Delivering Clean Growth:

CCUS Cost Challenge Taskforce Report

July 2018

COVER IMAGE: VIEW OF TEESSIDE INDUSTRIAL LANDSCAPE

Photo courtesy of Teesside Collective UK
Photographer: Dave Charnley

Foreword from the Minister

Climate change is one of the most pressing challenges we face both domestically and internationally and tackling it will require serious ambition and serious action. However, the global response to this challenge is also one of the greatest industrial opportunities of our time.

As the world pivots to a low-carbon economy we want to maximise the advantages for UK industry from this transition and to ensure we benefit from the innovative new technologies that will be at the heart of meeting our climate ambitions. I believe CCUS is one of the most exciting technologies in this space.

There is international recognition that we need CCUS to meet the global climate ambitions agreed through the Paris Agreement in 2015, and while there are now over twenty CCUS projects globally, it remains a pre-commercial technology. This means there is a genuine opportunity for the UK to become a global technology leader for CCUS, working internationally with industry and governments to drive down the cost of deployment.

As I set out through the Government's Clean Growth Strategy, we want to have the option to deploy CCUS at scale during the 2030s, subject to costs coming down sufficiently. I believe the opportunities from CCUS are real and could have a tangible impact for the UK on tackling some of the biggest challenges we face in decarbonising our economy.

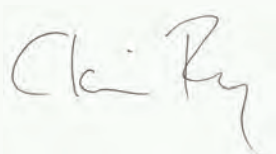
Whilst we have made great strides in decarbonising our power sector, we know that the UK still needs gas. Every scenario proposed by the Committee on Climate Change to meet our legally binding carbon reduction commitments includes the continuing use of natural gas. CCUS may have a role to play in helping to cut the carbon impact of gas, extending the life of our existing plant.

There are also significant opportunities to deploy CCUS in industry, not only to reduce emissions, but to improve productivity and the competitiveness of our industrial centres. I am excited to explore further the deployment of CCUS within industrial clusters to support decarbonisation in industry, and potentially in transport and in heat through hydrogen.

Seizing the opportunities of CCUS will not be easy and will require bright minds from across the country to work together. Low cost, large scale deployment of CCUS will require partnerships between government, businesses, brilliant innovators, the best scientific and engineering minds, communities and centres of industrial excellence.

The CCUS Cost Challenge Taskforce was the first example of what we can achieve when we bring together leading experts to provide advice on how we can achieve these aims. I am grateful to all members of the Taskforce, in particular the Chair Charlotte Morgan, for their work in producing this report.

I look forward to continuing to work in partnership with industry to understand further the challenges and opportunities set out in the report and in doing so, securing the economic and climate benefits that CCUS has the potential to deliver.



The Rt Hon Claire Perry MP

Minister of State for Energy and Clean Growth

Foreword from the Chair

Having worked in the energy sector for the past 24 years, I have witnessed and been part of many of the changes that have affected the sector as it has evolved. Ten years ago, very few would have predicted the make-up of our electricity mix today. The shift to low carbon generation in the electricity market has been phenomenal.

As the Committee on Climate Change ("**CCC**") concluded in their recent progress report to Parliament, UK emissions reductions in the electricity sector have been driven as a result of bold strategic commitments. But as the next decade draws closer there is still much to do, particularly if as a country, we are to reach those parts of the economy which are harder to decarbonise. The time to take the next step in the decarbonisation pathway is now and will require strategic global leadership.

As a Taskforce we endorse the CCC's call for a clear, funded approach to the deployment of CCUS at scale. The role that CCUS can play in reducing emissions cuts across many sectors, not just electricity but also heating, industry and transport. As a technology CCUS has the potential not just to support the UK's carbon reduction commitments, but also to support clean growth, improved productivity and competitiveness in a future low carbon economy.

For this to happen we must recognise the value of CCUS, and the urgency with which we must deploy it in the UK. By acting now and working with industry and governments around the world, the UK can become a global technology leader in this field.

This taskforce has worked tirelessly to show the value of CCUS, and the challenges ahead if CCUS deployment is delayed further. The recommendations contained within this Report are intended to provide government and industry with a series of actions which can support the Government's ambition of having the option to deploy CCUS at scale from the 2030s. As a Taskforce, we look forward to working with the Government as it develops the Deployment Pathway.

Finally, I was honoured to be asked to chair the CCUS Cost Challenge Taskforce by Minister Perry. I have relished the debate and the engagement of the whole industry, which, with the right signals from government, is poised to deliver both growth and decarbonisation. I am hugely grateful for the dedication and commitment of the Taskforce members, and would like to personally thank all of those who have contributed to the report.

Charlotte Morgan

Partner, Linklaters LLP
Chair, CCUS Cost Challenge Taskforce appointed by HM Government

THE CONTEXT:

The Clean Growth Strategy and the CCUS Cost Challenge Taskforce

The Clean Growth Strategy reaffirms the UK Government's commitment to lead the way to a low carbon future and underlines the enormous opportunity for the UK that is emerging from the global transition to a low carbon economy. The Clean Growth Strategy sets out the Government's new approach to carbon capture usage and storage ("**CCUS**"), and recognises the potential importance of CCUS to support the decarbonisation of the UK's economy[1].

The CCUS Cost Challenge Taskforce was established in January 2018 with the remit of informing and proposing a strategic plan to Government for supporting the development of CCUS in the UK, in order to meet Government's stated ambition of "having the option to deploy CCUS at scale during the 2030s, subject to costs coming down sufficiently[2]".

In this report, the Taskforce proposes a range of measures and actions to inform a new approach to CCUS deployment that will enable cost reductions to be secured. By demonstrating that CCUS can deliver decarbonisation across industry, power, and provide solutions for heat and transport, the report focuses on building a long term, commercially sustainable and cost-effective decarbonisation service industry for the UK. This, in turn, can bring new industrial opportunities, secure long term jobs, deliver new economic development across our industrial heartlands and secure international competitiveness through new decarbonised products and services.

We have identified viable business models, funding mechanisms, and an innovation pathway, as well as suggesting options to support the lowest cost delivery of a potentially transformative technology, underpinned by a series of short, medium and longer term recommendations.

Our conclusion: CCUS meets the three tests of the Clean Growth Strategy

Developing and deploying CCUS in the UK is consistent with all three tests set out by the Minister of State for Energy and Clean Growth in launching the Clean Growth Strategy[3]:

- **Delivering maximum carbon emissions reduction:** CCUS can support cost-effective decarbonisation across a wide range of sectors, while simultaneously supporting clean growth across the economy. CCUS is a key technology which can enable decarbonisation in some high value industrial sectors, retaining and creating key jobs as part of a modern industrial strategy.
- **Following a clear cost reduction pathway:** Cost-effective CCUS can be achieved through industry and Government working together to:
    - **Unlock early investment:** Industry and Government working together to create a stable, long term, supportive policy environment to unlock development of at least two CCUS clusters to be operational from the mid-2020s, anchored by "**catalyst**" projects to enable learning by doing, to pull through innovation and reduce the cost of capital, meaning future projects cost less.
    - **A new business model for CO_2 transport and storage infrastructure:** Separating the business model for CO_2 transport and storage ("**T&S**") infrastructure from the business models for CO_2 capture projects can reduce overall commercial risks and costs, by reaching cost-effective public-private risk sharing arrangements. Developing viable business models, as well as sharing of T&S infrastructure, and the strategic re-use of existing oil and gas assets are considered important steps that can enable potential cost reduction in CCUS.
    - **Create CCUS clusters:** The development of clusters (i.e. regional groupings where several CCUS facilities share infrastructure and knowledge) and associated Clean Growth Regeneration ("**CGR**") Zones can help drive lower cost CCUS, unlock value for local economies, and foster continuous technical innovation. Early progress is required to develop these clusters.
- **Making the UK a global technology leader:** By acting now, the UK will be able to make the most of its current engineering, geological, and commercial advantages to build a strategic supply chain, and grasp the opportunity to develop a large export market share of a potential globally significant sector.

1 UK Government, 2017. The Clean Growth Strategy: Leading the way to a low carbon future
2 CCUS Cost Challenge Taskforce, 2018, Terms of Reference: https://www.gov.uk/government/groups/ccus-cost-challenge-taskforce
3 Rt Hon Claire Perry MP, Speech 12 October 2017: https://www.gov.uk/Government/speeches/launch-of-the-clean-growth-strategy

The Taskforce has four key messages for Government

- We need to **recognise the CCUS opportunity and the urgency of acting now** in order to deliver CCUS at scale, at lowest cost. Project lead times are long, and time is limited if we are to deliver CCUS on the scale which may be necessary by 2050, with potentially well over 100 million tonnes of carbon dioxide per year needing to be stored[4]. This can be achieved with joint industry and Government vision, supported by the first projects becoming operational from the mid-2020s and an industry pipeline of financeable projects.
- **CCUS can unlock value across the economy** to enable low carbon industrial products, decarbonised electricity and gas, a hydrogen economy, greenhouse gas removal, and new industries based around utilising CO_2.
- **We need viable business models** to move the technology to a sustainable commercial footing.
- We believe that **CCUS can already be deployed at a competitive cost**. Project concepts being proposed are comparable on cost with other first of a kind low carbon technologies. Our approach is to focus on deploying CCUS in clusters, with the cluster stakeholders identifying how the value of CCUS can best be secured to benefit their local economies and needs.

*To progress action on these key messages we have set out a series of **RECOMMENDATIONS** which show a way in which Government and industry could work in partnership to secure cost-competitive CCUS in the UK.*

4 Committee on Climate Change, 2018, Reducing UK emissions – 2018 Progress Report to Parliament

VIEW OF TEESSIDE INDUSTRIAL LANDSCAPE

Photo courtesy of Teesside Collective UK
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The Taskforce's key messages

1. We need to recognise the CCUS opportunity and the urgency of acting now in order to deliver CCUS at scale, at lowest cost.

The Committee on Climate Change (or "**CCC**") in their 2018 Progress Report to Parliament[5] indicate that the UK will need to store at least 60, and potentially well over 100 $MtCO_2$ each year by 2050 (up to a maximum of 180 $MtCO_2$ per year[6]), if it is to meet the 2050 target under the Climate Change Act. This is why the CCC has recommended that the first CCUS cluster is operational by 2026, with approximately 10 $MtCO_2$ being stored each year by 2030, on the path to at least 20 $MtCO_2$ each year by 2035. This staged build-out is crucial in order first to create a new industry, to de-risk it, and then expand it to the required scale during the 2030s and onwards.

In the Clean Growth Strategy, the Government stated its ambition is to have *"the option to deploy CCUS at scale during the 2030s, subject to costs coming down sufficiently"*. To achieve this ambition, we recommend that, consistent with the CCC's 2018 Progress Report to Parliament, a minimum of two CCUS clusters (incorporating capture plants and CO_2 stores) are operational from the mid-2020s to enable the commercial model to be tested, lessons to be learnt and applied to subsequent projects, and to realise the Government's ambition of having the option to deploy CCUS at scale during the 2030s, should the costs come down sufficiently. Given the typical project development time of between five and eight years, investment decisions need to be taken by the early 2020s at the latest if this is to be achieved.

Government ambition matched with industry commitments: A pipeline of deliverable and financeable projects needs a joint industry and Government vision to unlock the investment required and deliver a strong partnership with the private sector.

With viable business models in place and clear Government and industry commitments to the policy framework, our view is that CCUS projects can be financed through private investment. Developing CCUS projects is capital intensive and the cost of financing will be directly related to risk allocation as well as the maturity of the sector.

Reducing the cost of capital will be a significant component of future cost reduction in CCUS. For example, the UK has become the world's largest offshore wind generator[7] against a backdrop of two decades of clear UK Government commitments (including policy and support systems: FITs, ROCs and CFDs) and industry delivery, with significant cost reductions achieved, partly through reducing the cost of capital.

There needs to be a similar vision and commitment to CCUS, in order to galvanise and focus the CCUS industry and its supply chain to drive down the costs of CCUS deployment, and to deliver the required scale of deployment for CCUS. With this, and the right business models, the private sector will be able to deliver CCUS cost-effectively.

2. CCUS can unlock value across the economy.

The UK's industrial decarbonisation action plans published in October 2017 identify CCUS as "an important technology for industrial decarbonisation, particularly for the cement, chemicals, oil refining and iron & steel sectors"[8]. CCUS is seen as the most effective way to abate CO_2 emissions from some process industries such as steel, lime, cement, and chemicals. For example, in cement production most CO_2 emissions come from calcining calcium carbonate, rather than from energy use.

Consumer-facing companies are already under pressure from their customers to show, and lower, the environmental impact of their products. Deploying CCUS can lower the carbon footprint of industrial products. With the right policy incentives CCUS can help UK heavy industries be competitive in a low carbon world and attract new investors looking for ways to produce low carbon, cost competitive industrial products. For the longer term, we have set out proposals for a 'decarbonised product mark', a certification system for low carbon industrial products which can be an independent revenue stream for such industries.

CCUS can help balance the power system.

Gas or biomass electricity generation with CCUS can, in addition to being low carbon baseload, also be "flexible" or "dispatchable" so electricity output can be adjusted to meet

5 Committee on Climate Change, 2018, Reducing UK emissions – 2018 Progress Report to Parliament
6 Upper limit of 180 $MtCO_2$ per year by 2050 from: Committee on Climate Change, 2018, pers.comm. 29 June
7 Global Wind Energy Council, 2017, GWEC Global Wind 2017 Report
8 Department for Business, Energy and Industrial Strategy, 2017. Industrial decarbonisation and energy efficiency action plans

changes in electricity demand while still capturing the emissions from generation[9]. This characteristic complements the intermittency of renewables.

The UK Energy Research Centre estimates the cost of renewables intermittency as £10/MWh in 2030[10], rising substantially thereafter. If the electricity system is not sufficiently flexible to accommodate high renewable capacity, low carbon flexible generation with CCUS is one option which can reduce system costs of £4-8 billion per year[11].

CCUS unlocks a hydrogen economy to decarbonise the heating and transport sector.

Though we recognise that there is currently no broad consensus on the best approach to long term heat decarbonisation, hydrogen has the potential to play a significant role in the future in decarbonising industry, transport and heating, and opportunities exist for the UK to lead the creation of a hydrogen economy.

Hydrogen can be used by industry and other large gas consumers for both power and heat to reduce their on-site emissions, either by blending hydrogen into the existing natural gas networks or by replacing the natural gas with hydrogen. In transport, hydrogen with CCUS could be an enabler for decarbonising the transport fleet, including trucks, trains and shipping. Longer term, it may also offer the potential for the UK to lead the "green" transformation of the shipping industry.

Developing Greenhouse Gas Removal (GGR) technologies.

CCUS infrastructure is a prerequisite for many of the most advanced GGR technologies, including BECCS and direct air capture, which can deliver negative emissions. Functioning CCUS infrastructure will therefore be critical to enable these GGR technologies to be deployed to support a move to a net zero carbon economy, compensating for the residual 'hard to decarbonise' sectors such as marine transport, aviation and agriculture.

Retaining skills, creating new jobs, and becoming a global leader.

The UK is a world leader in addressing climate change and has considerable expertise in the low carbon sector, which has created thousands of domestic jobs as well as export opportunities for low carbon services[12].

CCUS can enable the UK to both retain and generate new high value jobs, pioneer new low carbon manufacturing industries and companies and export these goods and services around the world. Developing CCUS would enable the UK to realise the value of its considerable natural geological resources for offshore CO_2 storage and, in some cases, take advantage of significant cost reductions from re-using existing pipeline infrastructure. This opportunity can be taken up now.

3. **We need viable business models.**

   To meet the timescales of CCUS clusters being operational from the mid-2020s, projects may have to be initiated using funding mechanisms that largely already exist or could be implemented quickly, while minimising the impact on consumers and taxpayers.

   We recognise that different business models will be needed for CO_2 capture plants in each sector, for example, to develop hydrogen, industrial capture and possible power projects.

   In parallel, we recommend a new business model for CO_2 T&S, in which the revenues of the CO_2 capture plant are independent from those associated with T&S. The preferred model for the T&S would follow the regulated asset base ("**RAB**") structure used in other regulated industries and the T&S fee would be shared between the projects that use the T&S infrastructure.

   It is also important to explore how GGR technologies which rely on CCUS and provide negative emissions could be incentivised. More focus is needed on this topic.

   The Taskforce's view is that the Government's Review of CCUS Delivery and Investment Frameworks, announced in the Clean Growth Strategy, is a priority and we recommend that Government collaborates and consults with industry on the Review to develop viable business models and an agreed risk allocation for CCUS.

9 Mac Dowell et. al., 2017. IEAGHG Report 2017/09 – The FlexEVAL project. "Valuing flexibility in CCS power plants"

10 Heptonstall et. al., 2017. A systematic review of the evidence on the costs and impacts of intermittent electricity generation technologies – 2016 update

11 Imperial College London and NERA Economic Consulting, 2015. Value of Flexibility in a Decarbonised Grid and System Externalities of Low carbon Generation Technologies

12 Office for National Statistics, 2018, UK Environmental Accounts: Low Carbon and Renewable Energy Economy Survey: 2016 final estimates

4. **We believe that CCUS can already be deployed in clusters at a competitive cost.**

   We recommend that CCUS is established in clusters to maximise potential cost reductions from economies of scale, and to realise the cross-sectoral value of CCUS. We propose that industry and Government develop a policy framework to enable this and, in turn, the CCUS industry will work in partnership with national, devolved, regional and local Government to bring forward innovative business plans for the development of CCUS clusters.

   The Taskforce's view is that the deployment of CCUS at scale is key for driving cost reductions, such as has been the case for offshore wind. Shell, the developers of the Quest CCUS Project in Canada, believe that the cost of their next project could be up to 30% lower[13].

   The Taskforce recommends that carefully targeted development funding is made available to support this. With a policy framework and funding commitment from central Government, industry, working with the devolved administrations and regional and local Government (including local authorities, Local Enterprise Partnerships, and City Mayors, where appropriate), can develop innovative, detailed, and costed CCUS cluster proposals.

   The UK already has potential cluster locations, each of which presents different opportunities for development. We do not recommend what should be a catalyst project in any cluster – that will depend on the opportunities at that cluster and the business plans that each cluster puts forward.

Clusters at the heart of Clean Growth Regeneration Zones for jobs and innovation.

Each CCUS cluster could be the foundation for a Clean Growth Regeneration ("**CGR**") Zone, to drive new thinking around CCUS innovation, deployment, investment and how CCUS can integrate with other decarbonisation options to support wider industrial decarbonisation. The CGR Zones can support the Government's decarbonisation and innovation vision, with CCUS clusters anchoring investment in regions, thereby boosting local jobs and skills. These Zones should form a key part of the Local Industrial Strategies.

Putting policy in place.

We have suggested criteria for cluster selection and recommend that Government progresses this urgently and publishes its policy framework and criteria in early 2019. This will enable rapid progress to be made in selecting regions that would become the focus for early CCUS investment and keep development of the first CCUS projects on track to be commissioned from the mid-2020s. Each cluster plan would be considered against the investment required and their ability to support the Government's ambition to deploy CCUS at scale during the 2030s, subject to the costs coming down sufficiently.

A "CCUS roadmap" of enabling actions is needed to deliver these key messages.

The Taskforce's view is that Government needs to work with industry to set out a CCUS roadmap to support its commitment to deploying CCUS in the UK. Our view is that innovation, cost reduction and learning will come from an industry and Government galvanised around a clear goal to be achieved by a specified time.

The Deployment Pathway publication, to be published by the end of 2018, should include a roadmap developed jointly by industry and Government to show how CCUS can be developed and deployed across the different sectors, by providing clear pathways and enabling mechanisms to be put in place up to 2030.

13 Global CCS Institute, 2016 (online), Shell's Quest Carbon Capture and Storage Project reaches significant milestone. Available at https://www.globalccsinstitute.com/news/institute-updates/shell%E2%80%99s-quest-carbon-capture-and-storage-project-reaches-significant-milestone, Accessed 27/06/2018

Table of Recommendations

Recommended actions to take now to unlock industry action

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.
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.
3. Government to publish a policy framework and criteria to enable and prioritise CCUS clusters in the first half of 2019.
4. Government to respond to the Taskforce s recommended business models for CCUS through its Review of Delivery and Investment Frameworks for CCUS.
5. Industry, Government, and local partners to work together to support the development of innovative business plans for the development of CCUS clusters.
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.
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).
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.
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).
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.

Recommended actions to take next to unlock investment

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

Recommended actions for longer term to unlock ambition

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.
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.
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.

Introduction

The UK is a world leader in acting against climate change

The UK was one of the first countries in the world to set legally binding climate change targets through the 2008 Climate Change Act[14] which committed the UK to reducing greenhouse gas emissions by at least 80% by 2050 compared to 1990 levels. It is also among the hundred and seventy-six countries that have so far ratified the 2015 Paris Agreement.

As part of the UK's commitments to its carbon budgets it established the Committee on Climate Change ("**CCC**"), an independent body which advises and holds Government to account on its plans to meet each five year carbon budget.

CCUS is a vital method of achieving the UK's Paris Agreement goals. Without it achieving the 'well below 2 degrees' objective would be, on average, some 138% more expensive (and, indeed, in most models, the target could not be achieved without CCUS[15]). In 2016 the CCC wrote specifically to Government advising of the "*...critical importance (of CCUS) to meet the UK's carbon targets at least cost and to fulfil the ambition of the Paris Agreement*[16]". The CCC highlighted that because of the limited low carbon alternatives to CCUS across a number of sectors and applications, there was an "estimated doubling of the cost of meeting the UK's 2050 target if CCS is not available".

In launching the Clean Growth Strategy, the Minister for Energy and Clean Growth set out a vision to transform the UK economy through innovation, vital infrastructure investment and a clear commitment to emission reductions and clean growth for all sectors of the UK economy.

As part of the Clean Growth Strategy, the Government set out its commitment to CCUS. One of the commitments made as part of the Government's new approach to CCUS was to establish a CCUS Cost Challenge Taskforce (the "**Taskforce**") to inform and propose a strategic plan to Government for supporting the development of CCUS in the UK, in order to meet Government's stated ambition of "having the option to deploy CCUS at scale during the 2030s, subject to costs coming down sufficiently". The Taskforce was convened in January 2018 with over 40 leading experts from across industry and academia.

CCUS infrastructure is key to unlocking huge clean growth potential in the UK and can contribute to a cost-effective pathway for reducing UK CO_2 emissions.

14 UK Climate Change Act, 2008. https://www.legislation.gov.uk/ukpga/2008/27

15 Intergovernmental Panel on Climate Change, 2014. Climate Change 2014 Synthesis Report

16 Committee on Climate Change, 2016. A strategic approach to Carbon Capture and Storage

What is Carbon Capture Usage and Storage?

CCUS is a method of mitigating the contribution of fossil fuel, industrial processes and other emissions to global warming by capturing and using or storing the carbon dioxide (CO_2) before it is released into our atmosphere.

The first stage of CCUS is the separation and capture of CO_2 from emitters before it is released into the atmosphere. The CO_2 can then be transported to be stored safely in offshore rock formations that are located deep underground. This is essentially the same process that has trapped naturally accumulated stores of gas and oil underground for millions of years. For smaller volumes of captured CO_2, there are also opportunities for the captured CO_2 to be utilised in a variety of industrial processes and transformed into new products.

The UK's North Sea gives us a unique potential to store large volumes of CO_2. Analysis by the CCC states that the UK will need to store at least 60 and potentially up to 180 $MtCO_2$ per year by 2050. We are also developing ways to use the captured CO_2 in a variety of industrial processes and to make new products which can drive the UK's clean growth economy.

As the world's major institutions working on energy and climate change issues all agree, CCUS is critical for achieving the global emissions reduction targets. CCUS gives industry an opportunity to thrive in a future low carbon world, it can play a key role in decarbonising 'difficult' sectors, and with bioenergy, CCUS can achieve 'negative emissions' to remove CO_2 from the atmosphere.

Our Vision

We, the members of the Taskforce, wholly support the Government's ambition for CCUS. We want to find new ways to enable the UK to meet its domestic decarbonisation commitments at the lowest net cost while maximising the social and economic benefits for the UK from this transition. Strategic investment in CCUS infrastructure now can deliver a low cost, low risk, multi-functional route for decarbonisation of the UK's industrial, transport and heat sectors in addition to valuable services to the UK energy sector, including support for the growth of greenhouse gas removal ("**GGR**") technologies.

In our report, we have focused on areas where the public and private sectors can work in partnership. We have suggested a credible pathway to implement CCUS now and enable cost-effective deployment in the UK during the 2030s. We believe this can be achieved by developing the cost structures and risk sharing proposed in this report. Moreover, as this industry advances, we expect to realise the potential significant reduction in the costs of CCUS projects through developing technology, viable business models, and from learning by doing. Our emphasis on shared infrastructure, economies of scale, and reducing the commercial risks, as well as continued investment in innovation, takes its inspiration from what has happened with offshore wind in the UK, where we have seen dramatic reductions in subsidies over the last five years.

We see CCUS as giving the UK the opportunity to further develop clean growth industries, to improve productivity across the UK and to ensure that the UK is the best place to grow those industries which rely on CCUS to decarbonise. In short, CCUS can be a critical part of the infrastructure required to deliver clean growth in the UK.

AEROVIEW OF THE GRA
PORT FACILITY

Photograph reproduced witl
**from INEOS.

CCUS can be a critical part of the infrastructure that delivers multi-service, multi-functional routes to cost-effectively decarbonise large sections of the UK economy and support the growth of greenhouse gas removal technologies.

HISARNA CAST HOUSE. PRODUCTION RUNNER. HOT METAL FLOWS FROM THE FOREHEARTH INTO A TORPEDO LADLE

Photo courtesy of Tata Steel. © Studio John de Konin

PART A:

The CCUS Opportunity

Why we need to act now

Seizing the UK's CCUS opportunity

Several promising projects located within strategic clusters could be operational from the mid-2020s if supported by the actions that we recommend in this report[17]. These and the potential storage sites that the UK can develop are shown in Figure 1 to the right.

Location of potential first CCUS clusters and CO_2 storage sites

"We will work with the ongoing initiatives in Teesside, Merseyside, South Wales and Grangemouth to test the potential for development of CCUS industrial decarbonisation clusters". – UK Government, Clean Growth Strategy 2017[18]

Teesside

Teesside has a highly developed process industry and heavy manufacturing which is seeking to decarbonise. Recognised as a European Project of Common Interest (PCI) for its strategic importance to the UK and Europe, this is an area that could invest efficiently in CCUS and generate significant benefits for the region[19]. Teesside can access suitable CO_2 storage sites in the Southern North Sea.

The development of a CCUS cluster is being actively promoted by the Tees Valley Combined Authority which established the Teesside Collective and which, with UK Government funding, has set out how a CCUS cluster could be developed in the area.

Humberside

Humberside is the location of a wide range of heavy industrial plant, including oil refining, steel manufacture, cement, chemicals and others, making it a potential location for a CCUS cluster.

Humberside can access suitable CO_2 storage sites in the Southern North Sea and the area is linked to the industrial CCUS cluster at the Port of Rotterdam by a shortlisted PCI project.

Merseyside

The Merseyside area is the location of significant heavy industrial activity and power generation, including one of the UK's large oil refineries and several CCGT stations. Further large manufacturing, including glass, chemicals, and paper industries, make this cluster a candidate for a CCUS cluster. Proximity to the Cheshire salt basin means that the area is also suited for the development of a hydrogen network with salt cavern storage.

Merseyside can access suitable CO_2 storage sites in the East Irish Sea.

Scotland

The Scottish cluster is made up of St Fergus and Grangemouth areas. Grangemouth is the centre of the chemicals manufacturing and refinery industry and the largest concentration of CO_2 emissions in Scotland. Grangemouth would be a candidate for a CCUS cluster in Scotland.

St Fergus is a natural hub for CO_2 transport to offshore storage, given the potential for re-use of existing offshore pipelines and suitable CO_2 storage sites in the Central North Sea.

St Fergus is the landing point for around 35% of all the natural gas used in the UK making it a potential location for future hydrogen production with CCUS. St Fergus also provides the potential for ship import or export of CO_2 from the UK or Europe, via Peterhead Port, and the re-use of the Feeder 10 natural gas pipeline to bring CO_2 up from Central Scotland.

South Wales

There is a large manufacturing base in South Wales (specifically around Port Talbot and Swansea) which includes oil, steel, cement, hydrogen and chemicals industries, that are critical to the economy of Wales. This mix of industries and the presence of electricity generating power plants, using both gas and biomass, is ideal for the development of a CCUS and hydrogen cluster. Decarbonising the steel works will be important in preserving this industrial activity, and the UK manufacturing base that this supports.

As there are no offshore CO_2 storage sites in the immediate area, CO_2 from the South Wales region would need to be sequestered through use as a feedstock or transported by ship for storage.

17 Committee on Climate Change, 2018. An independent assessment of the UK's Clean Growth Strategy: From ambition to action

18 UK Government, 2017. The Clean Growth Strategy: Leading the way to a low carbon future

19 Teesside Collective, 2017 (online) Teesside Carbon Capture and Storage (CCS) Transport Infrastructure Backed By European Commission. Available at http://www.teessidecollective.co.uk/teesside-carbon-capture-and-storage-ccs-transport-infrastructure-backed-by-european-commission/ Accessed 29/06/18

Figure 1: UK's potential CCUS clusters and CO_2 storage sites

Urgency – we need to start now

To meet the Government's aim of "*having the option to deploy CCUS at scale during the 2030s, subject to costs coming down sufficiently*" we need to start implementation as soon as possible, given the time needed by industry to develop potential projects for deployment. The CCC, in their 2018 Progress Report to Parliament[20], indicate that the UK will need to store at least 60, and potentially well over 100 $MtCO_2$, up to a maximum of 180 $MtCO_2$[21] each year by 2050, if it is to meet the 2050 target under the Climate Change Act. We also recognise that to make this a success industry and Government need to work in partnership if the first CCUS cluster is to be operational by the mid-2020s.

CCUS deployment growth and timescales

Delivering an industry capable of storing at least 60, and potentially up to 180MTPA, will take considerable time and ambition. It needs to be supported by a consistent policy framework and investment. The chart to the right (Figure 3) shows actual and projected experience curves of build rates of nuclear, offshore wind and CCUS in the UK. These are expressed in terms of the CO_2 abated by each technology, and do not show subsequent plant closures. This illustrates the challenge that will be faced by the UK if it chooses to develop a large scale CCUS industry by the 2050s. This is why the CCC has recommended that the first CCUS cluster is operational by 2026, with approximately 10 $MtCO_2$ being stored each year by 2030, on the path to at least 20 $MtCO_2$ each year by 2035. This staged build-out is crucial in order first to create an industry, to de-risk it, and then expand it to the required scale during the 2030s and onwards.

Figure 2: Chart to show required build rates of CCUS capacity, in three phases to 2050

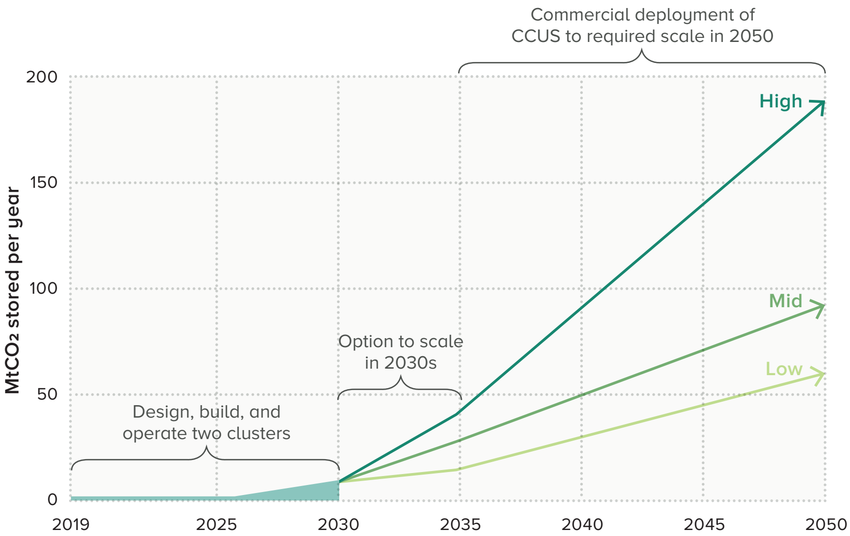
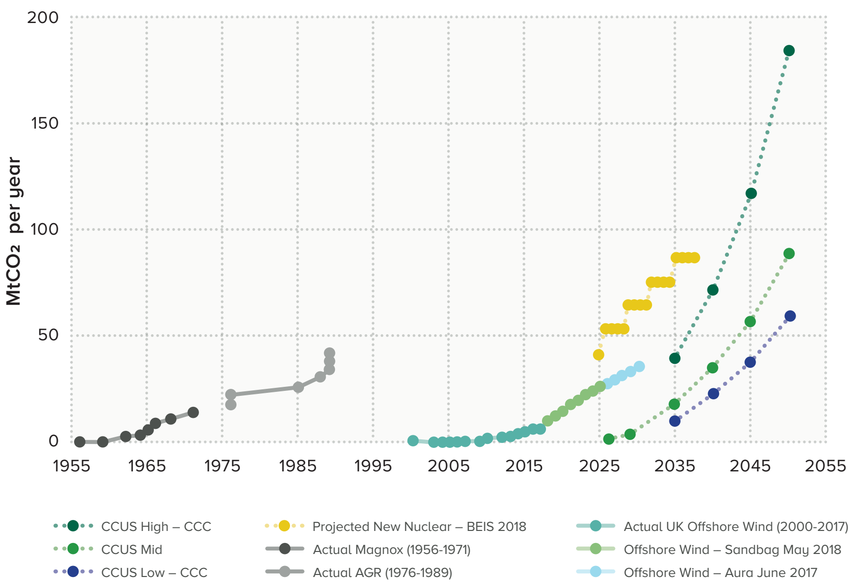


Figure 3: Chart to show actual and projected experience curves of build rates of nuclear, offshore wind and CCUS in the UK. Analysis by CCUS Cost Challenge Taskforce



20 Committee on Climate Change, 2018, Reducing UK emissions – 2018 Progress Report to Parliament

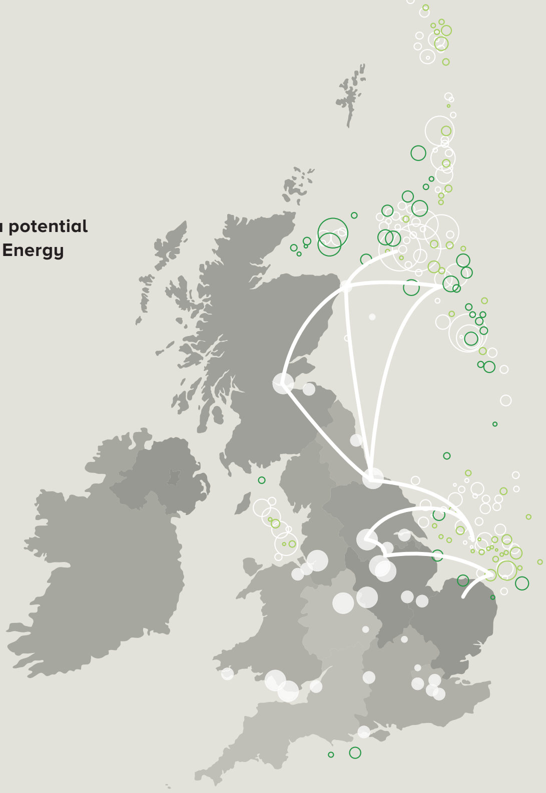
21 Upper limit of 180 $MtCO_2$ per year by 2050: Committee on Climate Change, 2018, pers.comm. 29 June

CASE STUDY

> “Our assessment is that deploying CCS at scale in the 2030s will require deployment of CO_2 infrastructure and initial capture projects at a level of around 10 $MtCO_2$ per annum being captured and stored by 2030, on the path to at least 20 $MtCO_2$ per annum in 2035”.

COMMITTEE ON CLIMATE CHANGE, 2018 PROGRESS REPORT TO PARLIAMENT

Figure 4: Representation of a potential east coast CCUS network. © Energy Technologies Institute LLP



The East Coast Study[22]

This extensive study modelled the benefits and costs of investing in a CCUS industry in respect of plant and infrastructure down the whole of the east coast of the UK over the next 40 years. The gross societal and economic benefits across this period were estimated at £160 billion, outweighing the investment costs of £34 billion by a factor of five times.

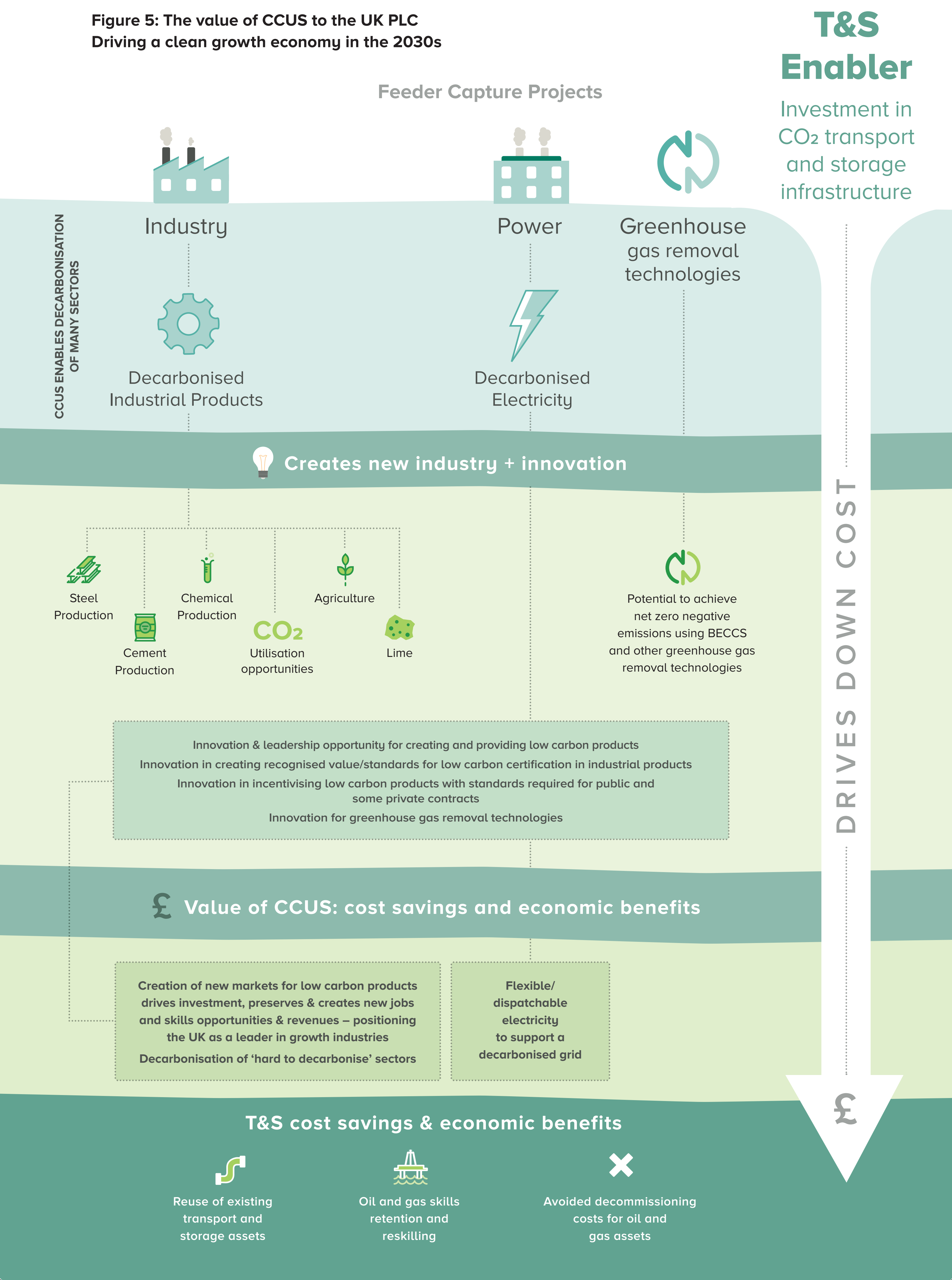
This comprises:

- *£94 billion avoided costs of emissions – translating into more competitive product pricing and cash flow for reinvestment.*
- *£54 billion of increased domestic economic activity including investment in CCUS and the linked host plants as well as the impact of CCUS on the creation and retention of economic activity (and jobs) in the identified linked economies that might otherwise be lost without a decarbonisation solution. For some of the industries concerned (iron & steel, cement, fertilisers, chemicals and pharmaceuticals, refining, natural gas processing, etc.) there is no alternative decarbonisation technology currently available.*
- *£9 billion positive balance of trade impact through the export of goods and services and provision of CO_2 storage services for imported third country CO_2 (assumed up to 5 $MtCO_2$ per year).*
- *£5 billion in health and wellbeing benefits based on data published or the economic value of the co-benefits linked to avoided CO_2 emissions.*

The analysis made so far is not exhaustive and indeed could have significant upside potential. Not all linked economies have been evaluated – for example, enhanced oil recovery in the UKCS, which would add significantly to the gross value added in the wider economy, along with wider employment potential for CCUS projects. The study also champions the linking of EU countries into the East Coast CCUS infrastructure (importing CO_2) which could generate far more potential than the storage capacity of 5MTPA by 2060 assumed in relation to the UK.

22 Summit Power, 2017. Clean Air, Clean Industry, Clean Growth: How Carbon Capture will Boost the UK Economy.

Figure 5: The value of CCUS to the UK PLC
Driving a clean growth economy in the 2030s



Feeder Capture Projects

H_2

Hydrogen

Decarbonised Gas

Industry

Heat

Hydrogen fuelled power and balancing services for system management

Transport

Creates new industry + innovation

H_2 Providing hydrogen as a fuel for industry to replace fossil fuels and for industrial heat

Replacing heating systems with 100% hydrogen heating – domestic decarbonisation

Transforming natural gas networks to be hydrogen networks

Hydrogen fuelled trains

Hydrogen fuelled ships & ferries

Hydrogen fuelled cars

H_2 O_2 New hydrogen fuel cells production and energy storage

Hydrogen fuelled HGVs / large vehicles (buses / bin lorries)

Innovation in decarbonising gas

Innovation in regulation of clean transport

Innovation in hydrogen production processes

Innovation in hydrogen in transport services

Innovation hubs for hydrogen fuel cells and for skills and knowledge

£ Value of CCUS: cost savings and economic benefits

Decarbonised gas supplies to create a secure, flexible, low carbon energy mix

Avoided cost and social challenges of fully electrifying homes or installing heat pumps

Avoided cost of rail electrification

Avoided full cost of electrifying larger vechicles

T&S new industry & innovation

Innovation in transport and storage processes and technology

EOR Potential for enhanced oil recovery

Global R&D leadership in new industries

Creation of new transportation and storage assets

Potential pan-European CO_2 storage services

Build up offshore storage services sector

Value and benefits of CCUS

CCUS can play a critical role in reducing CO_2 emissions in the most cost-effective way, at the pace and scale required to meet our commitments

The CCC's assessment of the Clean Growth Strategy, published in January 2018, stated that Government should not plan to meet the UK 2050 climate targets without CCUS[23]. This echoed analysis by the Intergovernmental Panel on Climate Change ("**IPCC**") which showed that limiting global temperature increase to two degrees (the current international agreement is to achieve 'well below two degrees') would be, on average, some 138% more expensive without CCUS and, indeed, in the majority of models, the target could not be achieved without CCUS[24]. Further reports from National Grid and the Energy Technologies Institute (ETI) analysing UK decarbonisation scenarios demonstrate that the least cost pathways to deliver the UK's 2050 target require substantial deployment of CCUS[25,26].

Given the typical project development time of between five and eight years, decisions need to be taken by the early 2020s at the latest if this is to be achieved. If the UK is to commission the first CCUS clusters from the mid-2020s, the steps to unlock the value of CCUS need to be taken now. We recommend that this is achieved through a CCUS cluster-led deployment approach.

RECOMMENDATION: 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.

23 Committee on Climate Change, 2018. An independent assessment of the UK's Clean Growth Strategy: From ambition to action
24 Intergovernmental Panel on Climate Change, 2014. Climate Change 2014 Synthesis Report
25 National Grid, 2018. The Future of Gas: How gas can support a low carbon future
26 Energy Technologies Institute (ETI), 2015. Building the UK Carbon Capture and Storage Sector by 2030

Global CCUS developments and UK's opportunity in a multi-billion pound CCUS market

The last two decades have witnessed significant growth in the number of large scale CCUS projects that are operating or under construction around the world. Since 2000, this number has risen from four to over 20[27]. Often these developments have been stimulated through tax, planning conditions and availability of public funding.

Yet, to deliver the Paris Agreement the deployment of CCUS must be scaled up dramatically and must be commercialised at an accelerated pace[28].

There are encouraging signs that international momentum on CCUS is increasing. The recent adaptations to the 45Q tax credit have already started to drive new interest in CCUS developments in the US[29]. In addition to the UK, European CCUS ambition is growing, driven by activity in Norway and the Netherlands. China also is developing several CCUS projects.

The future CCUS market is estimated to be worth around £100 billion per year[30]. A market of this size will create huge opportunities in the supply of infrastructure and technology, provision of financial and professional services and the manufacturing of low carbon products. As a global leader in this market, the UK has the potential to be right at the heart of a growing and strengthening global industry that realises the benefits and values of any investment for our economy, but we must act now, or risk being left behind.

As the number of CCUS projects around the world continues to increase there will be opportunities for us to learn from other projects, thereby driving cost reduction. Developers of the Boundary Dam and Petra Nova CCS power plants in North America envision similar cost reductions of 20-30% for a second plant[31]. Those lessons are now available to us in the UK. The time to become a global CCUS leader is now.

27 Global Carbon Capture and Storage Institute (GCCSI), 2018. (online) Large-scale CCS facilities Available at https://www.globalccsinstitute.com/projects/large-scale-ccs-projects. Accessed 29/06/18
28 International Energy Agency (IEA), 2017. Five Keys to Unlock CCS Investment
29 IEA, 2018 (online) US budget bill may help carbon capture get back on track. Available at https://www.iea.org/newsroom/news/2018/march/commentary-us-budget-bill-may-help-carbon-capture-get-back-on-track.html. Accessed 29/06/18
30 CCSA & TUC, 2014. The economic benefits of carbon capture and storage in the UK
31 Global CCS Institute, 2014 (online), The future of carbon capture will focus on cost reduction. Available at https://www.globalccsinstitute.com/insights/authors/RonMunson/2014/11/05/future-carbon-capture-will-focus-cost-reduction Accessed 27/06/18

CASE STUDY

Carbon8 Systems Ltd Accelerated Carbonation: Carbon capture and use in action

Carbon8 Systems Ltd can accelerate the UK's options for using CO_2 in construction products by capturing CO_2 from industrial processes[32]. As acknowledged through peer review, Carbon8 is a world leader through its unique process and has received a number of awards including the Queen's Award for Enterprise in 2017. The process is commercialised within the UK, with interest from North America, India and Northern Europe. If begun now, plants could be built by the end of 2019, at sources of CO_2 isolated from permanent CO_2 storage capabilities.

How does it work?

CO_2 is captured directly from flue gas from industrial sources, such as steel works, cement, or biomass plants. The CO_2 is permanently sequestered through the carbonation of industrial residues, also produced onsite, and the manufacture of construction products.

How does this project meet the CCTF aims on value of CCUS and the cost challenge?

The process is scalable depending on the source of CO_2 and the residue. For a full-scale plant treating 40,000 tonnes of industrial residue per year, the capex is approximately £5m with a 3-5-year payback depending on the residue treated. Revenue for the process is generated from a gate fee for treating the residues and from sale of the product.

We have recommended that the fastest way for the UK to drive down costs and take advantage of the value that CCUS offers would be to deploy CCUS projects in clusters.

CARBON8 AGGREGATES' AVONMOUTH PLANT

Photo courtesy of Carbon8 Aggregates Ltd

32 Find out more about this case study at: www.c8s.co.uk

CCUS is required to support UK low carbon industrial competitiveness and attract new clean growth sectors to the UK

The UK has a well-established North Sea oil and gas industry and networks. This expertise can be used to support the growth and development of CCUS opportunities and the creation of new clean growth jobs in the UK.

According to recent research, every direct job in established high value industries supports up to four jobs in indirect employment[33]. Failure to deploy CCUS early increases the risk that these jobs and industries disappear from the economy and will affect places where these jobs are more concentrated (north of England, Wales and Scotland), causing further economic imbalance in the UK. With the right policy signals from Government, CCUS can help to ensure that the jobs of the skilled workforce are retained for the development of a new world leading industry.

This helps to make CCUS attractive to existing industrial locations by helping to protect existing jobs and create new ones in new CCUS clusters. For example, analysis shows that developing a CCUS network in the Tees Valley could support over 1,000 direct and indirect jobs in the UK during the construction period, and a further 350 jobs, directly and indirectly associated with the operation and maintenance of the network[34]. With the right local incentives, industry can work with national, devolved, regional, and local Governments to drive the creation of new jobs and prosperity in communities near CCUS projects.

The CCUS industry can also generate value through creating new industries, including in using CO_2. Many of these uses also support decarbonisation through sequestering the CO_2 in carbonised products such as cement and building aggregate[35]. The value of such products has significant potential as a route to cutting UK emissions, as well as supporting the commercialisation of carbon capture technologies and replacing carbon-intensive products, bringing with it new jobs and skills for the UK.

R ***RECOMMENDATION:*** *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 in supporting opportunities for future clean growth and development).*

Strategic use of natural and legacy assets – reducing CCUS costs and potentially reducing decommissioning costs

The UK benefits from vast areas of safe and secure offshore CO_2 storage[36]. This natural geological advantage is further bolstered by the depth of knowledge of this offshore area following many years of oil and gas activity, and recent efforts to appraise and publish UK CO_2 storage data through the CO_2 stored database and the supporting ETI report[37]. Projects should ensure that they make use of this significant data, which can reduce storage appraisal costs.

The legacy of the UK oil and gas industry offers further potential cost advantages through the reuse of existing onshore and offshore infrastructure. In some cases, the repurposing of suitable gas pipelines (both on and offshore) can bring very substantial cost savings[38]. The Acorn CCS project in north east Scotland estimates a £750 million cost saving from the reuse of three offshore and one onshore gas pipelines (see case study) and the CCEP project (see case study) estimated that the reuse of Feeder 10 pipeline would save up to £440m of costs. Overall, the cumulative benefits of reusing assets may exceed £500m of entry costs into CCUS regional clusters. The opportunity to reuse existing assets also applies to pipelines in the East Irish Sea.

33 Turner et. al., 2018. Making the macroeconomic case for near term action on CCS in the UK? The current state of economy-wide modelling evidence
34 Cambridge Econometrics, 2015. The Economic Impact of Developing a CCS Network in the Tees Valley
35 Zero Emissions Platform, 2017. CCS and Europe's Contribution to the Paris Agreement – Modelling least-cost CO_2 reduction pathways
36 Energy Technologies Institute, 2017. Taking stock of UK CO_2 storage
37 CO_2 stored database (online) http://www.co₂stored.co.uk/home/index
38 ACT Acorn project (online) http://www.actacorn.eu

3

CASE STUDY

Avoiding decommissioning of offshore assets by repurposing them for CCUS may also provide a benefit to the Exchequer, which shares up to 50% of the decommissioning liabilities. However, action is required to ensure that assets of strategic interest for CCUS deployment are preserved for CCUS, and industry and Government should work with the Oil and Gas Authority ("**OGA**") to provide clarity on maintaining such assets.

R ***RECOMMENDATION:*** ***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.***

Acorn: a clean growth CCUS catalyst

Acorn is a low cost, low risk CCUS project, designed to be built quickly, taking advantage of existing oil and gas infrastructure and a well understood offshore CO_2 storage site[39]. The project is located at the St Fergus Gas Terminal – an active industrial site where around 35% of all the natural gas used in the UK comes onshore.

Acorn can act as a catalyst for supporting growth and creation of new industrial opportunities in the north east of the UK and beyond through creation of a major hydrogen and CCUS hub at St Fergus; developing the port of Peterhead to be an international CO_2 storage hub in the Central North Sea. With the right support, Acorn could be operating in the early 2020s.

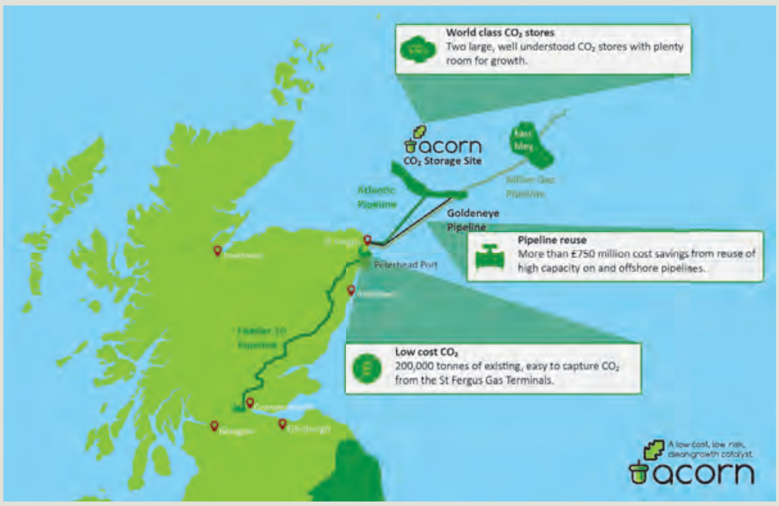
How does it work, and does it help to reduce the costs of CCUS?

Initially, Acorn will use the easy to capture CO_2 from within the St Fergus Gas Terminal, but the project is designed to support rapid growth for other large scale emission sources in the region. Acorn has been awarded European Project of Common Interest (PCI) status, making its infrastructure elements eligible for funding under the Connecting Europe Fund (CEF).

Acorn is currently assessing three large gas pipelines which can be repurposed to take CO_2 offshore, and an onshore gas pipeline that connects St Fergus to Central Scotland. These pipes alone offer the UK CCUS industry savings in the region of £750 million in capital costs when compared to commissioning new pipes. Upgrades to Peterhead Port would allow national and international shipping of CO_2. The Acorn CO_2 storage site is part of a huge sandstone formation (the Captain Sandstone), located 2km below the North Sea seabed. It is a well known site that benefits from extensive performance data from recent oil and gas activity and has been thoroughly examined to ensure safe and permanent storage of CO_2.

The Acorn feasibility work has been funded by the EU, UK and Scottish governments. Industrial partners have also expressed interest in funding and progressing the project, linking it to hydrogen generation, subject to clear government policy or specific project support.

Figure 6: The Acorn project will make use of the UK's built and natural assets



39 Find out more about this case study at: www.actacorn.eu

CCUS deployment also offers the UK the opportunity to develop its own market leading CO_2 storage services industry. Given the UK's potential for CO_2 storage in the North Sea, this gives the UK an opportunity to build up services for European emitters. In doing so, the UK can also lead multilateral efforts to create a flexible CO_2 storage market, providing multiple storage options and greater system resilience. To enable this development, the industry and Government should work together to ensure that the London Protocol amendment is ratified.

R ***RECOMMENDATION:*** *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.*

"CCUS is an important technology for industrial decarbonisation, particularly for the cement, chemicals, oil refining and iron & steel sectors".

THE UK'S INDUSTRIAL DECARBONISATION AND ENERGY EFFICIENCY ACTION PLANS, OCTOBER 2017

With the use of existing infrastructure, there may also be scope to use steady streams of CO_2 for enhanced oil recovery ("**EOR**") from mature assets, allowing for an extension in their productive life[40].

This would have benefits to the UK economy in terms of taxable revenues as well as the benefits derived from retention of skills and decommissioning benefits (see above). However, we recognise that there may be policy and economic reasons that limit the EOR opportunity.

CCUS offers a growth opportunity for a pan-European CO_2 storage services sector

The Zero Emissions Platform recommends developing CCUS on a European scale in clusters and estimates that the value of CCUS to the EU could exceed €1 trillion between 2017 and 2050 (where CCUS could be worth more than €50 billion each year thereafter)[41].

Given the UK's extensive potential CO_2 offshore storage[42], we stand to benefit from offering the North Sea as the chosen location for CO_2 storage from European CCUS projects, a capability which Norway has also begun to develop. There is also significant potential to collaborate with other countries on shared storage infrastructure, whether for permanent storage of CO_2 shipped to the UK or for the export of UK goods and services in this sector. Storing CO_2 from other countries would help further drive down the cost of building any new T&S assets through deriving third party revenue, subject to the ratification of the London Protocol amendment.

CCUS offers a practical way of achieving deep emission reductions from the UK's industrial sector

The industrial sector is responsible for nearly one quarter of the world's annual greenhouse gas emissions[43]. Several industry sectors produce high volumes of CO_2 not just from burning fossil fuels for energy, but as an intrinsic part of the production process. For example, 70% of CO_2 emissions from cement come from the chemical process of calcining calcium carbonate rather than energy use[44]. Sectors such as steel, cement and some chemical and fertiliser manufacturing, have no means of making deep emission reductions without using some form of CCUS technology.

Consumer-facing companies are already under pressure from their customers to show the environmental impact of their products. Deploying CCUS can lower the carbon footprint of industrial products. As we have suggested in Part C: Implementation, the UK has an opportunity to develop new standards and certification for low carbon industrial products through a 'decarbonised product mark'. With the right policy incentives UK CCUS clusters can make and keep our existing heavy industries competitive in a low carbon world, whilst also attracting international investors looking for ways to meet their needs for heavy industry in an environmentally responsible way[45].

40 SCCS, 2015. CO_2 Storage and Enhanced oil recovery in the North Sea
41 Zero Emissions Platform, 2017. CCS and Europe's Contribution to the Paris Agreement – Modelling least-cost CO_2 reduction pathways
42 Energy Technologies Institute, 2017. Taking stock of UK CO_2 storage
43 Global CCS Institute (online) Understanding CCS: Industrial CCS. Available at https://www.globalccsinstitute.com/understanding-ccs/industrial-ccs Accessed 29/06/18
44 Department for Business, Energy and Industrial Strategy, 2017. Cement sector: industrial decarbonisation and energy efficiency action plan
45 Benton, 2015. Decarbonising British Industry: why industrial CCS clusters are answer

CASE STUDY

Decarbonising power

CCUS can provide baseload or flexible power in a sector which, in the coming decades, will be increasingly dominated by intermittent renewable technologies. Unlike, for example, wind or solar, gas- or biomass-fired generation with CCUS is "flexible" or "dispatchable", meaning electricity output can be adjusted to meet changes in electricity demand. Evidence from projects such as FlexEVAL *"shows the particular value of flexible 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"*[46].

The UK Energy Research Centre estimates the cost of renewables intermittency as £10/MWh in 2030, rising thereafter[47]. If the electricity system is not sufficiently flexible to accommodate high renewable capacity, low carbon flexible generation with CCUS is one option which can reduce system costs[48]. It is the Taskforce's view that CCUS and renewables complement rather than compete with each other and CCUS has value by potentially enabling greater integration of renewables in to the system.

The ETI has developed a framework for comparing the value for money of power generation technologies on a level playing field basis (i.e. taking account of unpriced system impacts, externalities and the value of risk transfers in existing market arrangements). This suggests that CCUS for power projects can offer strong value for money for UK consumers and taxpayers[49].

46 Mac Dowell et. al., 2017. IEAGHG Report 2017/09 – The FlexEVAL project. "Valuing flexibility in CCS power plants"

47 Heptonstall et. al., 2017. A systematic review of the evidence on the costs and impacts of intermittent electricity generation technologies – 2016 update

48 Imperial College London and NERA Economic Consulting, 2015. Value of Flexibility in a Decarbonised Grid and System Externalities of Low carbon Generation Technologies

49 Frontier Economics, 2018. A framework for assessing the value for money of electricity technologies: a report for the Energy Technologies Institute

Caledonia Clean Energy Project

Summit Power's Caledonia Clean Energy Project[50] at Grangemouth will generate up to 1.3GW of low carbon power using natural gas as a fuel. This project has completed its feasibility study, confirming technical feasibility, and is deliverable by 2025. A potential storage site and transportation network that can be re-purposed has been identified. The project will seek a CFD for electricity generated and contracts to govern other commercial arrangements.

How does it work?

The project proposes a combined-cycle gas turbine (CCGT) plant with post combustion capture, with net power output up to 1.3GW, with the proportion of CO_2 captured over 90%. The equivalent strike price for the plant is expected to be between £80-£90/MWh, subject to the commercial models adopted in the UK. The majority of Scottish CO_2 emissions are located close to the project around the Firth of Forth, presenting an opportunity to use the project as a catalyst for industrial CO_2 capture in the Scottish cluster.

95% of the required pipelines for CO_2 transport and storage already exist. Short new connections are required to an existing onshore pipeline running to St Fergus. Repurposing existing infrastructure represents a saving of up to £440m in capital costs compared to commissioning new pipelines.

An estimated total storage capacity of 54,000 $MtCO_2$ has been identified in the UK Central and Northern North Sea formations. The Captain sandstone formation has been appraised as a store, and represents a low risk area due to the knowledge and experience gained from developing and operating adjacent oil & gas production.

How does this project meet the CCTF aims on value of CCUS and the cost challenge?

A plant of this nature could be a global first for the UK, offering flexible low carbon electricity to support grid resilience. There will also be significant cost savings associated with deployment using existing infrastructure.

50 Find out more about this case study at: https://summitpower.com/projects/carbon-capture/

Hydrogen economy

Supply of low carbon hydrogen provides an alternative to the electrification of heat, transport and industry, though it is recognised that there is no broad consensus on the best route to follow in the long term. National Grid looks to a future where the UK is producing hydrogen at scale, with natural gas and CCUS[51] and some reports have concluded that hydrogen may be the most cost-effective route to decarbonisation which, if proven, means that hydrogen could play a very significant role in the future[52,53]. Currently, reformation of natural gas using CCUS is thought to be the most cost-effective route for production of low carbon hydrogen at scale[54].

The use of hydrogen provides potential ways to decarbonise domestic heating. The "H21 Leeds City Gate" Northern Gas Network project (see case study) describes the potential for hydrogen to be used to significantly decarbonise parts of the existing gas usage, with the conversion of the gas distribution network to hydrogen – though demonstration is still required to prove the feasibility and safety of hydrogen conversion.

CCUS could also be an enabler for the production of low carbon hydrogen for use in the transport sector, including trains, HGVs, and shipping. Hydrogen HGVs and trains are already operating in countries such as Japan and Germany and hydrogen trains could avoid the need for costly and disruptive rail electrification or bi-modal trains.

The reduction of emissions in the maritime sector is an increasing priority, with the United Nations International Maritime Organization strategy published in April 2018 on the reduction of CO_2 emissions from ships consistent with the Paris Agreement temperature goals[55]. Hydrogen fuelled ships are one of the options that could deliver decarbonisation in this sector.

Greenhouse Gas Removal (GGR) Technologies

CCUS infrastructure is a prerequisite for many well-developed GGR technologies, including BECCS and direct air capture, which can deliver negative emissions. Through these technologies, functioning CCUS infrastructure will therefore be critical to enable these GGR technologies to be deployed to support a move to a net zero carbon economy, compensating for the residual 'hard to decarbonise' sectors such as marine transport, aviation and agriculture.

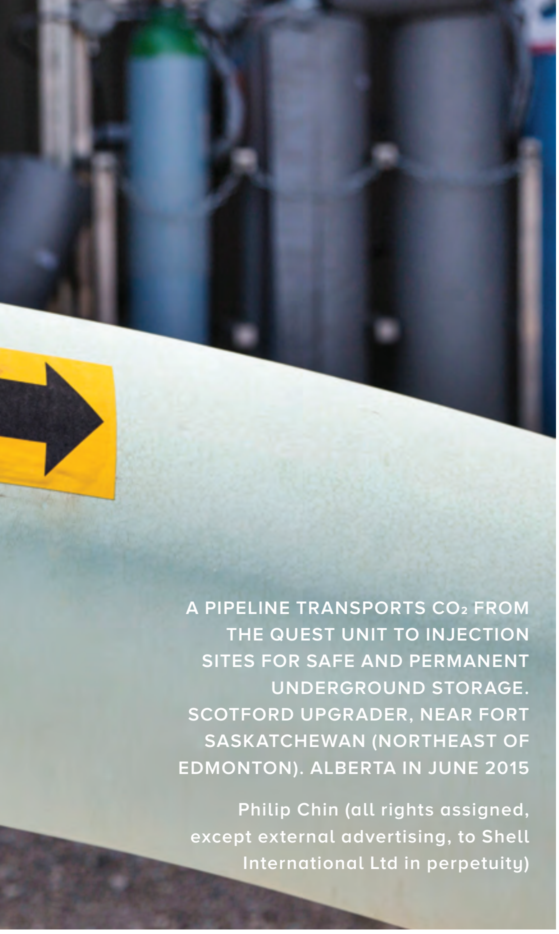
51 National Grid, 2018. Future of Gas: How gas can support a low carbon future

52 Northern Gas Networks, 2016. H21, Leeds City Gate Project Report

53 Parliamentary Advisory Group on Carbon Capture and Storage, 2016. Lowest Cost Decarbonisation for the UK: The Critical Role of CCS

54 Speirs et. al. 2017, Sustainable Gas Institute White Paper. A greener gas grid: what are the options?

55 As adopted by United Nations International Maritime Organization in April 2018. http://www.imo.org/en/MediaCentre/PressBriefings/Pages/06GHGinitialstrategy.aspx



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)

CASE STUDY 5

Tata Steel: decarbonised steel project

Key benefits/aims

The Tata Steel project concept showcases decarbonising the steel production process, driving clean growth in the UK steel industry ahead of competitors and exploiting the nation's geographically favourable CCUS potential. A world leading low carbon steel industry in the UK will slash the embedded emissions within our products and increase the value and profitability of the sector.

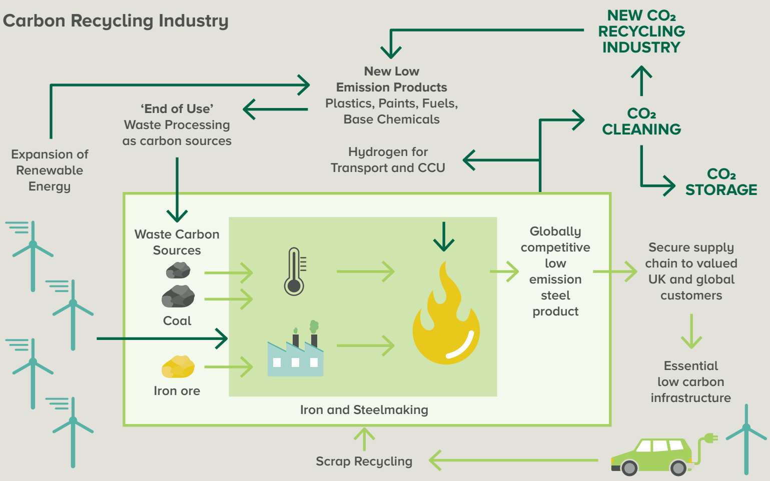
How does it work?

The chemical reactions in steelmaking produce large volumes of CO_2, CO and hydrogen. Tata Steel has invested in a £75 million technology demonstrator, HISARNA[56], based in the Netherlands, which will reduce CO_2 emissions by 20% and emit nearly pure CO_2, thereby driving down the cost of implementing CCUS. It has been calculated that HISARNA technology, plus a CCUS system, would produce an 80% reduction in CO_2 emissions. With increasing global demand for our modern, high value steel in products such as cars, batteries and low carbon buildings, we expect our steel to be required well beyond 2050 and can therefore provide a guaranteed CO_2 source and an ideal anchor for any CCUS project.

How does this project meet the CCTF aims on value of CCUS and the cost challenge?

By linking Tata Steel's works at Port Talbot with other South Wales industrial CO_2 emitters, a cluster with ~18 $MtCO_2$ emissions could be created. This includes an existing large scale hydrogen generating plant. This cluster could add significant value to the UK's steel, cement, oil and chemical products and create new low carbon chemicals (through CCU), ensuring secure, highly skilled jobs for the region and exportable knowledge. This project opens new pathways to carbon recycling and CCUS, that are already being accelerated by competitor steel-producing nations in the EU. New chemical processes and proofs of concept can be demonstrated to the world to secure UK-based supply chains and avoid reliance upon potentially inferior and high CO_2 imports.

Figure 7: Steel at the heart of a 'Circular Economy'



56 Find out more about this case study at: https://www.tatasteeleurope.com/en/sustainability/hisarna

Wider benefits of CCUS – GVA, health and global leadership

There have been several studies which consider the benefits to the wider economy of deploying CCUS. These studies all show material economic benefits and job creation, both regionally and nationally. A study by AMION Consulting into the economics of the HyNet project anticipates that it will result in 5,979 jobs for the North West and generate cumulative Gross Value Added (GVA) gains to 2050 of £16.9 billion for the North West and £30.5 billion for the UK[57]. Similarly, a proposed CCUS network in the Tees Valley is estimated to provide an annual increase of around £85 million in GVA in the UK over 2021-2024, including a £30 million annual increase in direct value added to the region; a further £20 million annual increase in direct value added to the rest of the UK, and an additional £35 million increase in value added in the UK due to indirect effects[58].

CCUS can also contribute towards improving air quality through enabling hydrogen for heavy goods transport. The benefits of CO_2 emissions reductions in Europe have been estimated to be around €24/tCO_2, by a WHO led study[59].

The deployment of CCUS can give the UK an opportunity to be a global R&D leader in the CCUS industry. Across the UK there are businesses and innovators with the potential to lead the development of CCUS[60], including the Carbon Capture Machine, developed at Aberdeen University. Econic Technologies in Macclesfield, and Carbon8 in Norfolk, are creating new value from CO_2 feedstocks. Furthermore, companies such as Goodwins in Stoke-on-Trent are key parts of the supply chain for emerging technologies like NET Power's Allam Cycle. This activity is further reinforced by the commitment of organisations such as Total in the oil and gas sector to allocate increasing proportions of research and development spend to CCUS. It is the view of all members of the Taskforce that CCUS presents an opportunity for the UK to show world leadership in the CCUS industry, with UK companies at the forefront.

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

57 Amion Consulting, 2018. Potential Economic Impacts of the HyNet North West Project

58 Cambridge Econometrics, 2015. The Economic Impact of Developing a CCS Network in the Tees Valley

59 World Health Organization, 2013, Health risks of air pollution in Europe – HRAPIE project

60 David Nevicato, 2018 (online). A collaborative approach to CCUS technology development. Available at https://www.Governmenteuropa.eu/ccus-technology-development/84438/ Accessed 29/06/18

NATURAL POWER'S HEALTH & SAFETY PROJECT MANAGEMENT TEAM

Photo courtesy of Natural Power

6

CASE STUDY

HyNet North West England Project

With the right support, the HyNet Project[61] will produce and supply decarbonised hydrogen to industry and (as a blend) to households, abating over 1.1 $MtCO_2$ each year. Subsequent extensions within the North West will include supply to additional industrial sites, for flexible power generation, and for fuelling of buses, trains and HGVs. All CO_2 from H_2 production will be stored at the Liverpool Bay and Morecambe Bay fields, which are of sufficient capacity to expand and accommodate further CCUS projects. The project creates extendable CCUS and hydrogen distribution infrastructure abating material CO_2 at lower cost than alternatives. The project decarbonises energy intensive industry (some of which has no viable alternative option), households and businesses, the transport sector (including buses, HGVs and trains), and can provide the flexible power needed to balance intermittent renewables.

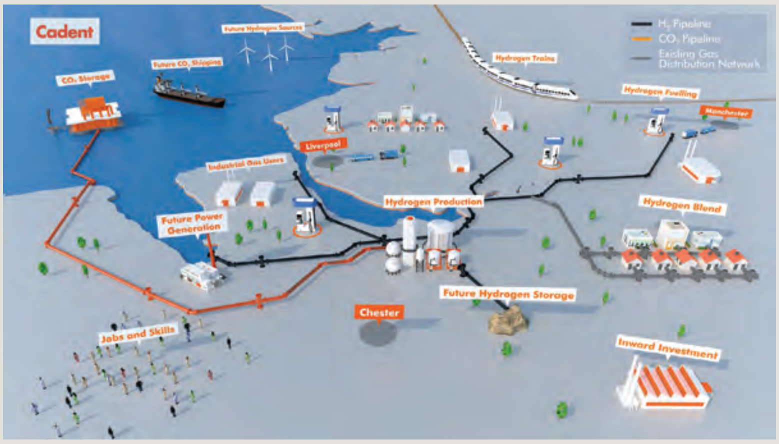
How does it work?

Hydrogen is produced from natural gas, with CO_2 captured as part of the same process. The hydrogen is then piped to energy intensive industries and blended in to the local gas network, up to approximately 15%. The project will reuse existing onshore and offshore pipeline infrastructure, which will significantly reduce costs when compared to commissioning new pipelines. Initially, the project will store over 1.4 $MtCO_2$ each year, which will be injected into the Hamilton gas field (125 $MtCO_2$ capacity). Extensions to the project will involve the nearby similarly sized Lennox gas field, whilst a further 1 Gt CO_2 of capacity is available at the nearby Morecambe Bay fields.

How does this project meet the CCTF aims on value of CCUS and the cost challenge?

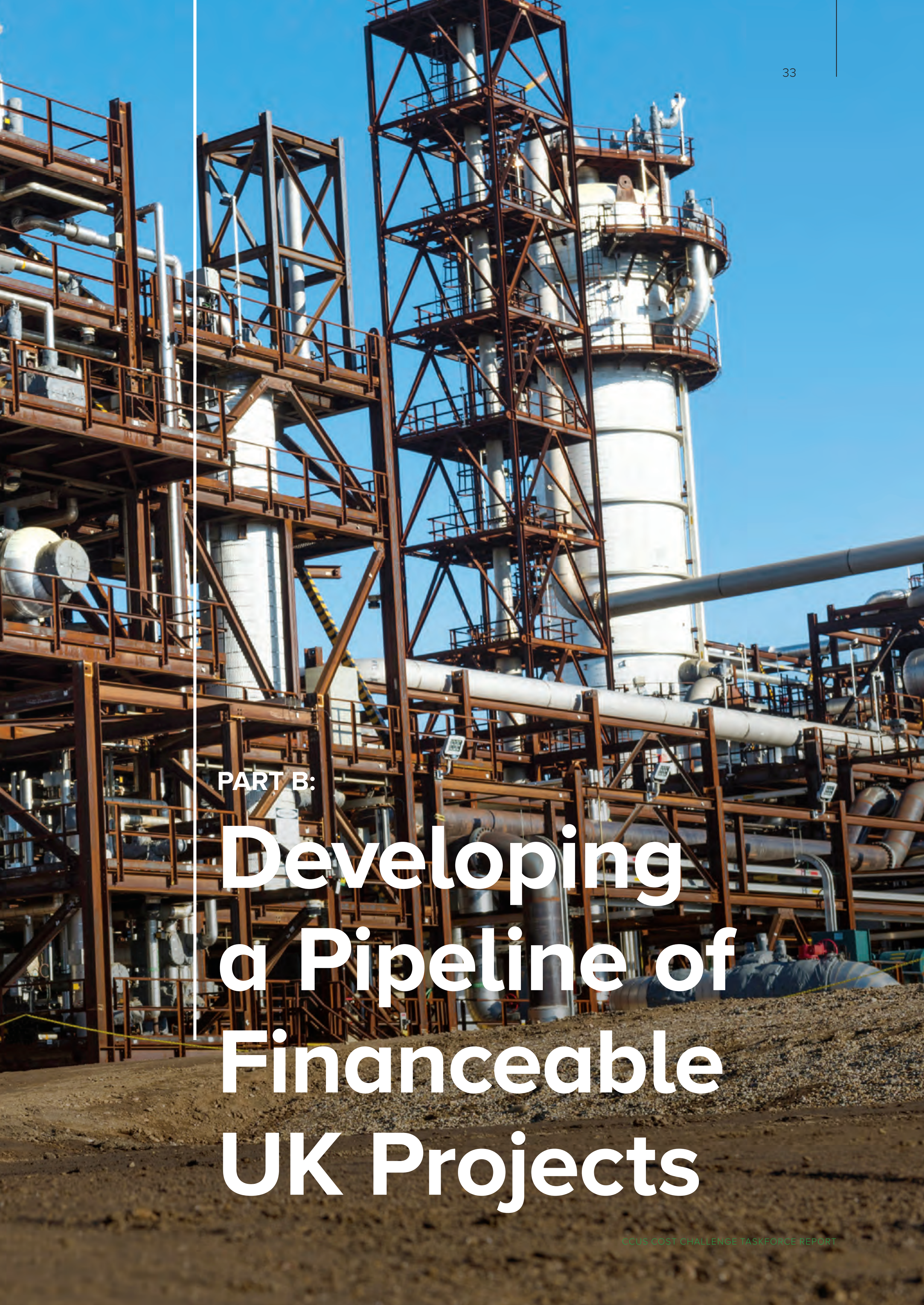
The Capex estimate for the initial project is £920 million, with a cost of abatement of £114 per tonne of CO_2. Subsequent extensions to the project, which use the same CCUS infrastructure, and potentially lower cost fuels, will significantly reduce this. Subject to agreement with the regulator and Government, from 2021, costs can be shared across all gas consumers by including them as an allowable cost in the regulated asset base.

Figure 8: HyNet North West England Project at a glance



61 Find out more about this case study at: https://hynet.co.uk/

WORKERS STAND IN FRONT OF THE QUEST CARBON CAPTURE AND STORAGE UNIT AT SHELL SCOTFORD NEAR EDMONTON, ALBERTA (SHELL SCOTFORD, NOVEMBER 6, 2015)



PART B:

Developing a Pipeline of Financeable UK Projects

The Taskforce's view is that with viable business models in place and clear Government and industry commitments to the policy framework, CCUS projects can be financed through private investment. However, developing CCUS projects is capital intensive and the cost of financing will be directly related to risk allocation. Experience from other sectors shows that a reduction in the cost of capital, supported by an appropriate risk allocation framework, could be a significant component of future cost reduction in CCUS as a whole.

The private sector is able to deliver CCUS, if it is operating within a well understood risk allocation framework. The technology and processes for CCUS are well understood and are already deployed at commercial scale globally.

Allocation of risks

For CCUS projects, the private sector can bear the majority of the risks. However, there are also some risks – largely those CCUS-related risks associated with long term CO_2 storage – which should be initially shared by Government and industry and transferred to the private sector as the CCUS sector matures.

As requested by the Minister for Energy and Clean Growth, the Taskforce has sought to identify the irreducible core of risk – those low probability but high impact risks – which the private sector, at least initially, cannot price or take and where, as a result, it may be better value for money for the Government to hold.

It is worth noting that with experience and increasing maturity of a UK CCUS industry, a number of what today we consider irreducible risks, may become more acceptable to the finance and insurance markets and could also reduce or be dropped over time. However, managing the irreducible risks is crucial to starting the CCUS industry in the absence of any compelling commercial rationale for the private sector to take these risks now.

The irreducible core set of risks identified by the Taskforce are:

Political risk: Government needs to provide long term policy stability to incentivise the private sector to make long term investment decisions in respect of CCUS.

Cross-chain risk: CCUS projects are made up of several distinct but interdependent components (capture, transport and storage) due to the differing nature of the process involved. Cross-chain risk is frequently interpreted as a failure of one of these components to deliver on their obligations and in doing so, preventing the project performing as a whole.

Our suggestion is therefore that Government consider reviewing the split-chain model for CCUS. In the split-chain model, the risk of impacts on the revenue of either one or other element of the chain not being available is not borne by the sponsors of the relevant portion of the chain. For the capture plant, for example, this would continue to receive revenue if it was available to operate but unable to operate due to the store being unavailable. For the T&S enabler (see section 'Project Delivery – CCUS Clusters') this would mean that the Catalyst project would still be required to pay the T&S fee even where the catalyst was unavailable. We also recognise that cross-chain risk may be a lesser issue as the CCUS industry develops.

Stranded asset risk: In the event that there is no capture project(s) the store would need to be permanently closed and any asset decommissioned. If the store was permanently unavailable there would need to be some form of termination compensation payable to the capture project(s).

CO_2 leakage risk: CO_2 leakage or migration risk is a low probability, high impact risk as there is a requirement to pay for CO_2 leakage at the prevailing EU-ETS allowance price. The lack of certainty over the price prevailing at the time of leakage makes the risk unquantifiable.

Uninsurability of CO_2 storage liability: We believe that the industry is able to bear a proportion of the CO_2 leakage risk and that this self-insurance can be supplemented by additional cover from the insurance markets as part of the overall cover for the project and indeed this has been the approach proposed by a number of previous projects[62]. There are limitations of the current insurance market, including the capacity of the market (which could be expected to increase over time) and the short term nature of insurance policies, which may mean that obtaining insurance following a claim could prove impossible or exorbitantly expensive.

R ***RECOMMENDATION:** 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.*

62 https://www.gov.uk/Government/collections/carbon-capture-and-storage-knowledge-sharing

Financing CCUS

It is generally true that given the right framework, clean energy projects can represent an attractive asset class for the commercial bank market.

The commercial bank market has previously been willing to engage with the CCUS industry (e.g. the White Rose project), suggesting that banks were willing to finance a CCUS project with a complex commercial structure with relatively well-defined risk sharing[63]. Whilst encouraging, failure to proceed with the project means that the bankability of the structure and risk allocation was never fully proven.

Green bonds: There is a rapidly growing green bond market and other green lending measures; these were highlighted and recommended in the Green Finance Taskforce Report[64] and may be suitable for CCUS projects, although the risk allocation will need to be considered as in many cases bond investors can be more risk averse. The evaluation process, monitoring and reporting requirements for green bonds also need to be fully understood and complied with.

Key features that a CCUS Green Bond should meet (based on the ICMA green bond principles):

Process for project evaluation and selection: based on criteria guided by the requirements that an issuer of a green bond should outline the process it follows when determining eligibility of an investment using Green Bond proceeds and outline any impact objectives it will consider.

Use of proceeds: requirement that an issuer of a green bond must use the funds raised to finance eligible CCUS activities which produce clear environmental benefits.

Management of proceeds: requirements that a green bond should be tracked within the issuing organisation with a declaration of how unallocated funds will be handled.

Reporting: annual reporting to the bond investors on the use of bond proceeds using quantitative and/or qualitative performance indicators, where feasible.

63 Department for Business, Energy and Industrial Strategy, 2016 (online) Available at Carbon Capture and Storage knowledge sharing https://www.gov.uk/Government/collections/carbon-capture-and-storage-knowledge-sharing Accessed 29/06/18

64 Green Finance Taskforce, 2018. Accelerating Green Finance: A report to Government by the Green Finance Taskforce

Engaging the finance community: Government and industry need to engage early with the financing community to build up trust and confidence in the immediate opportunities for CCUS projects in the UK, ensuring that the early projects meet the requirements of the finance community.

This engagement should consider the context in which potential financiers might provide finance as set out in Table 1 below.

Table 1: Drivers for the financing community

Financing Source	Rationale for engagement	Driver Now?	Driver in the future?	Comment
Equity	Legal obligation	No	?	Permit/consent requirement for O&G is an example, as is FGD and other measures for thermal plant in the past.
	Financial incentive	No	?	Norway (tax incentive) has demonstrated this can stimulate CCUS as has the availability of an EOR revenue stream. EU-ETS has failed – price uncertainty and exemptions.
	Competitive pressure	No	?	None from the demand side. Supply side interested in equipment supply rather than CCUS.
	Viable technical solution	Yes	Yes	Technology available in more or less proven form although performance may need to be proven in integration and at scale.
	Long term opportunity (for supply chain)	?	?	Can drive equity investment from the technology/ equipment suppliers to kick start the market.
	Profitability – attractive risk reward balance	No	?	Essential (fundamental) for successful commercial development of the industry but far from clear currently.
Commercial Bank Debt	Favourable policy environment	No	?	No clear policy environment, currently undermined further by failed competitions.
	Long term business opportunity	No	?	Financial institutions like to see a long term business opportunity for any new business – ongoing deal flow.
	Scale (in debt terms)	No	?	Significant capital investment and implied debt funding opportunity.
	Favourable risk allocation	No	?	No bankable risk allocation has yet been agreed for any commercial-scale project.
	Relationship rationale	?	?	In a new industry, banks focus heavily on relationship clients for confidence in the opportunity.
ECAs and multilaterals	To a certain extent the ECA and multilateral requirements are similar to those of the banks but with the additional focus on national content and risk allocation, where they provide commercial risk cover.			

R ***RECOMMENDATION:** 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).*

Figure 9: Cost Reductions and Savings

"Carbon capture and storage (CCS) is part of the cost-effective pathway for an emissions reduction of 80% by 2050, and its absence could double the cost of achieving that reduction. CCS becomes even more important for deeper reductions by 2050 and is essential to reach net zero emissions, committed to under the Paris Agreement".*

CCUS CAN CREATE NEW REVENUES, SKILLS AND SERVICES

- Creation of new jobs and private sector investment in transportation and storage assets with CCUS.
- Values/Revenues from balancing an overall energy system increasingly dominated by intermittent technologies.
- Attraction of new industrial developments in low carbon chemicals and steel to clusters can grow regional and national economies.
- Creation of revenue models for hydrogen and industrial CCS projects will develop these industries.
- Export opportunities and development of new UK oil & gas infrastructure skills.
- Creation of CO_2 storage services for pan-European assets.
- Incentive for industry to galvanise innovation in processed and new technologies will keep UK's global leadership.
- Development of a world leading hydrogen economy can avoid cost of electrification in multiple sectors and enables decarbonisation of heat, transport and industry.
- Potential revenue for EOR

"CCS is of critical importance to meeting the UK's carbon targets at least cost".

COST REDUCTIONS AND SAVINGS ACHIEVABLE WITH CCUS

Act now for these cost reductions

Retention and repurposing of existing assets reduces capital cost of deployment.

Early deployment retains jobs and skills in the Oil and Gas sector reducing costs of reskilling.

Deployment of hydrogen fuelled heating transport can reduce need for development of new decarbonisation techniques in these sectors.

Capture costs can fall with deployment as risks are better understood from previous projects internationally and domestically.

A viable business model to reduce risks and cost of financing

RAB model can bring down cost of capital on T&S enabler and the alteration of risk profile brings down risk contingencies.

Known pipeline of projects can bring down capital costs of deployment.

Secured revenue streams for each part of the CCUS chain can facilitate access to cheaper forms of finance.

Lower security requirements on storage capacity lowers costs of L/Cs, PCGs, increases cash revenue.

Other cost savings

Development of greenhouse gas removal technologies facilitates decarbonisation of hard to reach areas and can help achieve net zero emissions aim in a cost-effective way.

Large scale T&S enabler project can allow higher CO_2 volumes from a CCUS cluster (and potentially elsewhere) and can support cost reduction in CO_2 capture projects.

CCUS can enable cost-effective decarbonisation of multiple energy sectors in the UK and multiple low carbon opportunities.

* Committee on Climate Change, 2016. A strategic approach to Carbon Capture and Storage

BLAST FURNACE 4 IN PORT TALBOT

Photo courtesy of Tata Steel

Driving down the cost of CCUS

The comparative cost of CCUS

Since commissioning new economic modelling was outside the scope of this Taskforce, we have analysed the existing data available. However, we recognise that a great deal of past analysis has focused on the electricity sector, and that cost information from UK CCUS projects is limited. As such, it has been difficult to quantify the cost reductions which we anticipate in the UK. Furthermore, we believe that the frequently-used metric of the levelised cost of electricity ("**LCOE**") cannot be used to accurately compare CCUS across all its applications with other technologies.

However, in the absence of other metrics, we have concentrated on the available data. Several studies have considered the costs of CCUS for different technologies. The recent Summit Power study to develop a concept for a gas fired power plant with CCUS in Grangemouth has estimated the required strike price (including the T&S fee) to be in the region of £80-90/MWh[65].

The Taskforce's view is that deployment of CCUS is key for driving cost reductions, such as has been the case for offshore wind. Shell, the developers of the Quest CCUS Project in Canada, believe that the cost of their next project could be up to 30% lower[66]. We have identified below a number of ways in which the business model proposals in this report could further drive down the costs of CCUS delivery.

Cost cutting through viable business models

The report has identified a number of areas where we are suggesting changes to the business models which we think will drive cost reductions:

- **Cluster development:** It is the Taskforce's view that one way for the UK to drive down costs and take advantage of the values that CCUS offers would be to deploy the first CCUS projects in clusters, bringing the unit cost of CCUS down.
- **Splitting the CCUS chain:** This reduces risk for the individual elements of the chain and allows the contingencies which were included in the model used for previous competition projects to be omitted from the costs. It also removes a risk which financiers find challenging and would otherwise push up the costs of debt.
- **Lower cost of equity:** The RAB model targets a different kind of investor, with a longer term infrastructure investment horizon and a lower cost of capital. It is widely understood that equity investment returns in RAB models range between 7-12% IRR, depending on the asset class, whereas project development IRRs are generally targeting between 13-17%. Putting in place the RAB model for the T&S assets would bring down the cost of equity.
- **Lower cost of debt:** RAB assets can finance in the capital markets on the basis of a net debt to RAB ratio. This provides access to a lower cost of debt for those assets which are RAB funded and could provide a much lower overall cost to consumer.
- **Risk allocation:** A new risk allocation framework with Government owning, at least initially, those irreducible risks would reduce the cost of CCUS projects.

65 Summit Power Caledonia UK Ltd, 2018. Caledonia Clean Energy Project: Feasibility Study Phase 2, Final Report

66 Global CCS Institute, 2016 (online), Shell's Quest Carbon Capture and Storage Project reaches significant milestone. Available at https://www.globalccsinstitute.com/news/institute-updates/shell%E2%80%99s-quest-carbon-capture-and-storage-project-reaches-significant-milestone Accessed 27/06/2018

CASE STUDY

Clean Gas Project

We have recommended that the fastest way for the UK to drive down costs and take advantage of the value that CCUS offers would be to deploy CCUS projects in clusters.

The Oil and Gas Climate Initiative (OGCI[67]) led Clean Gas Project ("CGP") aims to design a full scale, integrated gas fired power plant with CCUS. CGP hopes to unlock the decarbonisation of industries in the Teesside area and deliver up to 1.8 GW of clean, dispatchable low carbon electricity to UK consumers.

Why is CGP different?

1. *CGP enables a full-chain CCUS project at scale in a key UK cluster.*
2. *OGCI – 10 Oil & Gas companies with previous CCUS and major project experience – behind CGP development and execution.*

How does it work?

The source of CO_2 for capture is a large combined cycle gas power plant, which will capture up to 5 $MtCO_2$ per year. This will form the centre of a cluster which could include a further 4 $MtCO_2$ per year of industrial emissions from fertilizer, petrochemicals, and other energy intensive industries in Teesside.

The captured CO_2 is transported via offshore pipeline to storage (an offshore saline aquifer or gas depleted reservoir) in the North Sea. The cost of full transportation and storage infrastructure is expected to be around 25% of the total project cost.

The storage site is being developed to store up to 6 $MtCO_2$ each year for 25 years of continuous operations, and has up to 700 Mt of CO_2 storage capacity.

Depending on the size of the project and business model adoption (full chain vs. split chain) total cost will be up to £4 billion with primary revenue sources from wholesale electricity price and CFD. The project can confirm technical and economic viability of a large gas power plant with post-combustion CO_2 capture technology.

How does this project meet the CCTF aims on value of CCUS and the cost challenge?

CGP will provide a large fully integrated CCUS project, kicking off a cost reduction curve from 'first of a kind' towards 'nth of a kind'. It will also provide strategic T&S infrastructure to enable wider decarbonisation of energy intensive industry and a competitive clean power solution which will provide optimum value for money compared to alternative technologies. The project also provides jobs and investment to regenerate and support long term competitiveness of industry in Teesside and helps with decarbonising the energy system.

67 Find out more about this case study at: http://oilandgasclimateinitiative.com/climate-investments/

Photo courtesy of Uniper

PART C:

Implementation

Project delivery – CCUS clusters

The Clean Growth Strategy highlights the Government's commitment to working with emerging CCUS projects in industrial clusters, as part of enhancing their long term industrial competitiveness. As shown on the map at Figure 1 each of the identified clusters presents different opportunities for the application of CCUS across different sectors (industrial, hydrogen or power) and the development of CO_2 storage facilities. While each cluster will approach CCUS differently, we recommend that each cluster will need:

- a well developed project with strong commercial sponsorship;
- an existing industrial base;
- good access to CO_2 storage capacity;
- strong local and regional support;
- assets that could be re-used for CO_2 transport and storage (where appropriate);
- to incorporate innovative new technologies, including for the use of CO_2;
- to consider the opportunities to maximise future inward investment; and
- a supply chain plan.

Project delivery through CCUS clusters

We recommend developing CCUS in clusters where there is local support and a significant investment opportunity, starting with the clusters identified in this report. To drive down costs and drive up value there may be benefit in splitting off the transportation and storage infrastructure[68] so that several diverse CCUS projects can cluster around one pipeline and store, which could be extended, if needed, in the future. The Taskforce believes that the T&S infrastructure can be an enabler (a T&S Enabler) for CCUS and adopting a cluster approach enables the costs to be spread across projects and could reduce unit costs associated with the T&S infrastructure.

The Taskforce believes that each cluster will need a "catalyst" project to act as an "anchor" for each cluster as well as access to T&S infrastructure. Whilst a future alternative transport method may be via ship, this may not be cheaper due to the need to liquify the CO_2. Therefore, given the opportunity to exploit the UK's natural geological advantages in storage sites, we have focused in the first instance on pipeline assets, although there should be in-built flexibility to allow for shipping assets to be added to enable the T&S Enabler to expand its commercial operations. In turn this has the potential to reduce costs to the UK consumer and taxpayer by receiving CO_2 and associated revenues from other sources in Europe.

Catalyst project: To realise the full value of CCUS within a specific cluster, a Catalyst project is needed to be the "anchor" for the T&S Enabler. The Taskforce is impartial as to the type of Catalyst project, instead each cluster should decide this based on the make-up of the existing industry and its potential investors.

Feeder projects: Our vision is that clusters should be capable of being built out with Feeder projects, to expand the network and provide an additional source of funding for the T&S Enabler. Each cluster should determine the type of Feeder projects, but we would expect them to be identified at the time the cluster was created so that decisions could be taken as to the relative sizing of the T&S assets.

We have identified seven possible options for progressing CCUS clusters, which are outlined in Table 2 to the right.

68 Green Finance Taskforce, 2018. Accelerating Green Finance: A report to Government by the Green Finance Taskforce

Table 2: Options for progressing CCUS clusters

Deployment Pathway	Description	Assessment of Pathway
Small scale demonstration Catalyst	This option would deploy a small scale capture catalyst project (e.g. <0.5 $MtCO_2$/yr), with storage of CO_2 in the UK. This pathway could make use of existing infrastructure to reduce costs. Catalyst likely to be industrial CCUS, because of the smaller scale.	Opportunity for a low cost CCUS cluster. Unit costs of T&S likely to be higher due to smaller scale. Fewer cost savings if T&S cannot take CO_2 from further feeder projects.
Large scale Catalyst	This option would deploy a larger CCUS catalyst (e.g. >0.5 $MtCO_2$/yr) with storage of CO_2 in the UK with oversized T&S infrastructure. It could be hydrogen, electricity or both (e.g. H_2 to a CCGT). Feeder projects would further reduce costs of the T&S infrastructure assets.	Greater scale contributes large part of delivering CCC recommendations (10 $MtCO_2$ per year by 2030). Lower unit costs and greater opportunity to draw in further CO_2 from Feeder projects. Overall costs higher due to greater size.
Hydrogen production Catalyst	This option would focus on creation of a new hydrogen economy and the use of CCUS as part of the decarbonised heating, transport, industrial and marine sectors. Hydrogen production also offers pure sources of CO_2 which could be utilised in some food production processes.	Dependent on scale, could have low unit costs. Provides opportunity to decarbonise wide range of sectors through supply of low carbon hydrogen. Market for hydrogen at scale not currently established and new business models would be needed.
R&D-led option with UK deployment delayed until 2030	This option would focus on ways to stimulate innovation in CCUS technologies but does not envisage CCUS deployment in the 2020s. Government would drive R&D activity, feasibility studies, store appraisals and FEED work but would not expect a commercial scale project to be operational until 2030.	This option would not deliver the Government's ambition of an option to develop CCUS at scale in the 2030s and it would be challenging to commit deployment of capture at scale without having first proven store operation for several years.
T&S enabler deployment	This option would invest in T&S infrastructure with the intention of enabling capture projects to link into it (e.g. a "backbone" investment), sized to allow for significant future capture projects in a cluster (but taking the risk on specifications of a future catalyst without one being in place at the start). The location of the T&S enabler would be chosen ahead of picking a CCUS catalyst.	By providing a "backbone" for a cluster, capture projects can link into the infrastructure at reduced cost. Likely to mean a significant role for Government investing in the infrastructure. There is an increased risk of stranded asset.
CCUS catalyst with shipping	Under this option, the UK would invest in CO_2 capture project(s) but not the T&S infrastructure. Instead CO_2 captured would be shipped for storage outside the UK.	This deployment option enables the Government to signal its future intent to develop CCUS without commitment to the T&S infrastructure. This option is challenged by the current restrictions under the London Protocol and the uncertain costs of shipping and storing CO_2 in a third country. UK still likely to have to develop its own CO_2 infrastructure at some point.
EOR-focused deployment	Under this option, the UK would focus on CCUS projects with EOR. CO_2 EOR has been deployed successfully in the US and Canada and provides a revenue stream to CCUS projects for the CO_2. However, those projects are onshore EOR and at present offshore EOR is not viewed as an economically attractive option for the UK.	At present EOR is not seen as an economically attractive option for the UK and would need to be considered in light of the UK's wider climate change and environmental policy perspectives.

Selection considerations for a CCUS cluster

- Level of local/regional support and priorities (e.g. as identified in the Local Industrial Strategies).
- Commercial viability – locations available, size of store, willing participants, unit cost of storage, compatibility with potential emissions sources and performance risk.
- Compatibility with Government's Industrial and Clean Growth Strategies and the Government's new approach to CCUS.
- Ability to reduce costs of T&S implementation through support of several projects.
- Ability of enabling T&S investment to leverage in private sector investment in CCUS.
- Opportunity for repurposing/retaining/enhancing existing industry and industrial assets.
- Attractiveness for new investment, growth and industry to that cluster, including of CO_2 utilisation.
- Opportunity for local and regional direct and indirect jobs, potentially through creation of a local supply chain.
- Materiality and extent of value for money options it could support.
- Ability to deploy CCUS from the mid-2020s
- The degree of 'optionality' (ability to encourage alternative CCUS technologies and incorporate CGR Zones) at each location.
- Level of support required and likely impact on customers and taxpayers.
- Air quality and wider public benefit of decarbonisation at location.

Business plans for clusters

We recommend that Government develops a policy framework to enable the first CCUS clusters to be operational from the mid-2020s. This policy framework should include criteria (Table 3), timeline and the detail on the assessment process as well as the schedule for the first, and subsequent, application rounds. Having a framework in place, supported by the CCUS roadmap, will give industry the certainty it needs to bring forward its business plans.

The cluster would be responsible for developing its business plan and submitting its proposals for developing a CCUS cluster. In each proposal we would anticipate a strong level of collaboration between industry, the relevant local and regional governments, and devolved administration as well as the T&S enabler and the CCUS Catalyst project, so that the two projects could be dovetailed and become operational concurrently.

A final decision on whether to proceed with a CCUS cluster would only be made once the cluster proposals are further progressed. Those clusters that are assessed as being suitable for further progression will be taken through to final assessment.

Development funding

We recommend that Government provides targeted funding for the development of innovative, comprehensive, and fully costed cluster business plans. Regional and local Government, and devolved administrations can work with national Government to support this effort. Industry would then mobilise its resources and expertise to develop detailed business plans for clusters.

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

We propose that the deployment of CCUS projects is spearheaded by industry with Government and the regulator supplying a stable framework for investment to be brought forward.

CASE STUDY

Northern Gas Network Project (H21 North of England)

Key benefits/aims

Northern Gas Networks in collaboration with Equinor and Cadent are developing a project to supply clean hydrogen using natural gas reforming with CCUS for decarbonising heat, power and transport across the North of England.

The project will build on the original 'H21 Leeds City Gate' work presenting a 'conceptual design' for converting the North of England to hydrogen between 2028 and 2035, and decarbonising heat. This project covers the areas of Hull, Liverpool, Manchester, Teesside, Tyneside, West Yorkshire and York which includes three million-meter points, circa 85 TWh per annum and 12.5% of net UK population.

How does it work?

The hydrogen will be produced in a large scale 12GW capacity hydrogen facility. The CO_2 source, an integrated part of the hydrogen production process, will capture 17 $MtCO_2$ per year.

The optimum option for CO_2 transportation is via pipeline from the hydrogen facility – likely in conjunction with natural gas entry points, for example at Easington or Teesside. Due to economies of scale, the transportation cost is likely to be under £6 per tonne of CO_2. Storage would be focused in the Southern North Sea to allow CCUS trade with Europe, and would take advantage of the UK's most extensive CCUS capacity. Further, the project includes inter-seasonal hydrogen storage of 11 TWh that enables flexible supply of clean energy.

How does this project meet the CCTF aims on value of CCUS and the cost challenge?

The H21 North of England project could represent a first policy for UK government to decarbonise heat:

- *The project would provide more decarbonised energy than the total amount of renewables supplied to the UK in 2017;*
- *Starting in 2026, by 2035 the project would be the largest CCUS project in the world; and*
- *The project provides a flexible energy infrastructure, decarbonising heat while providing the opportunity to incorporate future sources of green hydrogen, and offering support to growing renewable generation.*

Figure 10: Presentation of the H21 North of England project

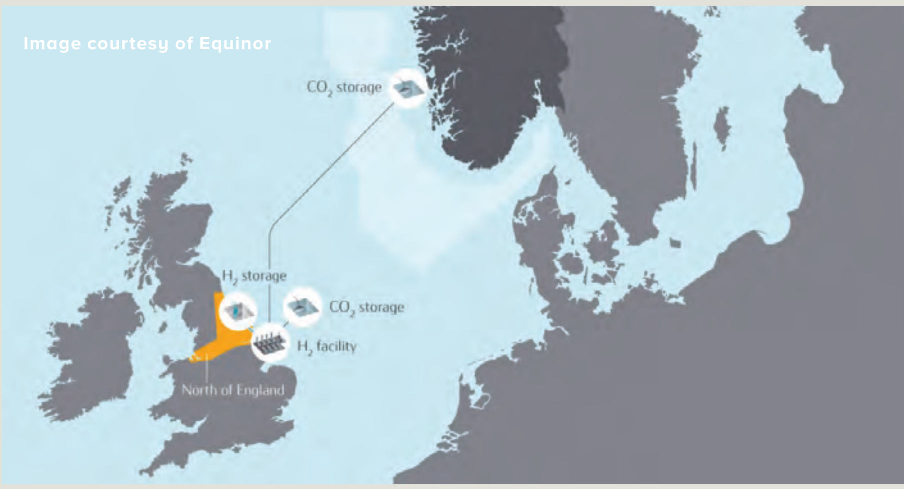
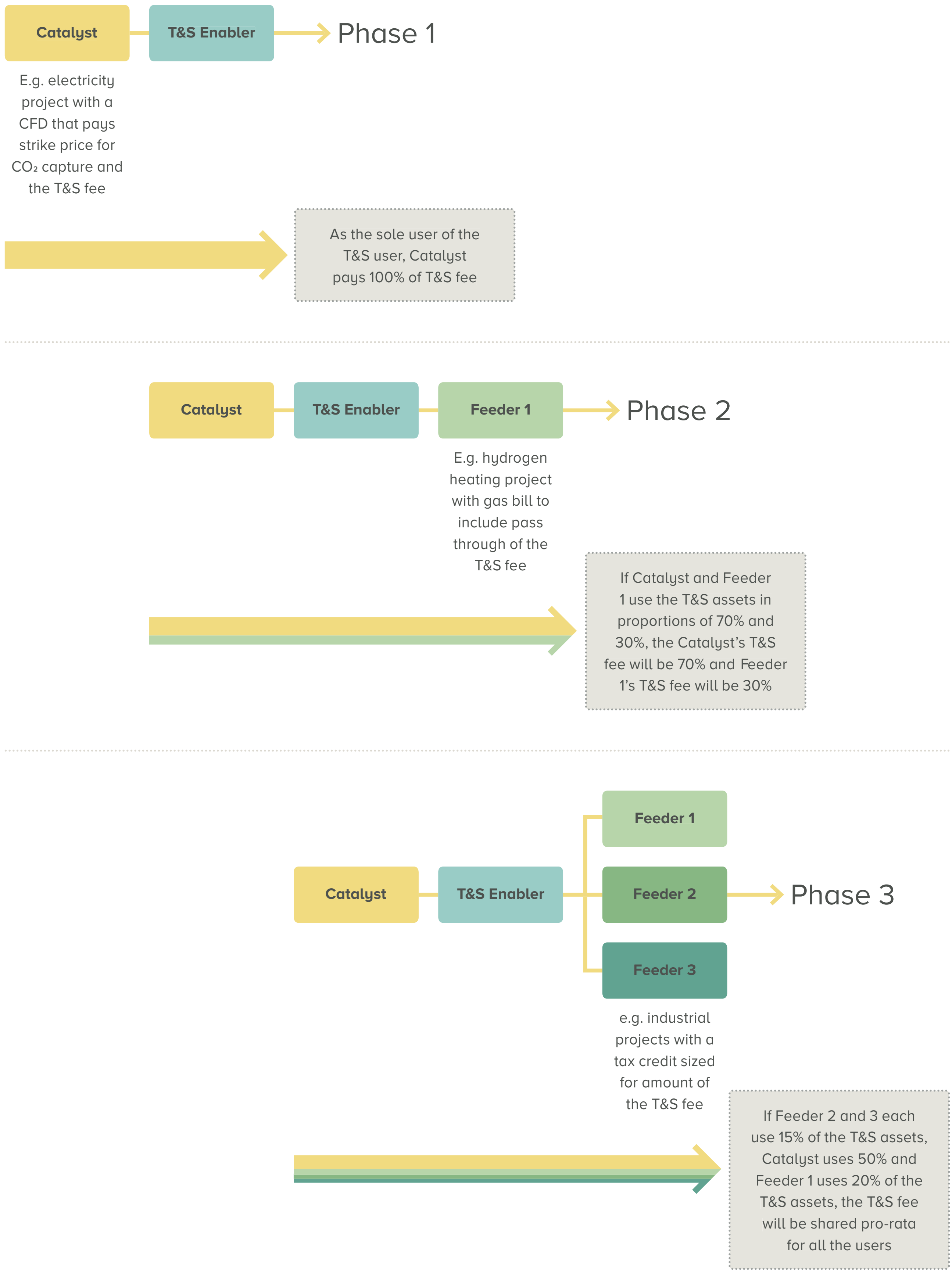


Figure 11: Sharing the T&S fee between capture projects



Business models for CCUS clusters

The UK already has a well understood regulatory framework to enable CO_2 storage[69], an experienced offshore oil and gas industry, a successful CFD mechanism supporting low carbon electricity generation, and a mature regulatory structure for gas transmission and distribution assets and well-functioning gas market.

However, there are no operating CCUS projects in the UK today, partly because of the challenge of allocating risks in a commercially viable way. We have proposed that separating out the ownership, operation, and risks of T&S infrastructure from capture projects has the potential to make financing easier and prevents permanently loading costs on to one project and one set of consumers. It also has the potential to encourage the development of strategic transport and storage hubs, large enough to support increasing volumes of CO_2, both within the cluster and elsewhere (e.g. shipped to the UK from mainland Europe).

69 Consoli et. al., 2017. Carbon capture and storage readiness index: comparative review of global progress towards wide-scale deployment

Sharing the costs

We recognise that the development of CCUS requires significant investment particularly if the T&S infrastructure is oversized for growth, and who bears the costs will depend on the type of business models and projects chosen. We have therefore looked at how these costs could be spread in two ways: firstly, by spreading these costs over Catalyst and Feeder projects and, secondly, how those costs are allocated to different funding streams.

As set out in Figure 11 the Catalyst project would initially bear 100% of the T&S fee. However, if Feeder project(s) are added to the cluster, the T&S fees would be shared proportionately. For example:

- In phase 1, if the T&S fee were £100, the Catalyst project would pay £100.
- In phase 2, one Feeder project joins the T&S network, meaning that the T&S fees are shared on a pro rata basis. If, by volume, the Catalyst project was transporting and storing 70% of the CO_2 and the Feeder project 30%, then the catalyst would pay £70 and the Feeder £30.
- In phase 3, two further Feeder projects join, such that the volumes of CO_2 transported and stored were catalyst (50%); Feeder 1 (20%); Feeder 2 (15%); Feeder 3 (15%) then the share of T&S fees would be catalyst (£50); Feeder 1 (£20); Feeder 2 (£15); and Feeder 3 (£15).

Different projects have different economic drivers and different beneficiaries. Previous CCS competitions used business models where the initial costs of CCUS would have been borne wholly by electricity consumers or the taxpayer. Our approach recommends that the costs are shared and have concluded it could be appropriate to:

- share the costs of developing business models and business plans with local, regional and central Government, the devolved administrations and industry;
- share the costs of the T&S Enabler(s) proportionately across the projects which use them;
- share the costs of electricity production with electricity consumers; and
- share the costs of the decarbonisation of heat with gas consumers.

Viable business models

If we are to achieve our recommendation that at least two CCUS clusters are operational from the mid-2020s, then the first capture projects may need to be supported via existing mechanisms. For example, electricity projects can use the existing CFD mechanism (adapted for CCUS) and hydrogen projects can seek to use the existing regional RAB models.

However, we believe there will need to be new business models for T&S and industrial CCUS projects, to support CCUS deployment at scale across sectors. We are therefore suggesting that:

- The T&S enabler is taken forward using a RAB model;
- Electricity projects utilise the existing CFD mechanism, adapted for CCUS;
- Investment in early hydrogen projects for the gas grid to be borne by gas consumers, using the existing RAB structures; and
- Industrial products are supported through a mechanism that may include a new tax credit scheme, new low carbon product standards or joint Government/industry investment.

We discuss each of these proposals below in more detail.

T&S Enabler Model

We are proposing that the Government further explores the use of a RAB model for the T&S enabler project. A RAB model can give the flexibility to enable future development over time, as the need for further infrastructure grows with cluster development and is used for gas networks as well as for some single asset models such as the Thames Tideway Tunnel, and for interconnectors.

The RAB model is attractive to those with longer term investment horizons. RAB models have low volatility in returns, a stable regulatory regime and the potential for future growth and deployment of further capital, all of which attract different investors from higher risk, higher reward projects. RAB models therefore command a lower cost of capital which helps drive down the overall costs of delivery. The RAB model could also help to attract bids which include strong operational expertise.

In our proposed RAB model, the GB regulator for electricity and natural gas markets, Ofgem, could economically regulate the T&S assets through the grant of a licence for CCUS T&S and would determine the T&S fees for the T&S licensee through a system of regulatory building blocks set out in the licence.

Through primary legislation[70] there would be a duty on the regulator to ensure that the licensee (the T&S provider) is able to finance its functions. This would include the design, construction, financing, operation, maintenance and decommissioning of the T&S assets, including its monitoring obligations.

During the construction phase and the first five years of operation the building block methodology would be fixed in the licence. After that initial period, the regulator would carry out periodic reviews and, if necessary, adjustments to the T&S fees. This would allow for the T&S licensee to manage and respond to risks that may arise in the T&S sector or to expand the T&S network, while also ensuring that the costs to consumers are as low as possible.

The T&S fees would be calculated on certain building blocks and adjustments which would be set out in the T&S provider's licence.

70 We have not fully explored the extent to which the same result may be achieved without the need for primary legislation and so have presented the more conservative view here

Proposed formula for T&S fees

T&S fees = (RAB x WACC) + Opex + Depreciation + FCA + Tax + Decommissioning + Additional T&S Fees + Adjustments.

This formula would include:

- **RAB:** the regulated asset base, being the forecast capital cost of the project incurred by the T&S licensee in creating the assets during the construction period;
- **WACC:** the weighted average cost of capital for the T&S licensee, made up of the weighted average cost of the debt and the equity, to the extent possible determined by competition (to ensure attraction of providers with operational expertise) or, in the operational periods, as determined by the regulator;
- **Opex:** the costs incurred by the T&S licensee for the operation of the T&S assets, including operating, maintenance and management costs, costs of regulatory compliance, insurance costs and other similar costs associated with the operation of T&S in the operational phase such as monitoring;
- **Depreciation:** a sum to account for the depreciation of the closing value of the RAB following construction over the useful economic life of the assets, which creates a revenue stream for the amortisation of any financing of the capital cost;
- **FCA:** a financing cost adjustment to protect against movements in the market cost of debt during the construction period; during the operation period embedded debt would be taken into account by the Regulator;
- **Tax:** an allowance for the tax liabilities of the T&S provider, including business rates;
- **Decommissioning:** an allowance for the costs of decommissioning the assets after the closure of the store;
- **Additional T&S Fees:**additional capex to be logged onto the RAB for expansions of the system (for example the drilling of additional wells for injection, additional capacity, pipeline spurs to new Feeder projects, or shipping for development of overseas services); and
- **Adjustments:** including a reconciliation adjustment to update the RAB for actual expenditure such that T&S licensee's revenues are corrected from the amount earned on the forecast RAB to the amount which should have been earned on the actual RAB and to implement any of the incentivisation mechanism (if any).

9

CASE STUDY

NET Power

Having such a policy in place and a clear roadmap for the actions the industry and Government will take and how deployment will be rolled out (including a well developed timetable) will give industry the level of certainty it needs to bring forward its business plans for the clusters.

NET Power is a partnership between three companies[71] who have financed a 50MWth demonstration plant in La Porte, Texas to test a new natural gas fuelled power system which will emit near zero emissions into the atmosphere. The NET Power plant employs a new type of power cycle called the Allam Cycle, which uses high-pressure CO_2, instead of steam or air, as the working fluid to drive a combustion turbine. The CO_2 that NET Power plants generate is high pressure, high quality, and ready for pipeline transportation and storage.

The objective of the NET Power plant is to produce large quantities of electric power from carbon containing fuels with near to 100% capture, at the same cost as the best technology unabated plants using natural gas or coal. NET Power achieved first fire of its demonstration plant in May 2018, a critical step for demonstrating the operability of this new system.

In addition to testing the Allam Cycle, one of the NET Power partners, 8 Rivers, is developing a process which would produce low cost pure high-pressure hydrogen for clean power generation and transport fuel.

How does it work?

The Allam Cycle uses an oxy-combustion process (oxygen separated from air) to burn the fuel with pure oxygen. The CO_2 produced in this combustion is recycled back to the combustor multiple times, producing a working fluid of concentrated, high-pressure CO_2.

The use of CO_2 as the working fluid allows much higher efficiency than either steam-based cycles used in existing coal-fired stations or air and steam used in natural gas combined cycle stations, which results in less CO_2 produced per kW/h and less CO_2 to sequester. It produces only electricity, liquid water and pipeline-ready CO_2 (which can then be transported and stored). As carbon capture is part of the design of this process, the plant does not require extra capture equipment.

NET Power's 50MWth demonstration plant in La Porte, Texas, which began testing in early 2018

Photo courtesy of NET Power and CB&I

71 Find out more about this case study at: https://www.netpower.com/

Electricity projects

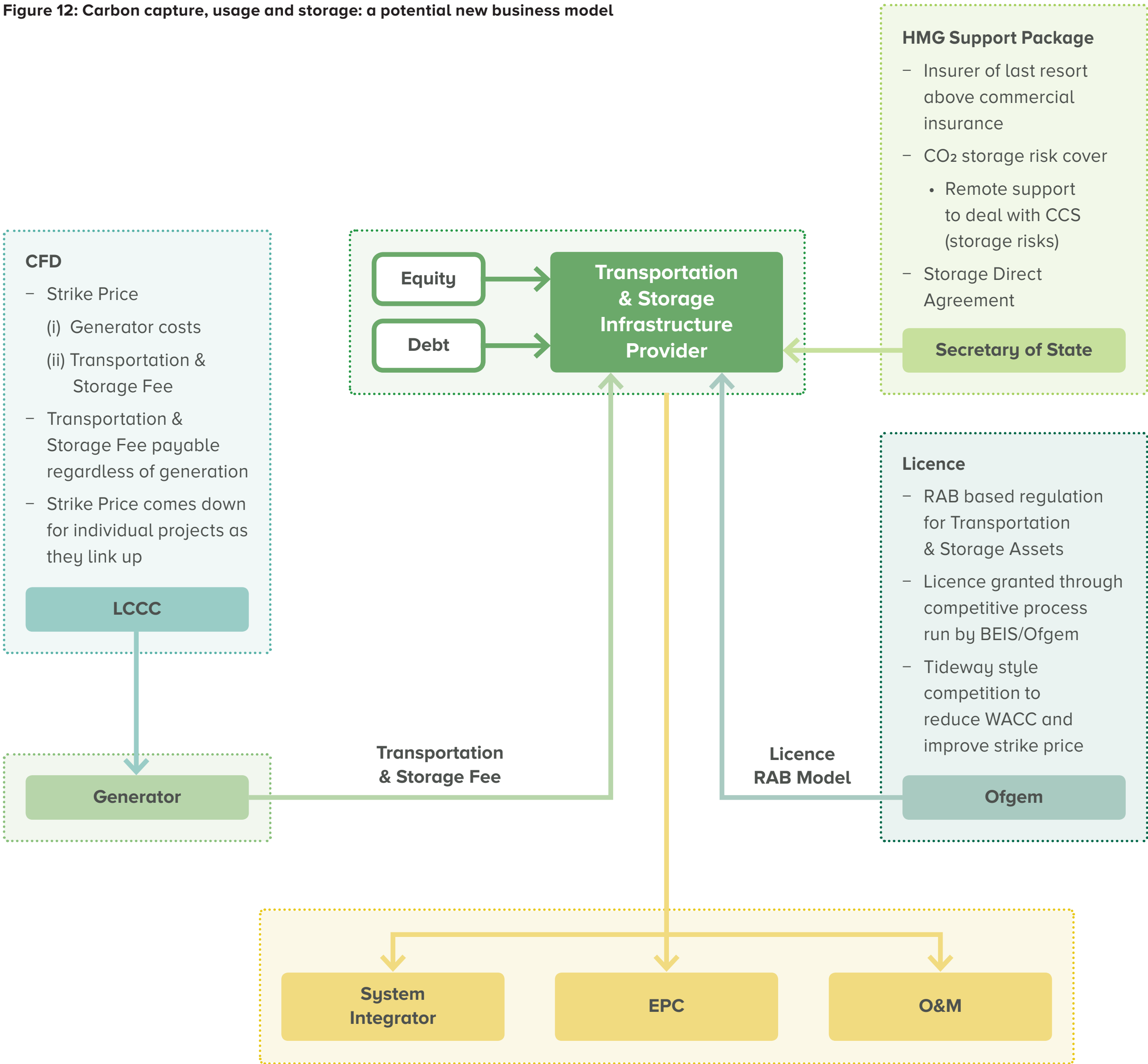
Those capture projects which are electricity generating ones could be supported using the existing CFD mechanism (or any equivalent mechanism that may be introduced in the future).

The *Energy Act 2013*[72] provides the legislative foundation for the CFD regime and sets out that for CCUS, CFDs can only be awarded by the Secretary of State for BEIS (i.e. through bilateral negotiation rather than competitive auction). In the future, Government should consider whether CFDs for CCUS projects could be awarded through a competitive process. In addition, the CFD model could be adapted to incentivise flexible generation through allowing targeted revenues.

The CFD strike price for CCUS would need to reflect the cost of capture and generation as well as the project's relevant proportion of the T&S fee. However, the T&S fee could be a separate pass-through element of the overall revenues and not part of the CFD strike price. By separation of the T&S enabler from the capture project, the T&S fee would flex on a pass-through basis as a separate element in the CFD revenue payments. This model is represented in Figure 12.

72 Energy Act 2013 http://www.legislation.gov.uk/ukpga/2013/32/enacted

Figure 12: Carbon capture, usage and storage: a potential new business model



Industrial projects

In order to meet decarbonisation targets while continuing to grow the economy, there is an urgent need to incentivise energy intensive industries to decarbonise. This is likely to rely heavily on CCUS for a large number of energy intensive industries[73].

There is no incentive mechanism to support industrial decarbonisation through CCUS, although tax legislation in force in the United States could provide a useful model. This regime incentivises capture and the storage and use of CO_2 by industry (also known as 45Q) by providing, over a 12-year period, tax credits of $50 per tonne for CO_2 which is geologically stored, and $35 per tonne for CO_2 which is utilised. The International Energy Agency argues[74] that 45Q is an important example of how the implementation of well-placed legislation can, at a low cost to the taxpayer, dramatically increase the viability of the CCUS industry, with approximately $1 billion of possible further capital investment in carbon capture projects anticipated by 2026.

Although other business models should also be considered by the Government's Review of CCUS Delivery and Investment Frameworks, a similar tax incentive system could be implemented in the UK aimed at energy intensive industries. The benefit of this approach is that no funding is required until projects are capturing and permanently storing or utilising the CO_2[75].

We also suggest enhancing competitiveness of low carbon industrial products through developing a decarbonised product mark (see Part C: Implementation). Once this is fully implemented, the support from the tax credit could reduce in line with the value attributed to these low carbon products by the consumer.

Greenhouse Gas Removal technologies

We recognise that GGRs are likely to play a crucial role in tackling climate change, and that there is no existing mechanism which incentivises their role in providing negative emissions. We do not propose a business model in this report, but propose that further work is conducted by Government, industry, and academia to develop an appropriate business model which could support the development and deployment of GGRs in the UK.

R ***Recommendation: Government to respond to the Taskforce recommendations for the implementation of new business models for CCUS through the Review of Delivery and Investment Frameworks.***

73 Committee on Climate Change, 2018. An independent assessment of the UK's Clean Growth Strategy: From ambition to action

74 Bennet and Stanley, 2018 (online) US Budget bill may help carbon capture get back on track. Available at https://www.iea.org/newsroom/news/2018/march/commentary-us-budget-bill-may-help-carbon-capture-get-back-on-track.html Accessed 29/06/18

75 For example, a tax credit based on a price per tonne of CO_2 stored. The price per tonne would need to be sufficient to cover both the cost of implementing CCUS and paying the T&S fee. This could be coupled with local or regional tax policies (in CGR Zones) to assist in the attraction of new industry

Hydrogen projects

The UK is highly dependent on gas for heating with over 80% of homes heated this way[76]. National Grid's Future of Gas report highlights the potential for replacing methane in the gas grid with hydrogen, either in full or as a blend (up to 15% hydrogen)[77]. However, we recognise there is currently no broad consensus on the best route to long term heat decarbonisation.

The CO_2 captured in the creation of hydrogen from natural gas would need to be transported and stored, paid for through the T&S fee. The costs of hydrogen with CCUS assets would include (i) the cost of the capture technology separating the CO_2 from the hydrogen, (ii) the T&S fees for disposal of the CO_2, and (iii) the network piping the hydrogen to link up with transmission or distribution networks.

The CFD mechanism in the electricity market spreads the cost of decarbonising power across all electricity users nationally. To minimise the impact on gas users a similar approach could be taken for decarbonising heat and funding hydrogen assets. The alternative would be to include the costs of the hydrogen plant and attendant pipework in the regulated asset base of the relevant regional gas distribution licensee.

We recognise that for hydrogen heating projects seeking to take financial investment decisions shortly, there may need to be shorter term measures such as funding through the RIIO-2 mechanisms as part of gas distribution networks. An exemption would also be required to the Gas Safety (Management) Regulations (GS(M)R)[78] specification to enable a higher blend of hydrogen to be included in the gas distribution and transmission networks.

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

R ***RECOMMENDATION:*** *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.*

Hydrogen with CCUS can also support decarbonisation in transport, industrial processes and power. For example, in transport hydrogen could support decarbonisation across:

- **Shipping:** Decarbonisation of shipping presents a significant opportunity for innovation and creation of new hydrogen industries. Norway is currently considering the development of hydrogen powered ships.
- **Buses/fleet cars:** Hydrogen fuel cells are already being used in buses (in Aberdeen and London) and taxis (Green Tomato Cars).
- **Trains/ HGVs:** Hydrogen trains are already in production for the German networks, and Japan is looking at hydrogen for HGVs, which could provide an alternative to electrification.

76 Committee on Climate Change, 2016. Heat in UK Buildings Today

77 National Grid, 2018. Future of Gas: How gas can support a low carbon future

78 Gas Safety (Management) Regulations 1996 http://www.legislation.gov.uk/uksi/1996/551/made

10

CASE STUDY

H21 Leeds City Gate

Key benefits/aims

The H21 Leeds City Gate project confirmed that UK gas distribution networks can be converted from natural gas to 100% hydrogen incrementally from 2026. The project showed a pathway to fully decarbonising heat across the UK in the domestic, industrial and commercial sectors to a level commensurate with the Climate Change Act obligations. Such a conversion would also support decarbonisation of transport and electrical generation.

The H21 project has an extensive global interest and has formed the basis of all other gas network projects as well as the UK Government's 'Hy4Heat' and the UK Gas Industry's 'H21 NIC' £25m and £15m projects respectively.

How does it work?

Hydrogen for a city the size of Leeds would be produced using natural gas in four steam methane reformers with a combined capacity of 1.0 GW. This is equivalent to 6.4TWh of annual energy for heat with 1.5 MtCO$_2$ captured and stored safely each year. The H21 project has built on the extensive work of the Teesside Collective in considering building CCUS infrastructure off the North-East Coast, which could also be used by this major industrial cluster. Where possible, reuse of existing North Sea infrastructure would be considered to further minimise costs.

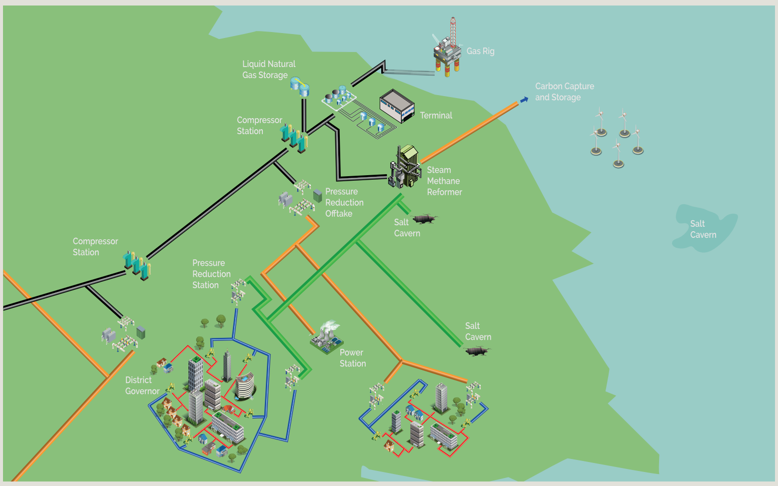
The H21 project shows how incremental conversion of all UK cities over time allows stepping stones to scaling CO$_2$ storage as more cities covert to Hydrogen. This provides significant cost reductions through economies of scale.

How does this project meet the CCTF aims on value of CCUS and the cost challenge?

The H21 project creates a low risk strategy for scaling CCUS deployment in the UK whilst decarbonising heat to a scale commensurate with climate change obligations. Benefits include:

- *Primarily decarbonising heat (domestic, industrial and commercial) but with potential to supply hydrogen for power generation and transport;*
- *Maintaining long term choice for customers (gas or electric heating); and*
- *Creating new employment opportunities and a supply chain for decades to come.*

Figure 13: Overview of the H21 Leeds City Gate project



Innovation to drive CCUS costs down and increase revenues

Technological innovation and creating new markets

The UK ranks in the top five in the Global Innovation Index[79]. Clean industrial growth, enabled by CCUS, gives the UK the opportunity to move even further up the ranking.

The UK has centres of outstanding engineering, delivery, technical and academic excellence. This resource base of skills, expertise and knowledge can be channelled to develop and sustain a highly competitive CCUS industry. The creation of new industrial products which capture and use CO_2 can create new revenue streams, new markets and new export opportunities.

With our cluster-centric approach, innovation can be incubated around the regions working on different CCUS projects.

CCUS technologies: areas for potential cost reduction, productivity gains and new technology options

- **CO_2 capture technology:** key is combination of capture materials with lower regeneration energy requirements combined with improved (intensified) process devices which lower capex and opex.
- **CCUS processes:** new processes designed to vastly reduce or eliminate the energy penalty of regenerating CO_2 from a captured state and/or to operate the capture process at pressure, eliminating compression costs.
- **Industrial transformation:** there are significant innovation opportunities for decarbonisation that would unlock revenues and utilisation for the CCUS projects. One of the most important areas for development concerns hydrogen and the Government's policy on the decarbonising of heat and transport. There are also important decarbonisation ambitions needed for cement, steel and other high energy users.
- **Utilisation innovation:** CO_2 use is currently widespread but not yet seen as economic. The creation of new products through new uses for CO_2 should be encouraged and the Government and industry should work on creating a pull factor to increase demand for decarbonised products and services.

R ***RECOMMENDATION:** Industry to foster sharing of innovation in technologies and processes in line with the foundations set out in the Industrial Strategy.*

Figure 14: Championing innovation at each CGR Zone

Clean Growth Regeneration Zones

The Industrial Strategy outlines five key productivity drivers: ideas, people, infrastructure, business environment and place. To best harness this, Government, or regions under their own initiatives, could develop CGR Zones, as recommended by the Green Finance Taskforce Report, with a CCUS focus[80]. The CGR Zones can support the Government's decarbonisation vision by anchoring investment into CCUS clusters, thereby boosting jobs and skills in those regions. These can be identified in the Local Industrial Strategies as responsible for championing innovative techniques to reduce costs and drive up benefits.

79 Dutta et. al. (Eds), 2017. The Global Innovation Index 2017

80 Green Finance Taskforce, 2018. Accelerating Green Finance: A report to Government by the Green Finance Taskforce

11

CASE STUDY

Carbon Capture Machine: Carbon capture and use in action

Carbon Capture Machine (CCM UK) Ltd[81] is a research-led CO_2 utilisation company that is commercialising CCU process technology which converts CO_2 into saleable products. CCM (UK) is the only European finalist in the $20 million NRG COSIA Carbon XPrize competition, and as part of this competition is currently building a pilot plant in Wyoming.

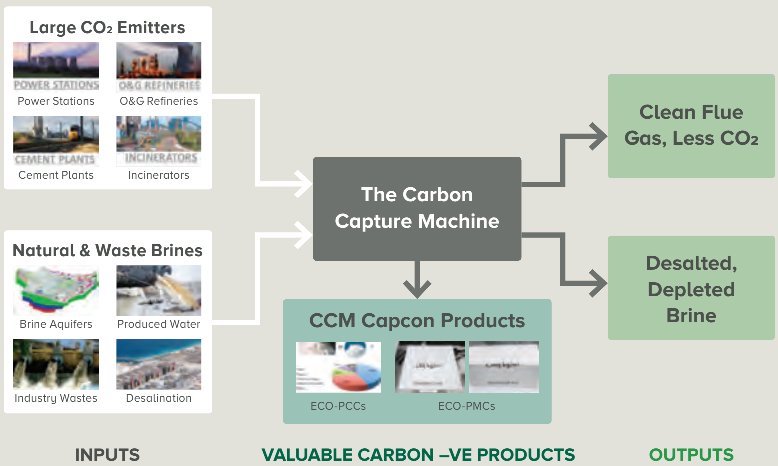
How does it work?

The Carbon Capture Machine (CCM) removes CO_2 from combustion gas streams and converts the gas to stable and permanent mineral products. These replace traditional carbon-intensive products. Examples include Precipitated Calcium Carbonates (PCCs) and Precipitated Magnesium Carbonates (PMCs), which are used to make new products such as fireproof insulations and replace traditionally produced carbonate in a wide range of industrial applications (e.g. pigments, food supplements, and paper making). This technology can enable utilisation of CO_2 as part of a circular carbon economy.

How does this project meet the CCTF aims on value of CCUS and the cost challenge?

CCM is key for showcasing UK CO_2 utilisation technology and the UK's leadership in CCUS as well as the potential of innovation to reduce costs.

Figure 15: Carbon Capture Machine at a glance



81 Find out more about this case study at: https://ccmuk.com/

BOC Teesside hydrogen plant

Photo courtesy of The Linde Group

Implementation of CGR Zones could include:

- A CCUS cluster which includes a clear commitment to innovation and utilisation of CO_2 alongside the development of T&S and Catalyst and Feeder projects.
- Setting up multi-disciplinary teams of innovators in each cluster to co-ordinate cost reduction trajectories and build greater financial resilience for the CCUS cluster.
- An oversight body which coordinates the development of CCUS projects at cluster locations based on the greatest and widest value that can be achieved and harnessing the needs and expertise of the customers (i.e. those that will benefit from a project being developed in the region) and supply chain in that region.
- Local incentives such as business rate reductions, a product “mark” that distinguishes a product as low carbon and fast-track options for procurement and planning activities.
- Co-ordinating with national and international knowledge sharing initiatives such as the Global CCS Institute to co-ordinate local, national and international CCUS developments and sharing the latest best practice information to accelerate uptake of CCUS solutions.
- Sharing international best practice in conjunction with the Foreign & Commonwealth Office, Department for International Trade and international partners through international agreements and collaboration partnerships, enhancing the UK’s global leadership on climate change.

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

Innovation of the regulatory landscape

As the CCUS sector develops, there are opportunities for industry and Government to work together to develop world leading standards for new decarbonised industrial products and export this regulatory, legal, and financial expertise to countries looking to develop CCUS. The cross sectoral applications of CCUS also give an opportunity for cross-sector regulatory collaboration.

The UK can lead in enabling the decarbonisation of cross-cutting sectors through use of CCUS (such as heating and transport via low carbon hydrogen). How this is regulated will be key and we suggest it could be directed by a UK-wide oversight body responsible for ensuring overall efficiency, cost-effectiveness, and fairness as is suggested for decarbonisation of heat by National Grid in the Future of Gas report[82]. This body would further analyse the following:

- Government's heat & transport strategies with a hydrogen component.
- Introduction of CO_2 credits or another regulatory incentive for avoided CO_2 emissions that would drive businesses to invest in a cluster, such as we have proposed for industrial CO_2 capture projects.
- Carry out studies on extending the producer responsibility principles from the waste sector to apply to CO_2 emissions.
- Introducing procurement criteria to encourage use of low carbon industrial products.

While such policies may appear ground breaking, starting the debate around these regulatory measures would provide a clear horizon to unlock revenues for CCUS, accelerate decarbonisation and provide industry with a clearer trajectory. The debate around these issues will also drive greater innovation within industry.

R ***RECOMMENDATION:*** *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.*

Decarbonised product mark

Our heavy industries are already under pressure from their customers to reduce their carbon emissions. To accelerate decarbonisation, it is crucial to build new business models around decarbonised products[83] and services and create a pull factor to increase demand for these. A new industry led, and Government supported, accreditation scheme for all decarbonised products or services could build on the EU's Green Public Procurement[84] proposals and identify the UK as leading on low carbon development while unlocking business investment into new low carbon options such as CCUS.

With the value that CCUS offers for the industrial sectors, the UK can lead in developing decarbonised steel, cement, lime, chemicals and other product models. We can build the new low carbon standards in these sectors and develop a compelling and coherent branding for low carbon industrial products and services – a decarbonised product mark – offering a unique selling point of decarbonised products. Once established these can be marketed to drive new sources of revenues as customers see the enhanced value of transparency around their purchasing choices. This builds on the recommendation in the Green Finance Taskforce to establish a Green Investment Accelerator.

R ***RECOMMENDATION:*** *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.*

Delivering the Taskforce's key messages

A "CCUS roadmap" of enabling actions is needed

The Taskforce's view is that Government needs to set out a CCUS roadmap to support its commitment to deploying CCUS in the UK. Our view is that innovation, cost reduction and learning will come from an industry and Government galvanised around a clear goal to be achieved by a specified time.

The Deployment Pathway publication, to be published by the end of 2018, should include a roadmap developed jointly by industry and Government to show how CCUS can be developed and deployed across the different sectors, by providing clear pathways and enabling mechanisms to be put in place up to 2030.

R ***RECOMMENDATION:*** *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.*

82 National Grid, 2018. Future of Gas: How gas can support a low carbon future

83 We use the phrase 'decarbonised products' broadly to cover decarbonised electricity, heat and hydrogen as well as materials from decarbonised industrial processes such as cement and iron and steel

84 European Commission (online) Green Public Procurement. Available at http://ec.europa.eu/environment/gpp/index_en.htm Accessed 29/06/18

Glossary

BEIS – the Department for Business, Energy and Industrial Strategy

Capex – capital expenditure or investment

Catalyst project – first capture projects in a regional cluster that will anchor the T&S enabler to that regional cluster

CCC – Committee on Climate Change – an independent, statutory body established under the Climate Change Act 2008 to advise the Government on emissions targets and progress made in reducing greenhouse gas emissions

CGR Zone – clean growth regeneration zone

CO_2 – carbon dioxide

CFD – contract for difference established under Energy Act 2013

CCUS – carbon capture usage and storage

EOR – enhanced oil recovery

Feeder project – follow on capture projects in a regional cluster that will feed into the T&S enabler at that cluster

GGR – greenhouse gas removal – technologies that remove greenhouse gases from the atmosphere

IPCC – the Intergovernmental Panel on Climate Change

LCCC – Low Carbon Contracts Company, the counterparty to the CFD contracts and manager of those contracts

LCOE – levelised cost of electricity

Mt – million tonnes (or megatonnes)

MTPA – million tonnes per annum

MWh – megawatt hour

NPV – net present value

Opex – operational expenditure or investment

OGA – the Oil and Gas Authority, a government company that works with Government and industry to regulate, influence and promote the UK oil and gas industry

NPS – National Policy Statement, as may be applicable to planning policy for England and Wales

R&D – research and development

RAB – regulated asset base – as described in Part C: Implementation

RIIO-2 – Revenue=Incentives+Innovation+Outputs (RIIO) is the price control for the network companies running the gas and electricity transmission and distribution networks. The RIIO-2 period is due to start on 1 April 2021

T&S – transportation and storage parts of CCUS infrastructure

T&S enabler – first CO_2 transportation pipes and CO_2 stores in a CCUS transportation and storage hub into which future projects can connect

WACC – weighted average cost of capital

Membership of the CCUS Cost Challenge Taskforce

Members of the Taskforce:

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Allan Baker – Société Générale

Angela Whelan – Ecofin Foundation

Aniruddha Sharma – Carbon Clean Solutions

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Paul Booth – Tees Valley Combined Authority

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Delivering Clean Growth:

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