

- CCUS is being deployed around the world, but needs to accelerate significantly in order to meet global emissions reductions targets.
- We will continue to play a leading role in international multilateral organisations, working with other governments and industry to accelerate global deployment and achieve global cost reductions.
- We will continue to invest in supporting the development of CCUS technologies, positioning the UK as a global leader.

Collaboration at scale, investable commercial models and working with other governments and industry will be vital to drive cost reductions and shift perceptions on CCUS. That is why our global Accelerating CCUS Summit on 28 November 2018, co-hosted by the IEA, brought together Governments and industry to discuss concrete actions to accelerate CCUS globally. We will work with the IEA and others such as the Global CCS Institute to advance the conclusions from the Accelerating CCUS Summit.

We will work with Norway, Canada, Australia, USA, Japan, Saudi Arabia, Mexico and the UAE to build greater international CCUS collaborative links both bilaterally and multilaterally. We will:

- Develop new or build on existing agreements with other leader countries on CCUS.
- Work with other Governments, in particular Norway, to identify and address barriers to cross-border transport of carbon dioxide, highlighting the importance of ratifying the London Protocol to allow this.
- Through our co-leadership of the Mission Innovation CCUS Challenge, with Mexico and Saudi Arabia, deliver an action plan to build on the extensive Priority Research Directions report[84] that emanated from the September 2017 Carbon Capture Mission Innovation Workshop held in Houston.
- Work to progress CCUS globally, in particular through increased engagement with the investment community via the new CCUS initiative under the Clean Energy Ministerial which we are co-leading with the USA, Norway, and Saudi Arabia.

- Continue to play leadership roles at the Carbon Sequestration Leadership Forum (CSLF), North Sea Basin Task Force, together with full engagement with the IEA's CCUS Unit, Global CCS Institute and the IEA's Greenhouse Gas R&D Technology Collaboration Programme (IEAGHG) to promote collaboration.
- Continue to support developing countries and emerging economies to develop both the technical and institutional knowledge necessary to enable the deployment of CCUS technologies through our £70 million international CCUS programme, which uses Official Development Assistance (ODA).

Actions

- We will deliver an action plan in 2019, in collaboration with Mexico and Saudi Arabia, to advance the Mission Innovation CCUS Challenge.
- We will work with other Governments to identify and address barriers to cross-border transport of carbon dioxide and promote ratification of the London Protocol.

We are continuing to invest in CCUS to support deployment and cost reduction and ensuring we have a world-class research and innovation base for CCUS in the UK

According to the IEA[85], CCUS technology will experience significant technological advancement, cost reduction and broader application as the CCS industry grows.

This means that there will be opportunities which we can exploit as new technologies are developed which could further reduce the cost of CCUS. We are in a good position to do so. For example, UK companies such as Carbon Clean Solutions and C-Capture, and the UK invented Allam Cycle are demonstrating that next generation capture technologies offer important cost reduction potential. For this reason, we are investing £100 million to March 2021 to support industry and CCUS innovation and deployment in the UK[86].

In 2018, we announced three innovation programmes as part of our £100 million industrial energy and CCUS innovation programme.

We have designed these programmes so that they support a reduction in the cost of capturing and storing carbon dioxide and/or lead to a quicker, more widespread deployment of CCUS in the UK and internationally.

The UK has a well-established and strong CCUS research and development base and both the UK CCS Research Centre and Scottish CCS are world-leading CCUS research groups. We are, alongside the United States, Canada, and China, a leader in this field. The UK is the clear leader on scientific CCUS publications in Europe and, globally, ranks highly alongside the countries generating the most scientific publications and citations in the field, behind only the United States and China in numbers[87].

Delivering world leading research through our academic institutions will need to continue to support our aim of becoming a global technology leader in CCUS. In particular, we will maintain a specific focus on areas which can support cost reductions, support deployment and support UK leadership. We also recognise the importance of continuing to build the evidence base around CCUS during the 2020s, to inform any decision taken on whether (and how) to deploy at scale.

Working with UKRI, we will provide further detail on the next steps for CCUS innovation in due course, as current innovation programmes begin to deliver results. We expect that as initial CCUS projects are progressed during the 2020s, that academia and industry will continue to collaborate to deliver further R&D projects.

Actions

- We will deliver CCUS innovation programmes worth £45 million by March 2021.
- We will, working with UKRI, provide further detail on next steps for CCUS innovation in due course, as current innovation programmes begin to deliver results.
- We will work with UKRI, academia and industry to develop innovative new R&D projects and collaborative partnerships.

Summary – meeting our vision

Delivering our vision to become a global technology leader, unlocking the potential of CCUS and securing the added value which CCUS can bring to our industrial centres and businesses all across the UK will require significant collaboration with industry, academia and industrial centres.

It requires putting in place structures and frameworks that work in the context of an economy and energy system that is rapidly changing and evolving, to deliver our 2030s ambition to move beyond supporting CCUS through innovation to establishing CCUS infrastructure in the UK. Should the costs come down sufficiently this may enable the deployment of CCUS at scale in the 2030s.

The immediate priorities are to address the challenges to progressing CCUS in the UK and globally. Our actions, which are aligned with the Industrial Strategy, will focus on:

- **Ensuring the business environment works for all involved in CCUS through identifying the appropriate commercial frameworks to enable investment, innovation and cost reduction.** In the Clean Growth Strategy, we committed to review the investment and delivery frameworks for CCUS to support commercial deployment. This will enable us to understand the commercial frameworks required to enable investable CCUS projects and provide value for money.
  An important element of this will be to have an appropriate risk allocation between Government and industry, in particular addressing the 'irreducible core' of risks identified by the CCUS Cost Challenge Taskforce.
- **Ensuring we have the people and the delivery capability to deliver the CCUS infrastructure challenge, enabling deployment at scale in the 2030s, creating high value jobs for people across the UK.** We want to ensure that the UK has the right delivery capability to support the deployment of CCUS at scale during the 2030s, if the decision should be taken to do so. This includes the capability within central Government, but also within local and regional authorities across the UK, our industrial centres, the private sector, and investment community. We will assess the Government delivery capability needed to deliver this ambition, and will work with industry to ensure that the private sector also has the relevant delivery capability.

Key messages

- We will build the capability to deliver CCUS projects within the public sector, and will work with industry to ensure the appropriate delivery capability exists in the private sector.
- We will continue to engage with the CCUS industry through the CCUS Council, who will provide ongoing advice on building delivery capability and review progress against the actions set out in this Action Plan.

- **How best to deploy CCUS infrastructure, subject to cost reduction, in places and regions across the UK.** As we look to develop the commercial and policy foundations, we will continue to work with industrial regions to explore the potential of deploying CCUS in their area. Our Action Plan is designed to enable the development of the first CCUS facility in the UK, commissioning from the mid-2020s. We will, in 2019, commence detailed engagement with industry on the critical challenges to delivering CCUS in the UK, in particular the cost structures, risk sharing arrangements and the necessary market-based frameworks.
- **Having a strategic approach to ideas, innovation and development, enabling cost reductions.** Through our innovation programmes we will continue to support advancement of CCUS technology. This includes supporting the expansion of CCU at industrial sites; co-funding early project development work and innovative concepts and technologies; and supporting UK research projects through the second call of the Accelerating Carbon Technologies research programme[88].
- **Leading international collaboration to accelerate global deployment of CCUS.** We will continue to lead efforts, working with other Governments and industry, to accelerate global deployment of CCUS, which will help to drive down costs and expand the emerging market for CCUS technology. We will do this through multi-lateral initiatives, bilaterally, through our Official Development Assistance (ODA) programme for CCUS and with the IEA to progress the outcomes from the global Accelerating CCUS Summit held in November 2018.

Building public and private sector delivery capability

Meeting our ambition, vision, and commitment will require the right delivery capability, both in the public and private sectors.

In 2019, we will complete a review of CCUS and other infrastructure delivery organisations to understand the skills and capability required within Government to ensure successful delivery of CCUS projects during the 2020s, and to assess how best to deliver these within Government. We will work with bodies such as the Infrastructure and Projects Authority, the OGA and central government departments such as the Department for Environment, Food and Rural Affairs and Department for Transport. We will also consider advice from the National Audit Office[89] and Public Accounts Committee[90] to ensure that we have learned lessons from delivery of other infrastructure projects and have put in place appropriate governance structures.

Following the outcome of the review of CCUS delivery and investment frameworks, Government will work with industry during the early 2020s to examine the delivery implications of deploying CCUS at scale in the UK during the 2030s. For example, it may be necessary to understand the carbon dioxide storage facilities that may be required and a timetable for appraising them, in addition to the type of capture projects that might be needed.

Actions

- We will undertake and complete a review of infrastructure delivery organisations to understand the skills and capability required for successful delivery of CCUS projects during the 2020s, and publish a report on this in Autumn 2019.
- Following the outcome of the review of CCUS Delivery and Investment frameworks, we will work with industry during the early 2020s to examine the delivery implications of deploying CCUS at scale in the UK during the 2030s.

Industry will also need to ensure that the appropriate capability exists, within industrial centres, local and regional institutions, and the finance community to deploy CCUS in the UK. Government will work with all industrial areas who want to develop CCUS to benefit their own area and businesses, in order to ensure that places can build this capability.

Having this capability in place will ensure that developers are able to bring together viable commercial propositions. Ensuring that the industry can scale up could be a key consideration before any decision to deploy CCUS at scale during the 2030s is made, and could be a key part of the contribution to the UK's Industrial Strategy.

Action

Industry should, through working with Government, ensure that there is the relevant delivery capability in the private sector, and in local and regional institutions, to deliver initial CCUS projects which can meet the Government's stated ambition.

Advising Government on progress

Government will continue to engage with industry through the CCUS Council.

The Council, co-chaired by the Minister for Energy and Clean Growth and James Smith (formerly chair of the Carbon Trust and Shell UK), will advise Government on progress against the priorities as set out in the Clean Growth Strategy and in this Action Plan. The Council will also continue to monitor industry capability, CCUS costs, and deployment potential.

The CCUS Council will provide a crucial link between industry and Government in providing advice on industry capability and other CCUS developments during the 2020s.

Action

CCUS Council to provide ongoing advice to Government on building industry capability during the 2020s, and to monitor and review progress against the priorities set out in this Action Plan. The Council will also advise on ways to maintain UK's leadership in CCUS.

Overall deployment pathway timeline

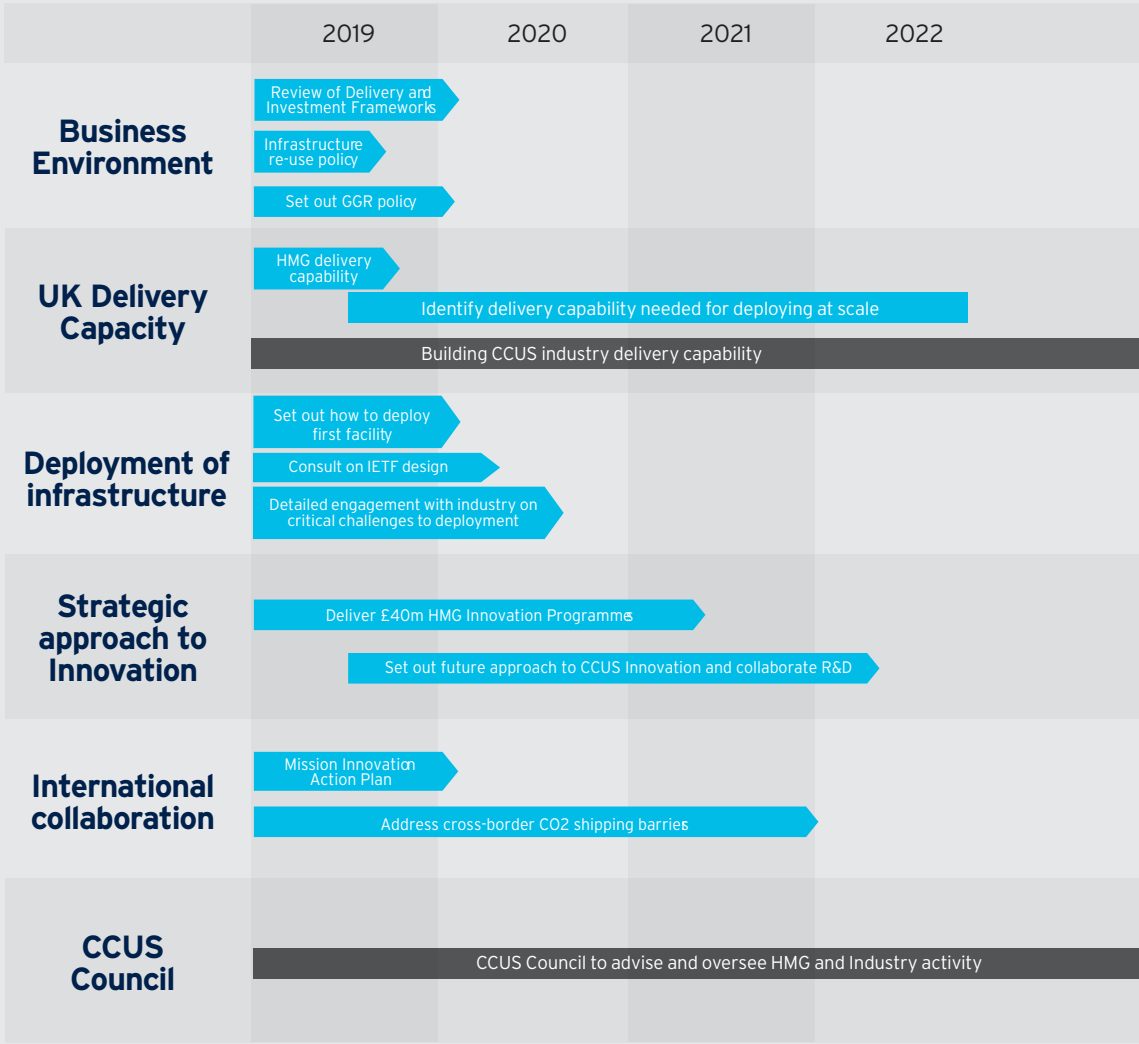
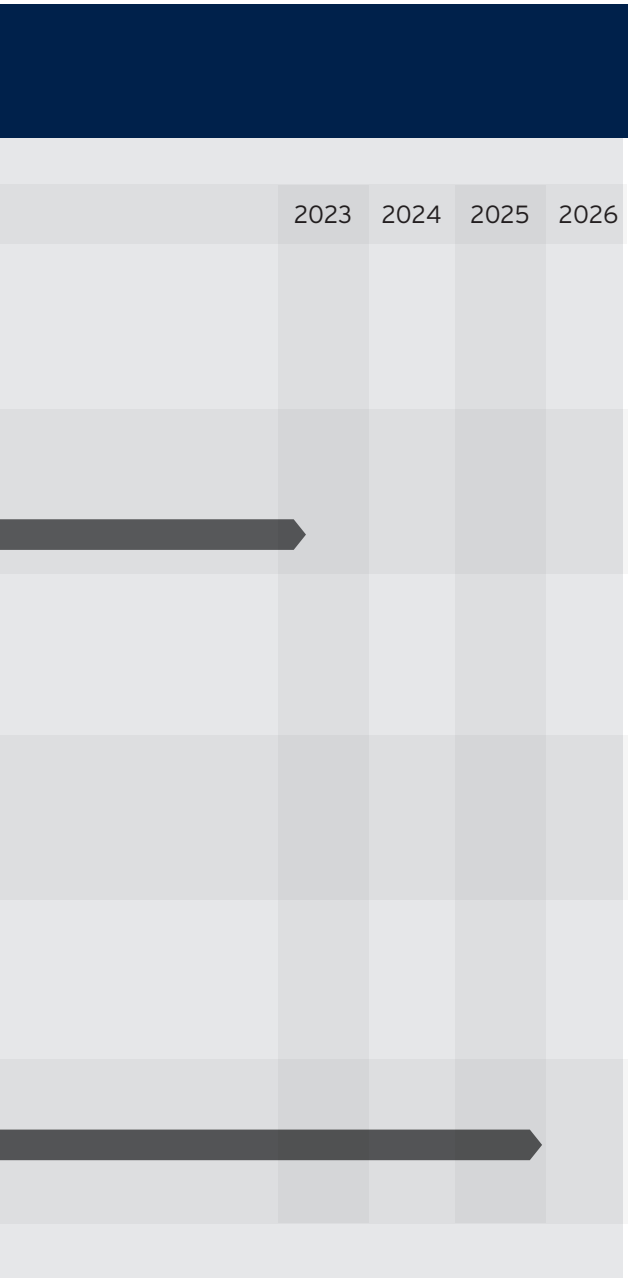


Table 3: Timeline showing the five key action areas and associated actions which we will take to work to achieve our vision of becoming a global technology leader and ambition of having the option to deploy CCUS at scale during the 2030s, subject to costs coming down sufficiently.



Key

HMG supporting actions

Industry actions

Actions to meet our Vision, Ambition, and Commitment

Action	Lead	By When
Action focus one: a supportive business environment		
We are reviewing the barriers to the deployment of industrial carbon capture and we will consult on emerging findings, including on a market-based framework for bringing forward industrial carbon capture, in 2019.	BEIS	**During 2019**
We will, through joint working with industry, keep under review the role of power CCUS and examine how it can provide the greatest value to the electricity system and support wider decarbonisation. We will consult on emerging findings, including potential market-based frameworks for power CCUS in 2019.	BEIS	**During 2019**
We will complete a process, with the Oil and Gas Authority, industry and The Crown Estate and The Crown Estate Scotland, in the first half of 2019, which identifies existing oil and gas infrastructure that has the potential for re-use to support the development of CCUS in the UK.	BEIS	**Spring 2019**
We will, in consultation with the Oil and Gas Authority, Health and Safety Executive, Marine Management Organisation, industry, The Crown Estate, and The Crown Estate Scotland, develop a policy on re-use of infrastructure for CCUS in the first half of 2019.	BEIS	**During first half of 2019**
We are reviewing the potential models and market-based frameworks that could best support investment in, and deployment of carbon dioxide transport and storage infrastructure in the UK, and will consult on emerging findings in 2019.	BEIS	**During 2019**
We will complete, and publish the outcome of, the review of delivery and investment frameworks by the end of 2019.	BEIS	**By the end of 2019**
We will publish work during 2019 setting out policy options for responsibly developing GGRs.	BEIS	**By the end of 2019**

Action	Lead	By When
Action focus two: the right people and delivery capability		
We will undertake and complete a review of infrastructure delivery organisations to understand the skills and capability required for successful delivery of CCUS projects during the 2020s, and publish a report on this in autumn 2019.	BEIS	**Autumn 2019**
Following the outcome of the review of CCUS delivery and investment frameworks, we will work with industry during the early 2020s to examine the delivery implications of deploying CCUS at scale in the UK during the 2030s.	BEIS	**Following action 1.6**
Industry should, through working with Government, ensure that there is the relevant delivery capability in the private sector, and in local and regional institutions, to deliver initial CCUS projects which can meet the Government's stated ambition.	CCUS Industry	**Ongoing**
Action focus three: deploying CCUS infrastructure in places		
In 2019 we will commence detailed engagement with industry on the critical challenges to delivering CCUS in the UK, in particular the cost structures, risk sharing arrangements and the necessary market-based frameworks.	BEIS	**During 2019**
We will examine in detail the scope of the opportunity for maximising economies of scale by developing a shared carbon dioxide infrastructure network in an industrial centre, and will report by the end of 2019.	BEIS	**During 2019**

Action	Lead	By When
We have announced an Industrial Energy Transformation Fund, worth up to £315 million, which will help businesses with high energy use to cut their bills and transition to a low carbon future, including through transformative decarbonisation investments such as fuel switching and carbon capture. We will consult on the Fund's design, including eligibility criteria, during 2019.	BEIS	**During 2019**
Action focus four: a strategic approach to innovation and development, enabling cost reductions		
We will deliver our £20 million CCU Demonstration programme by March 2021 supporting the construction of CCU technologies at industrial sites across the UK. In total, we will deliver CCUS innovation programmes worth £45 million.	BEIS	**March 2021**
We will, working with UKRI, provide further detail on next steps for CCUS innovation in due course, as current innovation programmes begin to deliver results.	BEIS	**In due course**
We will work with UKRI, academia and industry to develop innovative new R&D projects and collaborative partnerships.	BEIS, CCUS Industry	**Ongoing**
Action focus five: international collaboration to accelerate global deployment of CCUS		
We will deliver an action plan in 2019, in collaboration with Mexico and Saudi Arabia, to advance the Mission Innovation CCUS Challenge.	BEIS	**During 2019**
We will work with other Governments to identify and address barriers to cross-border transport of carbon dioxide and promote ratification of the London Protocol.	BEIS	**Ongoing**

Overarching actions	Lead	By When
CCUS Council to provide ongoing advice to Government on building industry capability during the 2020s, and to monitor and review progress against the priorities set out in this Action Plan. The Council will also advise on ways to maintain UK's leadership in CCUS.	CCUS Council	**Ongoing**

A pipeline transports CO_2 from the Quest unit to injection sites for safe and permanent underground storage. Scotford upgrader, near Fort Saskatchewan (northeast of Edmonton). Alberta in June 2015

Philip Chin (all rights assigned, except external advertising, to Shell International Ltd in perpetuity)

Response to the CCUS Cost Challenge Taskforce recommendations

The CCUS Cost Challenge Taskforce was established by the Minister for Energy and Clean Growth in January 2018. It was chaired by Charlotte Morgan of Linklaters LLP, and delivered a report to Government in July 2018 setting out the CCUS industry's view on how to reduce the costs of deploying CCUS in the UK.

The report, "Delivering Clean Growth", was received by Government, and its recommendations and conclusions have been closely considered. We will continue to work with industry to understand further the opportunities and challenges set out in the report.

Recommendation 1: Government to publish the CCUS Deployment Pathway by the end of 2018, including a commitment to have at least two carbon capture, usage and storage clusters operational from the mid-2020s.

Government response: We have published the CCUS Action Plan, of which this response forms a part, which is designed to enable the deployment of the first CCUS facility, commissioning from the mid-2020s. In 2019, we will commence detailed engagement with industry on the critical challenges to delivering CCUS in the UK, in particular the cost structures, risk sharing arrangements and creating the necessary market-based frameworks.

Recommendation 2: Industry and Government to work together to develop a CCUS roadmap for the UK as part of the Deployment Pathway publication by the end of 2018.

Government response: We are grateful to the industry for their joint work with Government since publication of the CCUS Cost Challenge Taskforce report. We have considered the roadmap which was delivered to Government, and this Action Plan sets out the actions which we believe are necessary to achieve our ambition of having the option to deploy CCUS at scale during the 2030s, subject to costs coming down sufficiently.

Recommendation 3: Government to publish a policy framework and criteria to enable and prioritise CCUS clusters in the first half of 2019.

Government response: In 2019 we will commence detailed engagement with industry on the critical challenges to delivering CCUS in the UK, in particular the cost structures, risk sharing arrangements and the necessary market-based frameworks. We will also examine in detail the scope of the opportunity for maximising economies of scale by developing a shared carbon dioxide infrastructure network in an industrial centre, and will report by the end of 2019.

Recommendation 4: Government to respond to the Taskforce's recommended business models for CCUS through its Review of Delivery and Investment Frameworks for CCUS.

Government response: Our review of CCUS delivery and investment frameworks is underway and we are considering a wide range of business models, including the Taskforce's recommendations for business models in infrastructure, power, and industry, and on the risk allocation between industry and Government. We will consult on our findings in 2019 and publish the outcome of the review by the end of 2019.

Recommendation 5: Industry, Government and local partners to work together to support the development of innovative business plans for the development of CCUS clusters.

Government response: We will undertake and complete a review of infrastructure delivery organisations to understand the skills and capability required for successful delivery of CCUS projects during the 2020s, and will report on this during the first half of 2019. Following the outcome of the review of CCUS delivery and investment frameworks, we will also work with industry to examine the delivery implications of deploying CCUS at scale in the UK during the 2030s.

Recommendation 6: Industry and Government to identify North Sea and East Irish Sea oil and gas infrastructure at risk of being decommissioned in the next 5-10 years which could be maintained as "strategic assets" for CCUS use in the future. A cross Governmental working group, including the OGA and the devolved administrations, to review these assets and include them in the CCUS Deployment Pathway to be published by the end of 2018.

Government response: We recognise the opportunity of re-using existing oil and gas infrastructure for CCUS, which could reduce costs for initial projects. We will complete a process, with the OGA, industry and The Crown Estate and The Crown Estate Scotland, in the first half of 2019, which identifies existing oil and gas infrastructure that has the potential for re-use to support the development of CCUS in the UK.

In addition, we will, in consultation with the relevant regulators, industry, The Crown Estate, and The Crown Estate Scotland, develop a policy on re-use of infrastructure for CCUS in the first half of 2019.

Recommendation 7: Industry, Government and the regulator to develop the mechanisms by which hydrogen projects could be funded through the RIIO-2 mechanisms before gas distribution networks business plans are due for submission (September 2019).

Government response: BEIS and gas distribution network operators will engage with Ofgem through the RIIO2 decarbonisation stakeholder groups and the ongoing RIIO2 development process, to consider whether there is a need for regulatory mechanisms to support network related hydrogen projects.

Recommendation 8: Government to support the timely achievement of an exemption to the Gas Safety (Management) Regulations (GS(M)R) specification to enable a higher blend of hydrogen to be included in the gas distribution and transmission networks, and to consider developing a policy that requires including a steadily rising percentage of hydrogen produced by low carbon methods) in gas supplied to customers.

Government response: We will consider supporting applications for exemption from, and proposals for amendment to, GS(M)R to enable the blending of hydrogen within gas networks. Before an exemption or amendment, it must be demonstrated that any changes to the current safety parameters will not lead to a diminution in safety, with the necessary consultation taking place.

We will consider, in association with the Health and Safety Executive (HSE) and other interested parties, and subject to the satisfactory demonstration of safety, the inclusion of a percentage of low-carbon hydrogen in gas networks, within the context of strategic decisions for the long-term decarbonisation of heat for buildings and industry, and the potential for an emerging hydrogen economy.

Recommendation 9: Working with industry, Government to more fully assess value of CCUS to the wider UK economy (including in terms of utilising existing infrastructure, skills capacity, and supporting opportunities for future clean growth and development).

Government response: We recognise the importance of continuing to build the evidence base around CCUS during the 2020s, to inform any decision taken on whether (and how) to deploy at scale. Through our own work and working with industry and academia, we are continuing to gather evidence on the economic, environmental and social value which CCUS can provide across the economy. We will continue to work with industry and academic institutions to expand our evidence base across all aspects of the CCUS sector, and will, where possible, make this research available in the public domain.

Recommendation 10: Industry and Government to work with the CCUS Council to monitor and recommend ways to maintain UK's leadership in CCUS nationally and internationally.

Government response: We will work closely with the CCUS Council, which will continue to provide ongoing advice to Government on building industry capability during the 2020s, and to monitor and review progress against the priorities set out in this Action Plan. The Council will also advise on ways to maintain UK's leadership in CCUS.

Recommendation 11: Industry and Government to develop and consult with the finance community on an agreed risk allocation for CCUS projects through the Review of CCUS Delivery and Investment Frameworks.

Government response: The review of CCUS delivery and investment frameworks is underway and we are considering a wide range of business models. We will consult on our findings in 2019, and publish the final outcome of the review by the end of 2019. As part of this process, we will work with the finance community, including members of the Green Finance Taskforce, in order to ensure that the outcome of the review takes account of their views. This will include tackling the issue of risk allocation between industry and Government.

Recommendation 12: Industry and Government to engage with the finance community and the Green Finance Taskforce to establish the agreed parameters for debt and equity (and any new green financing mechanisms) for CCUS projects (including accreditation requirements for a green bond, and a tax credit option).

Government response: We will engage with the finance community and members of the Green Finance Taskforce as part of the review of CCUS delivery and investment frameworks, in order to ensure that the outcome of the review takes account of their views. We are also working with Energy UK and CCSA to examine how to design an investable proposition for power CCUS. We will consult on our findings in 2019, and publish the final outcome of the review by the end of 2019

Recommendation 13: Industry to foster sharing of innovation in CCUS technologies and processes in line with the foundations set out in the Industrial Strategy.

Government response: We are supportive of industry and academia sharing innovation and knowledge of CCUS technologies, including through domestic institutions such as the UKCCSRC, and international partnerships like the UK-China (Guangdong) CCS Research Centre. In particular, we would encourage project developers to publish work where possible, as shown with the publication of the Carbon Clean Solutions Ltd pre-FEED work for the Klemetsrudanlegget waste-to-energy carbon capture project in Norway, to increase global knowledge sharing on CCUS, supporting global deployment and cost reductions.

Recommendation 14: Industry and Government to promote international cooperation, including accelerating the option of shipping CO_2 across international borders to enable the development of pan-European CO_2 storage services.

Government response: We will continue to lead collaboration on CCUS, with other Governments and industry, building on the global Accelerating CCUS Summit held in November 2018. We will work with other Governments, particularly Norway, to identify and address barriers to the cross-border transport of carbon dioxide. We will work with our co-leads of the Mission Innovation CCUS Challenge, Mexico and Saudi Arabia, to deliver an action plan which builds on the workshop held in September 2017 in Houston. We will also continue to co-lead the Clean Energy Ministerial CCUS initiative, and other multilateral organisations including the Carbon Sequestration Leadership Forum and the North Sea Basin Task Force. We will continue to support developing countries and emerging economies to develop both the technical and institutional knowledge necessary to enable the deployment of CCUS technologies through our £70 million international CCUS programme, which uses Official Development Assistance (ODA).

Recommendation 15: Working with sector regulators, industry and Government to assess opportunities for regulatory coherence and innovation across the heating, transport, gas and electricity sectors in the development of a decarbonised economy.

Government response: We agree that regulatory coherence will be important, given the potential applications of CCUS across multiple sectors. We will, in developing any CCUS regulations, work where appropriate with sector regulators to ensure regulatory coherence.

Recommendation 16: Industry to lead the creation of the decarbonised product mark, a clean industrial products certification system, to certify the low carbon USP of decarbonised industrial products and Government to encourage their domestic use and global export.

Government response: We will engage with industry if they wish to pursue the development of a decarbonised product mark and will consider ongoing policy in light of this development process.

The St Fergus Gas Terminal, possible site for the Acorn CCS Project.
Image credit North Sea Midstream Partners (NSMP).

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Maintenance support vessel next to the unmanned Tangguh platform in Indonesia, Asia. Image courtesy of BP plc.

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