OPTIONS TO INCENTIVISE UK CO2 TRANSPORT AND STORAGE

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EXECUTIVE SUMMARY

A need for broader policy support for CO_2 transport and storage

This report summarises the findings of a major research project, commissioned by The Crown Estate to investigate barriers and market inertia to the development of Carbon Dioxide Transport and Storage (CTS) infrastructure, to recommend solutions and fully understand the potential value that such actions can realise.

At the moment carbon capture and storage as regards full scale deployment for power generation is globally still in its infancy, particularly in demonstrating full-chain projects. The UK Government announced in April this year its intention to take forward two preferred projects under its commercialisation scheme to FEED studies with the aim that these would be amongst the world's first such projects.

Both of the commercialisation programme projects will be remunerated along similar lines to the CfD FiT and Carbon Price Support (CPS) envisaged for other low carbon generation technologies under Electricity Market Reform (EMR).

Both CfD FiT and CPS focus on the investment risks involved in power generation projects. However this approach only partly alleviates risks for Carbon Capture and Storage (CCS) projects – at the level of a full chain scheme and for the generation part of them. Transport and permanent storage of CO_2 faces a number of different issues quite different from those in power generation.

The current regime is likely to result in 'point to point' CCS projects which will suffer economically from having expensive transport and storage systems – yet it is clear that the costs would be dramatically lower if there was a mature infrastructure in place.

This report concludes that under the current regulatory and policy framework sector, development of the industry is likely to be slow, relying on uncoordinated deployment of full chain integrated projects that do little to promote a common transport infrastructure or the development of storage hubs.

Understanding the causes of high early stage costs and developing ways to overcome these are the key objectives of this report. In the absence of further interventions there are significant risks that there will be a tendency to:

- Develop smaller stand-alone projects;
- Only roll out CCS projects at a slow rate; and,
- Realise extremely slow growth of industrial non-power CCS projects.

Unless addressed these risks and market failures are likely to severely restrict the development of CTS infrastructure and hence the future CCS industry.

Several Market Failures stand in the way of development of a mature infrastructure

A series of workshops with industry representatives provided comprehensive background to the various sources of market failures impeding the development of CCS infrastructure. It is clear that there are many, and that these are not well addressed by the government's EMR framework and associated support mechanisms.

CCS projects face a particular combination of characteristics that make the investment proposition relatively unattractive and costly for utilities and financiers:

- Its immaturity as a sector as well as certain elements of the technology being at an early stage of development;
- High capital intensity in each element of the chain, with very specific function and location and long lead times; and,
- Dependency on policy support at a time when the path and direction of decarbonisation policy itself is quite uncertain – even more markedly at a regional level

Where these give rise to particular inefficiencies in the allocation of resources if the market is left to its own devices they create market failures.

The project identifies and concludes that there are a number of risks and market failures facing the CTS sector. Capture, Transport and Storage of CO_2 differ by industry type, risk/return profile and their development stage and must therefore be tackled appropriately. Unless addressed these risks and market failures are likely to severely restrict the development of CTS infrastructure and hence the viability of CCS as a future decarbonisation option.

The following risks and market failures appear to remain unaddressed by the current EMR framework:

- **Capital market issues** leading to high costs and low availability of both equity and debt due to financial restrictions and competition with other investments.
- **Missing markets** lead to a lack of pricing signals and could delay longer term roll-out if sufficient markets in CO_2 transport and storage do not develop after the CCSCP.
- **Lack of public knowledge** and acceptance could create significant project delays.
- **No strong carbon price signal in non-power industrial sectors** or market drivers for revenue leading to a very low take-up of low carbon technologies.
- **Co-ordination failures** leading to a need to develop novel business structures and a tendency to develop smaller stand-alone projects due to:
  - **access risk** to transport and storage for power stations;
  - **volume risk** for transport and storage networks and hubs;
  - **development risk** particularly for aquifer storage projects due to the long-development lead times.
- **Local market power issues for both transport and storage** meaning the cost charged for CO_2 transport and storage could be higher than would be optimal, discouraging the development of otherwise attractive new projects.
- **Exploration spill-overs (externalities)** exist such that that the volume of storage that is appraised is likely to be less and later than would be optimal for the long-term development of the industry.
- **Imperfect and asymmetrical information on storage sites** mean that project developers are likely to be cautious when developing storage sites as the performance and long-term viability of the site is unknown.

The analysis contained within this report indicates that without further intervention the current proposed regime will not lead to the development of a mature low carbon power generation industry within two decades and consequently removes a significant option from the potential energy system portfolio.

Encouraging an industry from its early stages through to full commercial deployment requires a dynamic set of policies that evolve in parallel with the industry's maturity. We can take a lead from several other industries, such as waste-to-energy and district heating that have successfully used such measures.

Early phase interventions that look to tackle the industry's current challenges are the priorities. Interventions that focus on the specific risks faced by the sector will need to be addressed immediately to ensure that projects currently under development can continue and the industry can continue to grow.

Our analysis concludes that early phase interventions that look to tackle the industry's current challenges are the priorities. Interventions that focus on the specific risks faced by the sector will need to be addressed immediately to ensure that projects currently in the pipeline can continue and the CCS industry can continue to develop. Choices made for the initial package of interventions will have a strong influence on whether or not the industry can progress through the policy gateways enabling it to be deployed at scale.

Early actions to set the development of the transport and storage infrastructure on a virtuous cycle of development

Our analysis and the outputs of the stakeholder workshops conclude that delivery of interventions requires a coordinated effort amongst a range of stakeholders. While Government has a key position, industry and The Crown Estate have an important role to play in implementation. Identified early stage intervention actions include the following:

Financial incentives

As transport and storage components suffer from being at the 'downstream' end of the CCS chain, mechanisms that provide revenue streams directly to them can greatly improve their development:

- Capital Grants targeted at storage characterisation can lower investment risk for storage developers by counteracting coordination failures; they can encourage exploration and development of larger or shared storage sites by compensating for spill-overs from exploration that derive from the wider market, and they can enhance access to information on storage sites to address the current issues of imperfect and asymmetric information.
- CO_2 purchase guarantees by Government can help overcome potential coordination failures faced by early transport and storage developers as well as helping develop shared infrastructure.

These could be sourced by redirecting funds from the CfD FiT mechanism.

Tax breaks

In order to bring more capital into the sector, especially from the highly related oil and gas industries, tax breaks have much promise.

- Broad tax breaks via tax credits could be used against tax paid on income from outside the CCS sector; and,
- Targeting tax break for Enhanced Hydrocarbon Recovery

Historically such devices have been used in a dynamic way to reflect the evolution of an industry.

Market creation

Lack of a market in the commodity of transport and storage means it is harder for new entrants to value their projects and leads to high market entry barriers. Two interventions are particularly relevant to this early stage of CCS development:

- Creating a market for leakage liability insurance (possibly by a similar pooling arrangement to the nuclear industry) to lower the risks and insurance costs for storage owners; and,
- Running competitive leasing rounds analogous to those in the offshore wind industry to start to establish demand and greater certainty for storage.

Knowledge generation

While knowledge generation interventions focused on R&D spending, and Health and Safety will bring benefits, public engagement and guidance programmes will bring clear value to the immediate challenges of delivering CCS projects as well as benefits in the longer term.

Clear benefits to UK and industry

No single measure alone will be sufficient to deliver the necessary development of the CTS sector in the UK, and a suite of interventions in parallel will be required.

DECC's scenarios for the development of CCS cover a very wide range of outcomes, but there is significant potential to influence the industry towards the higher deployment scenarios.

Higher deployment scenarios can have transport and storage costs around 40% lower than low deployment scenarios and can potentially lower the cost to government of reducing CO_2 emissions through CCS by 15% to 30%.

Actions taken now, although not likely to change the costs of the early projects, can set a landscape to drive to a lower cost path in future phases of deployment. Such a lowering of costs would provide a positive feedback cycle – leading to more deployment, and then further lowering of costs through decreased risks and economics of scale.

Our analysis concludes that delivery of the interventions requires a coordinated effort amongst a range of stakeholders. While Government has a key role to play, industry and The Crown Estate have an important role to play in implementing the interventions identified.

1. INTRODUCTION

1.1 Preamble

Removing environmentally damaging components of industrial processes and rendering them safe has been a feature of industries all over the world since the Industrial Revolution, and it is now completely commonplace for industrial plant to abate environmentally damaging by-products. Over time the recognised list of pollutants has grown as has the technology and practice to deal with them.

In that respect capturing the carbon dioxide from combustion and chemical processes and storing it in a safe place is a natural extension of a long line of additions to industrial processes – a next step in power station design, advances that have successively dealt with emissions of ash dust, sulphur dioxide and nitrous oxides. As it has become clear that there is a need to cut emissions of a particular substance, the industries have carried out the necessary technological development and then progressed through to commonly accepted design and operational practice.

With the clear connection between greenhouse gas emissions and climate change, has naturally turned on to capturing carbon dioxide, its safe and enduring storage. This has not proved to be an easy step – and in particular the challenge on Governments and Regulators around the world to encourage and incentivise its development from laboratory to commonly accepted industrial practice has been difficult.

A growing realisation that the transport and storage components of CCS need special attention – in parallel to the natural focus on power station scale capture of CO_2 – is the theme of this report.

1.2 Potential of CCS

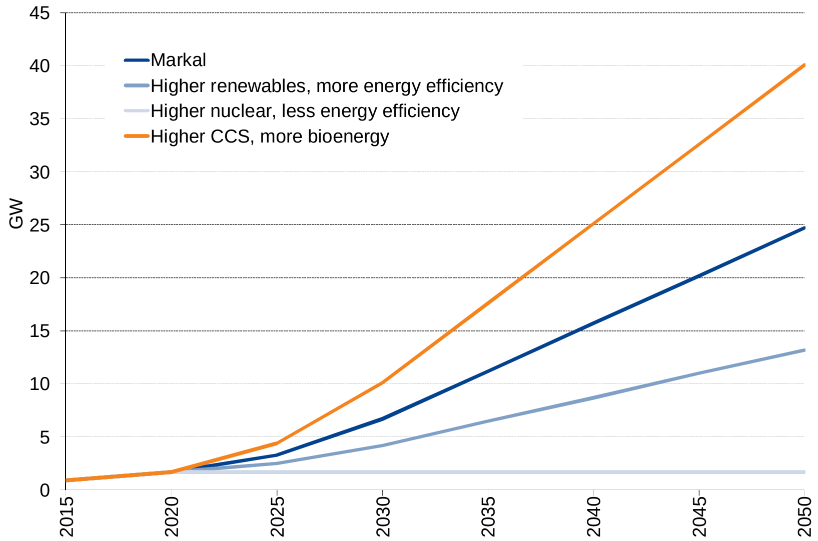
Carbon Capture and Storage remains largely untapped as a valuable technological resource, but many observers and institutions have growing belief in the contribution to society that it could make. In particular three facets of this contribution stand out: mitigating climate change; reducing costs of decarbonisation, and realising value to the UK and The Crown Estate. In this section we briefly describe each of these in more detail.

1.2.1 Mitigating Climate Change

Both DECC and the Committee on Climate Change have included CCS as a technology option in their plans to reduce carbon emissions.

DECC's Carbon Plan shows how the Government aims to meet the legal obligation of the Climate Change Act (2008) to reduce carbon emissions by 80% by 2050. In 2009, the Government set the targets for the first four five-yearly carbon budgets to reach a target of 34% reduction on 1990 levels by 2020. Although the carbon budget draws the line at setting individual targets for different technologies on the basis that their relative costs are still uncertain, CCS is considered a potentially important component as shown in Figure 1. Various scenarios show a range of targets ranging from 2-10GW in 2030 and growing up to as high as 40GW of CCS by 2050.

Figure 1 – CCS deployment (GW) in the DECC carbon plan



Source: DECC

The Committee on Climate Change has responsibilities for monitoring and reporting progress on the Carbon Budgets and its bullishness on the potential contribution from CCS is evidenced in its consistent stance to promote the development of carbon capture. In the CCC's 2012 progress report to Parliament, the CCS noted "…CCS technologies are of crucial importance to meeting targets for emissions reduction in the medium to long term…"

While both DECC and CCC are necessarily focused on the UK's emissions, there is scope for CCS contributing to EU-wide climate change policies. Although the European Commission has largely delegated actions to national Governments, it has taken specific steps through the CCS Directive to facilitate the development of storage facilities and initiated the NER 300 support for demonstration schemes (although the first round did not support any projects, the second call for applications has just been launched).

While many policies focus on the power, heating and transport sectors, CCS is almost unique in its flexibility to help reduce emissions from the industries where there are often no alternative abatement technologies – for example in the cement and fertiliser production processes. Although the power sector dominates the emissions from large point sources (emitting around 185mt in 2011), other large industrial point source CO_2 emissions are still significant at around 50mt in 2011.

1.2.2 Reducing costs of decarbonisation (to consumers)

It is widely accepted that decarbonisation will incur additional costs, and that in some shape or form, these will be borne by end consumers. Particularly when new technologies are under development there is considerable uncertainty about when they will reach maturity and their eventual costs when they do – such projections are even more complicated when entire new infrastructures are required for full roll out, for example with offshore wind and certainly for the pipes and storage facilities of CCS.

Furthermore, within each technology type there is likely to be a point where incremental deployment will involve rapidly increased costs – for example in moving to poorer sites for onshore wind, or solar generators. Inevitably there is, therefore, also a question about which mix of the low carbon technologies can achieve the lowest cost path.

CCS power generation does have the potential to compete with other low carbon technologies. Recent work by the CCS Cost Reduction Task Force has suggested that in its own right CCS for the power sector has the potential to reduce costs to close to £100/MWh[1] by the early 2020s and below £100/MWh shortly thereafter – comparable to the costs of offshore wind, for example.

Various other organisations have examined the value of having CCS in a complementary mix of low carbon technologies. The ETI suggested that the inclusion of CCS in the mix can reduce end customer costs by £35bn per annum (or up to 1% of GDP) in 2050[2].

In a similar fashion the IEA BLUE map scenario suggested that the overall cost of delivering emissions targets consistent with a 2 degree rise in temperature will increase by 70% if CCS is not deployed[3].

It is clear that a strong deployment of CCS has a significant role to play in ameliorating the costs of decarbonisation to end consumers.

1.2.3 Value to UK plc

Over the next decade, the main new technology built to meet renewables and decarbonisation targets in the UK is likely to be wind generation, both onshore and offshore. Inevitably the variable nature of this new wind generation capacity will create additional challenges for maintaining a secure and reliable electricity system, as conventional generation has to be available to take over when there is little wind generation, and switched off when there is a lot of wind generation. There are therefore significant security of supply and network management benefits in the longer-term to introducing alternative, potentially flexible, sources of low-carbon electricity such as abated coal and gas alongside intermittent renewable generation.

Development of the CCS storage resource potential can also add significant value to the UK. Compared to many other countries, particularly in Europe, the CO_2 storage potential for the UK is very large.

The Parliamentary Office of Science and Technology estimates that the UK has the potential to store 20-260Gt of CO_2 whilst the EU Geocapacity Project estimates a lower and narrower range of 14-25Gt. Despite the uncertainty both of these estimates represent tremendous potential for storage – they equate to possible storage of the lifetime emissions of between 200GW and 3,000GW of CCGTs and coal-fired power stations (current UK capacity of coal and gas-fired plant is around 50GW). There is likely to be plenty of surplus capacity to store other countries' CO_2 emissions as well.

Under the 2008 Energy act, The Crown Estate has the right to grant leases for the geological storage of CO_2 in the seabed and is already very actively engaged in the leasing of CO_2 storage. Agreements for Leases (AfLs) are offered by TCE which grant exclusive leases for the permanent storage in certain blocks. The lease itself provides the rights to install, commission, operate and maintain storage infrastructure, and store CO_2 permanently in the permitted storage site. It also provides the time for the tenant to carry out closure, decommissioning and post closure monitoring obligations.

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1 In real 2012 money – UK CCS CRTF Interim Report, November 2012.

2 http://www.ukccsrc.ac.uk/system/files/uploads/George%20Day.pdf

3 http://www.iea.org/publications/freepublications/publication/CCS_Roadmap.pdf

With such large amounts of CO_2 being transported out to storage facilities in the North Sea there is an additional potential opportunity to create a CO_2-based Enhanced Oil Recovery (EOR) programme – using of CO_2 as an agent to flush out additional reserves of oil production as the CO_2 is being moved to store. Although there are costs involved in transporting the CO_2 the additional distance to the oil field and adapting the platforms to use CO_2 many commentators see significant economic potential for North Sea EOR – Scottish Enterprise has estimated that additional oil production could provide £2.7bn value to the UK with increased recovery of one billion barrels of oil.

With the CO_2 actually having a value for EOR, along with the benefits of reduced payments for emissions under the EU ETS, the establishment of a CCS industry creates considerable potential value for UK plc and The Crown Estate.

1.3 Need for conducive development environment

Despite its potential, the CCS industry still remains in the early stages of its development. Although the routine storage and transport of CO_2 in EOR projects is very well established in places like Texas and Alberta, capture from full scale power station and industrial processes is only in its infancy. Other industries have faced similar challenges but with suitably targeted support overcome the technological and economic barriers to reach successful maturity.

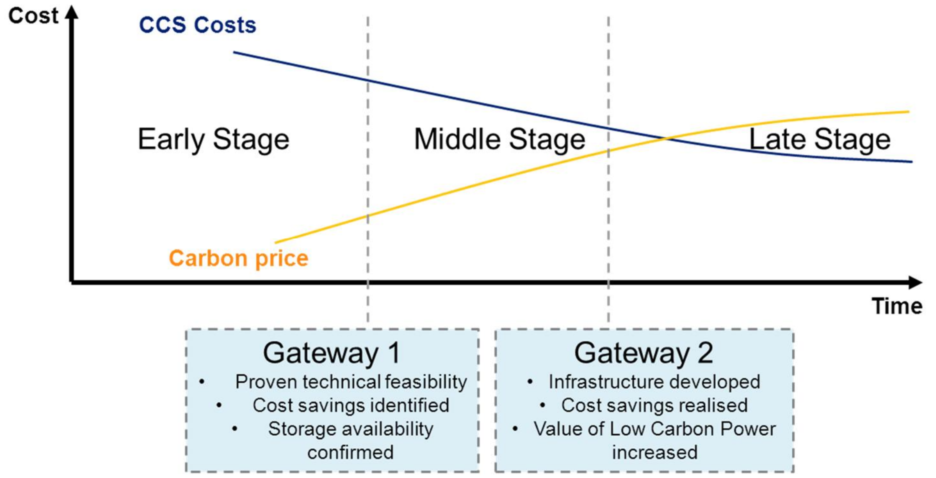
1.3.1 IEA Framework for generic industry development

As this report is concerned with interventions that need to be targeted to the industry as it develops, it is helpful to draw on the framework developed by the IEA which describes three 'lifecycle' stages:

- Early: Technical proving;
- Middle: Targeted deployment; and
- Late: Commercial competitive deployment

They are illustrated in Figure 2 below along with the two "Gateways" that describe the transition between them.

Figure 2 – CCS Industry Lifecycle



Adapted from IEA 2012: A Policy Strategy for Carbon Capture and Storage

As the pace of this progression is uncertain, and to some extent will be influenced both by external market factors; all policy, commercial, and regulatory interventions will need to be tailored in a flexible way.

1.3.2 Current status of CCS in UK and Global

CCS is firmly in the "Early Stage" section of its development in the UK, and in many aspects this also applies on the global stage. Capture technology has not been tested at a commercial scale, the storage capability in the North Sea has been mapped but there is uncertainty over how effective the stores would be in operation, and there is no integrated value chain in operation.

The Global Carbon Capture and Storage Institute tracks the development of large scale integrated CCS projects worldwide. There are currently only 8 projects worldwide that capture and injecting CO_2 into geological formations. All are based around the gas processing or fertiliser industries with the majority based in North America with the CO_2 used for EOR purposes. The first two integrated CCS projects on power stations, Boundary Dam (Canada) and Kemper County (USA), are both located in North America and are due to start operation in 2014.

In Europe, the Sleipner project in Norway is a world leading project in the storage of CO_2 and was the world's first commercial CO_2 storage project. The natural gas produced from the Sleipner West field contains up to 9% CO_2, far exceeding the 2.5% market specifications. For this reason, the CO_2 is removed from the extracted gas at an offshore platform and pumped 1000m below the seabed into the 250m thick Utsira Sandstone Formation.

The CO_2 gas processing and capture unit also serves to evade the 1991 Norwegian CO_2 tax (which would be the equivalent of NOK1 million per day) and enables Sleipner to obtain CO_2 credit for injected CO_2. Since production started in 1996, Statoil has stored over 10 million tonnes of CO_2. The Utsira Formation is estimated to be capable of storing 600 billion tons of CO_2, 3D seismic monitoring indicates that there is no leakage of injected CO_2 into other horizons with the gas remains *in situ*.

Operational experience in the UK is relatively limited, despite many plans. Ferrybridge C, Aberthaw and Longannet power stations have small scale test facilities for capture processes, but there are currently no full scale projects in operation.

The UK government is currently running a Commercialisation Competition for the provision of £1bn in capital funding to support the design, construction and operation of large scale CCS in the UK. In March 2013, DECC announced that two full scale integrated projects were preferred candidates for the £200 FEED study funding which will be awarded in June:

Peterhead

A 340MW post-combustion capture retrofitted to part of an existing 1180MW Combined Cycle Gas Turbine power station at Peterhead, Scotland and involving Shell and SSE with storage at Shell's Goldeneye Depleted Oil and Gas Field (DOGF).

White Rose

Oxyfuel capture project at a new 304MW fully abated supercritical coal-fired power station on the Drax site in North Yorkshire. The project is led by Alstom and involves Drax, BOC and National Grid.

It is not clear yet how many projects will receive funding under the scheme. Final investment decisions (FID) will be taken on the projects in [2014], with the aim of the selected projects entering into operation between [2017 and 2019].

1.3.3 Outlook for CCS under EMR

Inevitably emissions from the power sector will play a major part in any future developments for CCS in the UK and it is worthwhile looking in more detail at the latest outlook in the electricity market.

In the last ten years, some of the key building blocks to help CCS develop in this country have been put in place by the Government – for example reaching amendments to various international conventions (London and OSPAR) and developing appropriate licencing and operating regimes (e.g. for storage, and also setting HSE guidelines).

However, the support regimes for low carbon technologies have, until recently, largely focused on renewables – for example the ROC support mechanism.

EMR represents a major overhaul of the way in which low carbon technologies will be supported, envisaging a future in which such support will be gradually removed as technologies reach maturity.

For CCS the key components of the EMR are:

- Feed in Tariff for low carbon technology, based on Contract for Differences (CfD FiT);
- Carbon price floor – rising over time and setting a minimum price for emitting CO_2 from fossil fuel fired power stations; and
- Emissions Performance Standard (potentially rising to the point where all new fossil power stations will require carbon capture)[4]

This paper analyses and reviews the implications of such a policy framework for developing a mature CCS industry in the UK – but it is obvious, even on cursory inspection, that measures focus on the source of the emissions. We examine the current regime in more detail in Section 2.2.

1.3.4 How regulation needs to evolve as industry grows

Figure 2 illustrated the development of the CCS industry from the stages where it is still being proved technically through a period of targeted deployment and then to eventual commercial and competitive deployment.

At each stage, the industry faces quite different barriers, and it is widely accepted that regulatory environments will need to change and evolve at the same pace as the industry itself evolves. While this might be construed as a source of regulatory uncertainty, and therefore present an additional barrier to investment, history suggests that where there is a clear and common understanding of the points that mark evolution from one stage to another, the industry will flourish. This report documents the many barriers to development of the full CCS chain (i.e. fully including the transport and storage system) and then examines ways in which they can be overcome.

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4 A fourth element of the EMR is the capacity mechanism which will remunerate non-CfD FiT funded plant for the provision of firm capacity. As CCS will be CfD FiT funded for its first 15+ years of operation it is unlikely to be directly relevant.

1.4 Brief overview of the study and approach

Our approach is to first document a full list of the market failures that are preventing CCS reaching its full potential in the UK – for power generation sources, for industrial sources and for Enhanced Hydrocarbon Recovery (EHR). In order to do this we held a series of workshops attended by key industry stakeholders to collect a comprehensive set of issues that the industry faces and to consider possible solutions, including experience outside the sector.

Analogous industries have managed to deal with similar generic problems (for example in developing the infrastructure for district heating schemes) and implemented suitably targeted interventions to achieve success. We have reviewed the most applicable and used these as a source of compiling a potential set of policy and regulatory interventions focusing particularly on carbon transport and storage. The interventions address risks that developers and investors face.

In order to assess the impact of a targeted package of these interventions – it should be noted that the 'package' is a series of interventions that evolves with growing industry maturity – we have developed two industry scenarios to capture a sensible range of industry development given the current policies and commodity prices.

We were then able to assess the additional value created by the source using a sophisticated model, ADAPT CCS, developed during the course of the project that enabled detailed assessment of the impact of alternative policy interventions on the development of the CCS sector. This model is discussed further in Annex B.

It is clear that the benefits from further interventions are significant and robust to alternative developments in the market and worthy of further work to refine them.

The remainder of the report is structured as follows. Section 2 examines the main uncertainties that currently face the CCS sector and the ability of the current policy, regulatory and financial regime to address these. Section 3 draws on the case studies and the stakeholder workshops to assess a variety of intervention options to drive forward carbon transport and storage. Section 4 presents scenario analysis of how these interventions may impact the future UK CCS market. Section 5 concludes by summarising the main project insights and sets out priority implications for stakeholders.

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2. CURRENT CHALLENGES FOR THE SECTOR

The current challenges for the CCS sector were identified through a series of workshops with experts from the CCS and other industries. Our aim was to identify industry characteristics, risks and market failures that are hindering the expansion of the CCS sector in the UK by engaging with a cross-section of experts from The Crown Estate, Pöyry and external parties.

At these workshops the participants agreed that a rapid expansion of the sector is needed for the potential benefits of CCS to be fully realised, but there are many potential barriers that may prevent this from being achieved.

2.1 Characteristics, risks and market failures of the CCS sector

Current CCS industry characteristics and the existing regulatory, policy and financial backdrop for CCS development imply a range of risks for the development of the CCS chain. In particular:

- As an immature sector with certain elements of the technology at early stages of development;
- Each element of the CCS chain (CO_2 capture, transport and storage) is highly capital intensive, with a specific function and location[5] and long-lead times; and
- Dependency on continued policy support when at the same time the future path of decarbonisation is uncertain. Even where there is a strong requirement at a national level, individual projects need regional level certainty to develop large shared networks.

Together, these risks make the prospect of large long-term investments relatively unattractive and costly for utilities and financiers. Where such risks give rise to particular inefficiencies in the allocation of resources if the market is left to its own devices, they form market failures.

Figure 3 summarises the potential risks and market failures identified in the project workshops and noted in several previous policy documents listed in Annex A.

Some of them are general – they are not directly linked to a market failure and apply generically to early stage industries. In Section 2.1.1 below we discuss these more generic risks in relation to the CCS sector.

Several other risks are specific to CCS and, in some cases represent a significant market failure. Sections 2.1.2 to 2.1.4 describe how the following CCS industry market failures impact on the individual parts of the chain; CO_2 Capture, CO_2 Transport and CO_2 Storage:

  - Emission externalities whereby a firm's emissions cause impacts on other parties which it fails to take into account in its decisions;
  - Coordination failures; where one firm depends on another to successfully operate and there is imperfect foresight in planning;
  - Imperfect and asymmetric information; where there is insufficient information to take an efficient decision and the knowledge that does exist is not uniformly held;
  - Knowledge creation spill-overs; where other firms may benefit from one firm's knowledge creation activities;

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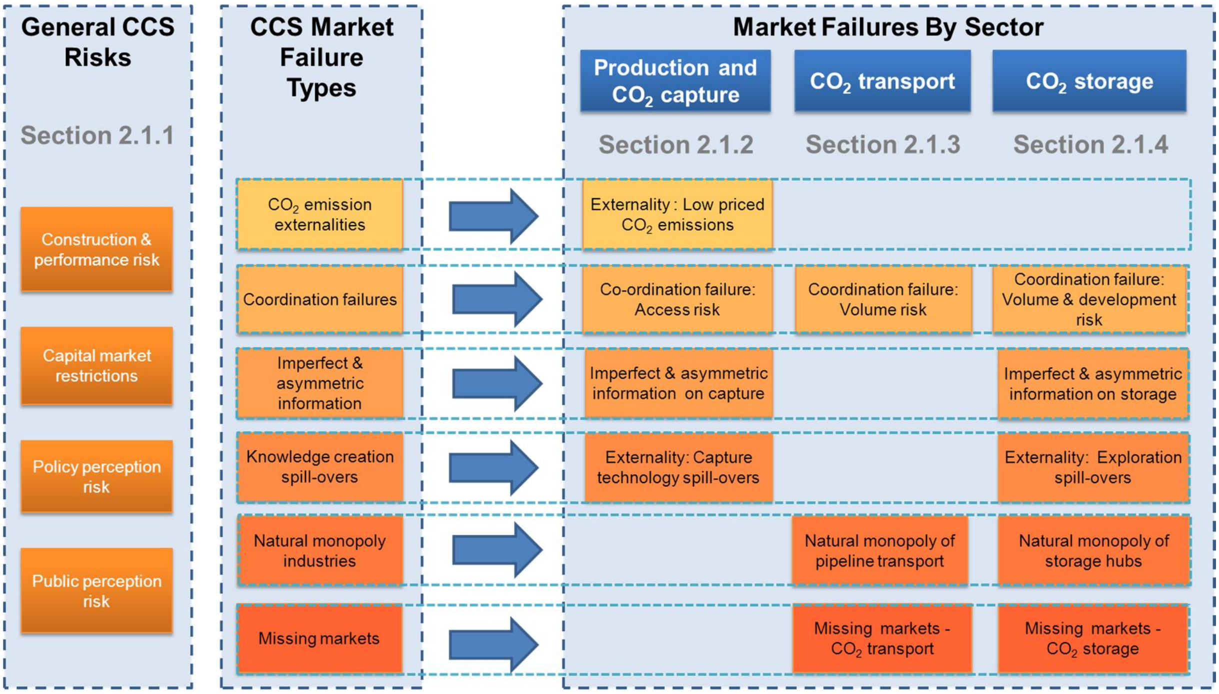
[5] If a good can be utilised for more than one function or moved for use in more than one location it is more adaptable and therefore, all other things being equal, less risky and more attractive to an investor.

– Natural monopoly industries where natural characteristics of an industry such as economies of scale lead few firms to dominate either locally or more widely
– Missing markets; where a market required for the efficient exchange of a commodity does not exist.

Typically the relative importance of all risks and market failures will change over time as an industry develops – this report focusses on those most relevant to the current industry.

Figure 3 – Overview of current risks and market failures in the CCS sector



Conceptually, policy interventions are made to address market failures and so correct inefficient resource allocation in the long-term. In addition, policy may also be aimed at addressing wider industry risks, particularly for immature industries where the Government wishes to accelerate the progression of the industry to shorter timescales than those that would be delivered by the market.

In the next part of the report, we discuss in some detail the many different risks that CCS projects face as a necessary background to possible ways of reducing or solving them. We conclude each section with a short summary of the likely way in which the risk will drive the roll out of CCS away from a far more optimal outcome.

2.1.1 General CCS risks

Technology, construction and performance risks

As it stands at the moment, full-chain CCS is a relatively immature technology and certain elements of the technology involved in it are only at their early stages of development. Whilst each of the individual elements in the chain has been demonstrated independently, there is also limited experience in operating some of the components at the scale and duration involved in an industry-scale project. Experience in running integrated CCS schemes is limited to very few projects, and development of the full chain will involve a complex new value chain with novel business structures and counterparty arrangements.

The immature nature of the technology means considerable uncertainty around the costs and performance of CCS, which can only be reduced by having the experience of building and operating CCS plants of sufficient scale. This extends right across the CCS chain from the capture unit, large CO_2 transport networks and multiple storage sites. Of particular current concern for CCS investors is the performance of CO_2 storage as:

- Site specific characteristics will drive injection rates of wells and the ability to manage potential leakage in sites once they are operational[6]. However, the types of storage are diverse and little information is available for many of them to predict performance reliably;
- There is a wide range of predicted well requirements and reservoir risks identified – realistic chance that many sites and well locations will not actually be suitable on deep analysis.
- The wide range of storage unit sizes and shapes as many sites are very much larger than traditional oil and gas fields. Some units are expected to be vertically stacked, although this has yet to be quantified and the implications assessed in depth.

While increased risks do not necessarily restrict an industry from developing, they do mean that investors will demand higher returns to compensate for the higher risks.

Potential market led outcome: As CCS is still in its infancy, roll-out will be slow until investors and developers are more confident of cost and performance. Early projects will face the most risks and developers are therefore expected to have higher return requirements.

Capital market restrictions

Recent difficulties in global financial markets have hindered the availability of both equity and debt capital, creating an effective rationing of it for investment. This has been most notable for projects that have a reasonably high risk profile (as is the case where capital costs are high and uncertain). As one of these, CCS projects are in a tough marketplace for their finance.

Virtually all large energy companies and utilities that have a strategic interest in CCS, have constrained balance sheet capacity and so limited ability to finance early CCS projects. There is currently no clear strategic advantage for their deployment of CCS to justify such a large commitment of corporate capital.

In addition, new banking regulations have made it difficult for lenders to commit to long term debt finance and in recent years the number of banks providing capital for large scale infrastructure projects has fallen considerably. This poses a further problem because the amount of investment required for each CCS projects will most likely require involvement from a number of syndicated lenders, with the attendant difficulties in bringing them together.

Such failures are not only an issue for CCS, but also apply to other capital intensive investments which have a high perception of risk – for example large scale renewable energy projects (particularly in the US) and new unconventional sources of oil and gas.

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6 It is worth contrasting here the widespread technical view that storage leakage should not be an issue and, on the other hand, widespread investor fears around storage performance and leakage liability. One large element of learning and risk reduction in early projects will involve bringing these viewpoints into greater alignment through the demonstration of a track record of good storage performance.

Potential market led outcome: Limited availability of equity and debt finance for CCS, due to capital restrictions and competition with a broad range of other investments – leads to significantly increased financing costs or an inability to raise funds altogether.

Policy perception risks

Inevitably the CCS industry is reliant on Government support through specifically targeted policies due to the current lack of market drivers for its widespread adoption. For projects to be developed, financial support is needed to ensure that investors can earn a sufficient return on the required billions of pounds of investment.

All investors and developers need clear and demonstrable commitments to CCS to attract the investment required, but at the moment their perception is that support for CCS is less well defined and certain than other sources of low carbon power. A similar situation occurred in the Waste Management Industry in the early 2000's when policy risk, in this case the policy for setting gate fees (payment for taking waste) was too great for companies to invest in Energy from Waste plants, despite their overall economic benefit. The effect of this risk was to stall development of the industry for several years.

Potential market led outcome: Developers shorten their investment horizons, and are unwilling to finance follow up projects or speculative, longer term investments.

Public perception risk

As with other new technologies of a similar nature, public perception can create a significant barrier to project development, particularly through restricting the ability of projects to obtain required licences and consents. One such example is the widespread local opposition to the establishment of Energy from Waste plants in the UK. Although now an established route for waste disposal and governed by strict European led air pollution limits, plant developers still face significant opposition from local residents who associate such plants with incinerators and damaging health effects.

In DECCs latest Public Attitudes Tracker survey 41% of respondents were aware of CCS. However, of those aware only 57% were actually in favour of it as a solution to decarbonising the power sector (compared to 82% for renewables for example). Such public attitude surveys are not conclusive but awareness of CCS should be managed to ensure that it does not become a major hurdle.

The danger of public perception to CCS is clear from the cancellation of numerous CCS projects in Europe due to public opposition: Vattenfall's Jänschwalde project in Germany[7] and Shell's Barendecht project in the Netherlands[8] were both cancelled because of powerful public opposition to onshore CO_2 storage. Although onshore storage of CO_2 is not envisaged in the UK there is still a great need for CCS to be accepted by the public as a legitimate technology for lowering UK carbon emissions.

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7 Germany repeatedly failed to enact necessary national legislation on the implementation of the EU CCS CO_2 Storage Directive due to public resistance to CCS. Vattenfall therefore announced the cancellation of the project which was previously the most advanced in the EU.

8 Barendrecht's town council refused to grant local permits and the Dutch government chose not to overrule in the national interest.

Potential market led outcome: Lack of public knowledge and acceptance of CCS could create significant delays for CCS projects through restricting the ability of projects to obtain necessary licences and consents.

2.1.2 Production and CO_2 capture market failures

Externality: Market failure from low priced CO_2 emissions

When industries face a low price for CO_2 emissions as is currently the case with the EU ETS two related problems arise which mean that the deployment of CCS likely to be lower than would be optimal from a societal perspective:

- The costs of emissions from power stations and industrial sites are much lower than Government estimates of the cost of damage caused by a unit of CO_2 and the additional cost is not directly incurred by the CO_2 emitter but rather by society as a whole. The costs of CO_2 damage are therefore only partially levied on the CO_2 emitter.
- Wholesale electricity market prices reflect the cost of emissions of CO_2 from marginal thermal plant. So when the price of CO_2 is low, wholesale prices are also low and power plants with CCS will not be able to recover their additional development costs through wholesale price revenue alone. The market mechanism that drives revenue to a CCS plant therefore only partially reflects the increase value of low carbon power.

The problem of having a limited signal from carbon prices is not unique to CCS. Historically residential and commercial space heating in the UK has had very little incentive to switch from high-carbon to low-carbon sources of heat. This lack of market incentive has severely restricted the growth of one of the most obvious solutions to this, namely District Heating CHP schemes.

Another example is the UK's waste sector which was historically targeted at delivering waste to landfill at least cost. However, as with CCS, it was widely recognised that there was a significant externality market failure because the disposal of the waste product did not fully price in the costs of landfill incurred by other parties, for example resource waste; leachate contamination of water courses and aquifers; and methane emissions (both the explosive risk and greenhouse effect).

Potential market led outcome: Much lower take up of low carbon technologies than would be regarded as 'optimal' as the market drivers for take-up do not exist.

Co-ordination failure – Access risk

Power plant developers will not build capture plant without assurances of access to a transport network than can take the CO_2 from the power station and deliver it to a storage site. There is a related issue for both the transport and storage whereby they will not develop necessary infrastructure without assurance of volumes from the power station – these related issues are discussed in the relevant sections below,

Similar access risks occurred in the 1990's in the UK offshore oil and gas sector, where the offshore industry did not want to invest in new fields without certainty over the volume and price of entry capacity (provided by National Grid).

Potential market led outcome: Required assurances for the ability to access transport and storage of CO_2 will only come from building end-to-end projects, probably under Joint

Venture structures or potentially with punitive take-or-pay contract conditions[9]. Without intervention to promote coordination, projects with oversizing or sharing of infrastructure cannot be easily incorporated into the structure and so are unlikely to go ahead.

Imperfect and asymmetrical information

Likely future performance of many capture technologies is not yet known and even now much of the current data on the performance of different technology options is not public. We have seen similar problems in roll out of district heating projects in the UK where a lack of information (e.g. costs, prices and reliabilities) for both consumers and investors hinders the widespread adoption of the technology.

Potential market led outcome: CCS project developers, technology developers and investors will be cautious in developing with a particular technology as it may be out-competed. This may hamper development and funding resulting in a delay to the roll out of CCS.

Externality: Capture technology spill-overs

As a technology evolves, rival projects (and the companies behind them) can benefit from the learning experience of previous ones when developing even more competitive new technologies. For example, this could be finding out which of a range of technical options has more promise (e.g. different capture technologies) or by benefitting from design solutions developed by others to make any of the different capture options more cost effective. This serves as a disincentive for an entity to invest in new technology, as it may not capture the full benefit of its investment.

Potential market led outcome: Technology developers incentivised to restrict access to design solutions limiting both current and new technology advancement leading to a sub-optimal level of investment in technology.

2.1.3 CO_2 transport market failures

Co-ordination failure - Volume risk

A CO_2 transport network will only develop if it can be assured that there will be both a supply of CO_2, and available storage to which it can be sent. If there is significant uncertainty for the direction of the CCS industry as a whole, and more specifically for CCS in a region relevant to the pipeline, it creates a large volume risk (or utilisation risk) for the transport pipeline operator.

Similar risks are relatively common in industries where development of networks relies on market signals such as transmission network entry capacity at gas terminals and district heating networks. In the case of both of these industries, fear of making large investment programmes in transport systems without certainty for supply and demand, has meant their struggling to develop sufficient capacity in the earlier stages of industry development.

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[9] Take-or-pay contracts (and the related send-or-pay contracts) stipulate that a certain volume of product must be paid for regardless of whether the product is actually taken (or supplied). They essentially act as a volume guarantee on a contract. They are relatively uncommon outside of the natural gas industry and so it remains to be seen how effectively they could be enforced in CCS.

Potential market led outcome: High risks will discourage any speculative oversizing of pipes to allow sharing with future projects, even where due to economies of scale it may be highly cost effective to do so. The required assurances needed for each source of CO_2 and storage sites results in limiting project development to end-to-end projects probably under shared ownership structures or otherwise through strong take-or-pay and send-or-pay contract conditions.

Natural monopoly nature of pipeline transport

For a transport network to be developed at lowest cost, to benefit from the strong economies of scale mean it will need for significant volumes of CO_2 to be available. Wayleaves and public perception/disruption issues create a significant barrier to entry of any alternate new network in a region. Together, these imply that onshore CO_2 transport, at least, will most likely be a natural monopoly as is certainly the case with other large network infrastructures such as electricity and gas transmission and distribution.

Potential market led outcome: When networks evolve from individual projects they will have significant market power. This potentially enables the pipes' owner to charge for transport at prices that are above those that are cost reflective (i.e. on terms that are not fair and reasonable). Prices charged for CO_2 transport could therefore be higher than would be optimal for the development of the industry, and so effectively discourage new projects.

Missing markets – CO_2 pipeline transport

There is currently no established market for CO_2 transport in the UK. Without this, pricing and valuation of this service is particularly problematic for third parties and financiers. In the longer term if, such markets did not develop sufficiently then regulation to impose alternative market structures may be required to meet the gap.

'Missing markets' are common failures in new industries where there is insufficient experience amongst contracting parties to allow for efficient price setting. One such example relevant for pipelines is UK district heating. Lack of experience from heat producers, housing developers and consumers in the supply and purchase of heat creates a large barrier to the establishment of widespread heat networks.

Potential market led outcome: Developers are strongly encouraged to use only integrated projects models for financing that internalise price and risk.

2.1.4 CO_2 storage market failures

Co-ordination failure – Volume risk and development risk

A storage site will only develop if it can be certain that there will be both a supply of CO_2 from a source and the means of delivery of that CO_2. Yet there is tremendous uncertainty in development pathways for the CCS sector as a whole, as well as within the region relevant to each particular storage site. Together these factors result in a large volume risk (or utilisation risk) for any storage site or hub of sites.

Additional risks arise from the lead time for storage development being far longer than the other CCS chain elements. This is particularly marked for aquifers, which need to gather significantly greater site characterisation data (compared to a depleted oil and gas field (DOGF) where much of the data should already be in existence) could extend out development timescales to up to 10 years.

Coordination failure is also a major problem in other industries which have high upfront costs combined with a heavily dependent supply chain. Capital intensive Energy from Waste plants that sit at the end of a waste transport network remained largely uninvestable until the 2000's whilst waste volumes and waste gate fees were uncertain.

Potential market led outcome: Volume risks discourage speculative characterising of larger storage sites or development of storage hubs. Even though this may be highly cost effective because of the strong economies of scale and giving developers access to de-risked storage sites. The required assurances needed for a source of CO_2 will come from building end-to-end projects probably under Joint Venture structures or otherwise through strong send-or-pay contract conditions. The additional risks involved in aquifer storage could make it too costly as an option for development and halt it, despite its promise.

Missing markets

There is no market for CO_2 storage in the UK at present. Neither is there a market for CO_2 as a feedstock for EOR projects. In the absence of either of these market indicators, valuation of CO_2 storage services is particularly problematic for third parties and financiers. .

The EU CCS Directive requires that financial security is provided upfront for a number of potential CCS specific liabilities creating additional costs. While existing risk management solutions can address some of these, CO_2 leakage risk represents an issue as a store would be liable any CO_2 that leaked at the prevailing EU ETS carbon price at leakage. Insurance products may be developed for a defined liability but no such market currently exists for storage leakage insurance either during the operational lifetime or in the post-closure period. Under current arrangements a storage site owner is required to continue to provide a financial security for potential CO_2 leakage from its store for at least 20 years after the site has finished injection.. Neither storage operators nor insurers are able to bear uncapped liabilities and some form of risk sharing with government, at least for early projects, will be required to develop CCS at scale.

Missing markets are a common failure in new industries where there is insufficient experience amongst contracting parties to allow for efficient price setting. EfW plants, for example, are located at one end of a chain of collection and transport (directly analogous to CO_2 capture and transport) and suffered from a similar missing market issues in the 2000's. EU driven restriction on landfill was introduced to try and encourage alternative waste policies but did not provide an alternative market for waste.

Potential market led outcome: Developers are strongly encouraged to only use integrated projects models for financing that internalise price and risk. There will be a higher risk and hence higher return requirements for investors where risks are not insurable – where insurance can be developed early projects will require the use of high cost bespoke insurance products to meet insurance requirements. If leakage liability is not shared with government there is the potential no CCS will develop in the UK.

Natural monopoly nature of storage hubs

Storage sites or hubs could benefit from significant cost savings if they are developed for larger volumes of CO_2. A hub for CO_2 can access economies of scale, increase utilisation of individual wells and lower the impact of single site failures. There are also barriers to new hubs because upfront costs, CO_2 volume risks and geological uncertainty at new a storage hub is far higher than at one which has operating experience.

Given these characteristics storage hubs are likely to be local natural monopolies.

Potential market led outcome: Where storage hubs are developed from projects and are controlled by few owners they will have significant market power. Potentially companies can price storage on terms that are not fair and reasonable, and the higher costs charged for CO_2 storage would result in sub-optimal development of the industry.

Exploration spill-overs (externalities)

Storage appraisal on the early projects will result in benefits to a much wider group than just those just undertaking the appraisal. Potential benefits include the proving of storage concepts, techniques for appraisal and injection as well as the learning benefits to other developers looking to develop sites in a similar geographic location or geologically connected structure)

All these reduce risks and costs to developers of projects that follow on from those doing the initial storage appraisal.

Potential market led outcome: As the benefits accrue to a wider group of individuals developers are incentivised to wait and let others explore first. The amount of storage appraisal activity is likely to be less and later than would be optimal for the long-term development of the industry.

Imperfect and asymmetrical information

The experience from assessing operating oil and gas fields strongly suggests that performance of any individual storage site cannot be fully assessed until after a reasonable period of operation. Certain types of geological formation are potentially far more uncertain than others. There is also a large disparity in available information on which storage sites are most likely to offer the best storage solutions because, of the relatively limited experience of CO_2 flows in the North Sea basin geology. This disparity exists both between different storage sites and between different potential storage site developers.

Potential market led outcome: Project developers are likely to be cautious when developing any storage while its performance and long-term viability are unknown.

2.1.5 Conclusions

While some of the market failures are relevant to the full CCS value chain, different potential market-led outcomes in each segment create different investment challenges. It is clear that tailored approaches to interventions will be required for each part of the chain to in order to provide a suitable environment for investment.

The current policy and regulatory frameworks attempt to address at least some of these issues and we summarise them in 2.2 below. However as they do not go far enough the risks and market failures that result as a consequent are summarised in Table 1 on page 21.

2.2 Effectiveness of current policy and regulatory framework

Government has recognised that interventions are required to advance CCS from its early stages. To date most interventions are focused around specific technology R&D and there are several embedded in the EMR proposals. Below we examine the current policy and regulatory framework in the context of its effectiveness in addressing CCS industry risks.

2.2.1 Current policy framework

Contract for Difference Feed in Tariffs (CfD FiTs)

CfD FiTs are targeted at technologies that are not commercial in the power sector and will provide a separate top-up revenue stream for fossil fuel power plants that produce power whilst capturing CO_2. Revenue will be provided for each unit of power produced at the plant multiplied by the percentage of the CO_2 that is captured. The price of these contracts is expressed in £/MWh and is referred to as the CfD FiT strike price.

However payments under the CfD FiT will be restricted by the Levy Control Framework (LCF) which is a treasury sanctioned cap on the maximum value of levies that can feed through to consumer bills. The cap is £7.6bn in real 2012 money in 2020 and covers both Renewable Obligation Certificates (ROCs) and CfD FiT supported low carbon power as well as some energy efficiency and other consumer focused schemes. The current split of this cap is unclear but could place major restrictions on the amount of CCS funded before 2020, particularly if nuclear and offshore wind projects develop quickly.

Risk addressed: Indirectly addresses current low priced CO_2 emissions by providing an increased revenue stream to power plants with CO_2 capture. Providing a longer-term mechanism has also helped to address perception of policy risk for power plants.

Carbon Price Support (CPS)

The Carbon Price Support will underpin the long-term CO_2 price by imposing an additional tax on fossil fuel consumption at UK power stations. By 2030 the combined carbon price under the CPS plus the EU Emissions Trading Scheme (ETS) is designed to reach £70/tCO_2 – the Government's estimate of the damage cost of an additional unit of emitted CO_2.

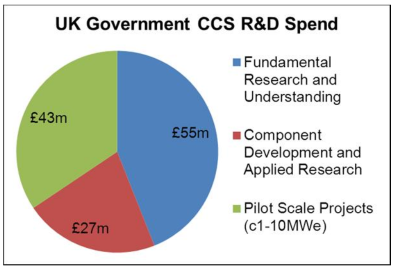
Unfortunately the EU ETS component of this price is currently very low (less than €3/tCO_2 in April 2013) meaning that power plants elsewhere in Europe have very little incentive to reduce emissions and face a significantly lower cost base than their UK counterparts. The larger this disparity becomes the greater the impact on UK competitiveness in Europe. Whilst Government has shown no moves away from this policy to date, if the gap between the European and UK electricity prices continues to grow we may see increasing pressure for the removal of the CPS.

Risk addressed: Directly increases the cost of CO_2 emissions by increasing the cost and therefore the penalty to power plants without CO_2 capture.

Government CCS R&D programme

Alongside Industry, Government is funding £125m of CCS R&D activities through fundamental and applied research as well as pilot scale projects. Although broad in its aims there is some concern that the DECC R&D budget has been directed primarily at capture research – the pressing need for storage research may require an additional funding focus both in the UK and Europe.

Risk addressed: The incentives have increased research into new technologies which helps to counter some of the 'Capture technology spill-overs', 'Imperfect and asymmetrical information' issues described in section 2.1. To the extent that R&D also is invested in aiding storage discovery and derisking storage it also partially addresses storage spill-overs.



UK CCS Commercialisation Programme (CCSCP)

The 2013 Budget provides up to £1bn of capital grant funding to facilitate development of the UK's first full-scale CCS projects. The funding is provided via a competitive process known as the UK CCS Commercialisation Programme (CCSCP) which will work alongside additional funding through CfD FiTs. The programme aims to support practical experience in the design, construction and operation of commercial-scale CCS. The £1bn is available for a maximum of two projects.

For the winning projects at least, CCSCP addresses risks and market failures by:

- incentivising demonstration of new technologies to help counter 'Capture technology spill-overs' as well as 'Imperfect and asymmetrical information' issues in both capture and storage;
- gathering experience and ensuring there is some knowledge transfer helping to establish some of the 'new markets' required for the effective development of the CCS industry;
- direct provision of capital to offset capital raising issues; and
- countering coordination failures (development and volume risk) for the early demonstration projects if part of the capital funding is directed to transport and storage infrastructure.

Emissions Performance Standard (EPS)

Part of the EMR package includes an Emissions Performance Standard which sets a limit on the annual CO_2 emissions allowed from a power plant. The standard was set at 450gCO_2/KWh and then translated into an annual cap based on an assumed load factor – this eventual cap was low enough that it would stop unabated coal plants from operating at baseload but would have no impact on new gas plants.

Even prior to the establishment of the EPS new unabated coal plants were constrained from being built in the UK because of restrictions in the consenting process. The EPS therefore does little to address any of the risks or market failures at present.

EU CCS Directive

The EU directive on the geological storage of CO_2 provides a framework that covers the entire lifetime of a storage site from site selection to pose closure monitoring and eventual liability transfer to the Member State.

Key elements of the EU Storage directive include:

- Use of existing legal frameworks to govern the directive whilst removing barriers from other legislation to allow for the subsurface storage of CO_2;
- Allowing Member States to select individually which sites or blocks are provided for CO_2 storage;
- Setting out minimum criteria for site selection that ensure 'neither significant risk of leakage nor health or environmental risks' will result;
- A requirement for proof of financial security to be provided to cover closure and potential leakage liabilities (under EU ETS prices) prior to the granting of a storage permit;
- Monitoring requirements that ensure that the site is behaving as predicted throughout the lifetime of the store;

- A minimum post-injection period of 20 years before transfer to the Member State plus a further 30 years of financial contribution covering at least the monitoring costs of the site; and,
- Third Party Access (TPA) under fair and open access rules to pipelines and storage sites although only to the extent that it can reasonably be made available – this is reasonably clear for pipelines but less certain for storage as 'availability' is governed by overall size of the store as well as maximum injection rates.

Risk addressed: The ability to transfer stored CO_2 liabilities to the state 20 years after site closure thereby containing the liability of CO_2 storage providers although the financial commitments are still large. TPA access arrangements, for pipelines at least, appear to restrict the ability of CO_2 transporters to exercise market power.

New Entrant Reserve (NER) 300 Process

An alternative source of funding was made available to CCS projects via the European Commission led NER 300 process. This process sought to fund a number of innovative renewable and CCS projects through the sale of 300m EU Allowances (EUAs). Applications for the process were in two tranches – the initial phase for 200m EUAs and a subsequent additional phase for the remaining 100m.

Unfortunately, the first round of the NER 300 failed to fund any CCS projects

As of April 2013 the call for applications for the second call for NER300 funding is underway – proposals must be submitted by 3 July and award decisions are currently scheduled for mid-2014 (although it should be noted that Phase 1 of the project suffered significant delays). The total budget for Phase 2 will include €300m rolled over from the first call plus some additional revenue generated from the sale of the remaining 100m allowances.

Funding for CCS via the NER 300 will still be a challenge due to NER 300 requirements for:

- the plant to be operational within 4 years of award.
- Member state co-funding of projects where there is little Member State budget available.

2.2.2 Risks, Market Failures, and Current Policy summary

Taking this current financing backdrop and policy and regulatory framework as a basis, Table 1 below compares the current risks faced by CCS developers with the risks identified in Section 2.1.

It also highlights key industry analogues for each risk. These analogues are examined more closely in Chapter 3 to assess specific interventions opportunities and the models for deployment observed in these sectors.

Table 1 – Comparison of current CCS risks and policy/regulatory framework

Risk / Market Failure	Potential 'market led' outcome	Ability of current regime to address risk	Key Industry Analogues
General CCS risks			
Construction & operation risk	Roll-out slow until investors and developers more confident of cost and performance	**Medium** Target of CCSCP & R&D	
Capital market risk	Limited availability of both equity and debt. Significantly increased financing costs.	**Low/Medium** CCSCP helps early projects only	• Renewable Energy • Offshore Oil & Gas
Policy risk	Developer unwilling to finance speculative, longer term investments.	**Medium** CfD FiT provides basis for longer term policy	• Waste Management
Public perception risk	Lack of public knowledge and acceptance may create significant delays for projects.	**Low**	• Waste management
Production and Capture Market Failures			
Externality Low priced CO_2 emissions	Much lower take-up of low carbon technologies (inc. CCS) than optimal due to lack of market drivers.	**Medium (Power)** **Low (non-power)** CfD FiT mechanism & CPS	• Heat networks • Waste Management
Co-ordination failure: access restrictions	Required assurances for access to T & S come from building JV end-to-end projects, or with strong take-or-pay provisions.	**Low** Addressed for early projects through CCSCP	• GB Natural Gas
Imperfect & asymmetrical information	Project developers and investors cautious in developing with a particular technology as it may be out-competed.	**Medium/High** CCS R&D and CCSCP programme	• Heat networks
Externality capture tech spill-overs	Technology developers incentivised to restrict access to design solutions limiting technology advancement.	**Medium/High** CCS R&D and CCSCP programme	
CO_2 Transport Market Failures			
Co-ordination failure: volume risk	Discourages speculative oversizing of pipes to allow sharing with future projects. Required assurances for a CO_2 source and store come from JV end-to-end projects.	**Low/Medium** CCSCP helps early projects only	• Heat networks • GB Natural Gas
Natural monopoly of CO_2 transport	Local networks have significant market power. CO_2 transport charges could be higher than optimal deterring new projects.	**Medium** TPA access regime for pipelines will restrict power	• Heat networks • GB Natural Gas
Missing markets for CO_2 transport	Developers can only use integrated projects models for financing.	**Low/Medium** CCSCP partially addresses	• Heat networks • GB Natural Gas
CO_2 Storage Market Failures			
Co-ordination failure: volume & development risk	Discourages speculative characterising of larger stores (aquifers) or hubs. Required assurances for reliable CO_2 source will come from building JV end-to-end projects.	**Low** CCSCP helps early projects only	• Heat networks • Waste Management • GB Natural Gas
Natural monopoly of storage hubs	Where storage hubs are developed they will have significant market power. Cost charged for CO_2 storage may be higher than optimal for development of industry.	**Low** Currently unclear how storage TPA will be enforced	• GB Natural Gas
Externality: exploration spill-overs	Volume of storage appraisal likely to be less and later than would be optimal for long-term development of the industry.	**Low** CCS R&D incentivises some limited exploration	
Imperfect and asymmetrical information	Project developers are likely to be cautious when developing a site as the performance and long-term viability of the site is unknown.	**Medium** CCSCP helps develop some capacity	• Heat networks
Missing markets for CO_2 storage	Developers only use integrated projects models for financing. High insurance costs.	**Low/Medium** CCSCP partially addresses	• Waste Management

2.3 Implications of current challenges for CCS roll-out

As we have seen in Section 2.1, the full chain of capture, transport and permanent storage of CO_2 faces a number of distortions –these are varied and those found in transport and storage are different from those in power generation. Unless addressed these risks and market failures are likely to severely restrict the development of Carbon Transport and Storage (CTS) infrastructure and hence the future CCS industry.

The current regulatory and policy framework recognises that there is a need for intervention in CCS. The government are seeking to address these issues for CCS by providing specific support under the UK CCS Commercialisation Programme and the Electricity Market Reform (EMR) process.

The Commercialisation Programme is aimed at incentivising demonstration of new technologies and gathering operational experience, both of which will help reduce the perception of construction and operational risk.

The EMR process will form the enduring regime under which CCS will operate and has two principle components relevant for CCS developers – Carbon Price Support (CPS) and Contract for Difference Feed in Tariffs (CfD FiTs). The CPS is aimed at providing a stable, predictable carbon price floor for power generators as an incentive to decarbonise. The CfD FiT funding mechanism (as it stands) looks to address market failures affecting CO_2 capture by providing a stable revenue stream. Both of these measures are clearly strongly directed at risks faced by power station investors and in part at least, alleviate those at the generation and capture end of the CCS chain.

However the following risks and market failures associated with Transport and Storage of CO_2 appear to remain unaddressed by the current framework with corresponding implications for the potential roll-out of CCS in the UK if left to the market to deliver:

- **Capital market issues** leading to high costs and low availability of both equity and debt due to financial restrictions and competition with other investments;
- **Missing markets:** a lack of timely pricing signals could delay longer term roll-out if sufficient markets in CO_2 transport and storage do not develop after the CCSCP**.**
- **Lack of public knowledge** and acceptance could create significant project delays.
- **No strong carbon price signal in non-power industrial sectors** or market drivers for revenue leading to a very low take-up of low carbon technologies.
- **Co-ordination failures** leading to a need to develop novel business structures and a tendency to develop smaller stand-alone projects due to:
  - **access risk** to transport and storage for power stations;
  - **volume risk** for transport and storage networks and hubs;
  - **development risk** particularly for aquifer storage projects due to the long-development lead times
- **Local market power issues for both transport and storage** meaning the cost charged for CO_2 transport and storage could be higher than would be optimal, discouraging the development of otherwise attractive new projects.
- **Exploration spill-overs (externalities)** exist such that that the volume of storage that is appraised is likely to be less and later than would be optimal for the long-term development of the industry; and

- **Imperfect and asymmetrical information on storage sites** mean that project developers are likely to be cautious when developing storage sites as the performance and long-term viability of the site is unknown.

We conclude that in the absence of further intervention, the currently proposed regime will only encourage CCS to a limited degree. Developers will be heavily incentivised to develop only smaller point-to-point solutions in a relatively slow sequential fashion. Therefore, although the industry may be driven forward by external market forces and reach the gateways described in 1.3.1, it will develop slowly and potentially in a much less efficient way.

Yet such a picture of future development runs counter to the recommendations of the Government's own CCS Cost Reduction Task Force which stated that the key to the cost reduction and long-run competiveness of CCS is:

- *'Investment in large CO_2 storage clusters, supplying multiple CO_2 sites'* and *'large, shared pipelines, with high utilisation;*
- *investment in large power stations with progressive improvements in CO_2 capture capability which should be available in the early 2020s;*
- *a reduction in the cost of project capital through a set of measures to reduce risk and improve investor confidence in UK CCS projects; and*
- *exploiting potential synergies with CO_2-based EOR in some Central North Sea oil fields.'*

The government has already signalled its commitment to fund early CCS projects via EMR mechanisms. Funding projects using a mechanism that does not efficiently address risks, and thereby passing over opportunities to lower costs, will increase the overall level of financial support required for the delivery of CCS.

More widely, taking CCS from an early stage technology to a commercially viable one suitable for private sector development and one that is widely adopted will require reducing the overall costs which include the cost of capital, sufficiently enough to make CCS commercially competitive with traditional generating technologies. While the outcome from DECC's commercialisation programme may result in one or two projects, the challenge will be how to maintain momentum among other projects unsuccessful in obtaining DECC funding and scale up the industry beyond that.

Support for follow-on projects needs to be progressed if the sector is to be capable of ramping up and making a large scale contribution through the 2020s. The first follow on CCS projects will need to progress, potentially to final investment decision before many learnings have emerged from the projects supported by DECC's commercialisation programme. Given the challenges identified for the sector there is a real risk that follow-on projects will not emerge resulting in a hiatus extending into the 2020s, without targeted intervention.

In the long-run projects need to be investable without the benefit of public funding, this will require significant progress on a range of issues and will not be delivered by the market on its own. Further targeted intervention is required to facilitate these developments and deliver these opportunities.

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3. WHAT IS NEEDED TO FACILITATE DEVELOPMENT?

Chapter 2 examined the many challenges faced by the UK CCS industry if it is to be developed beyond the current DECC commercialisation programme. Development of commercial CCS, will require interventions to be made that target the unaddressed risks within the sector.

3.1 Intervention options: Learning from industry analogues

Even where risks are specific to CCS, valuable lessons can be learnt from other flourishing industries that have had to overcome similar barriers and resulting risks in the early stages of their development.

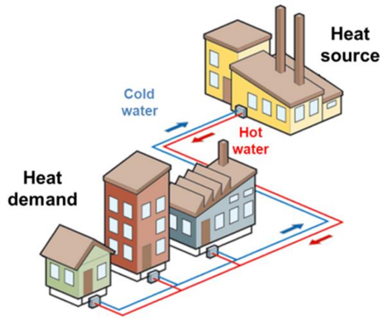
In our stakeholder workshop a number of different industries were assessed to identify the interventions that were successful and therefore may be applicable to address similar issues within the CCS sector. Particular parallels were apparent for five industries:

- Heat networks
- Waste Management
- Offshore oil and gas
- US Renewable Energy
- GB Natural Gas Transmission Network

Some of these are now working well in the UK and others have been successfully rolled out elsewhere – often facilitated through specific interventions to target the risks. The pattern of roll-out, and the models for deployment observed in these very different industry sectors can be used as a guide for the development of CCS under different intervention approaches.

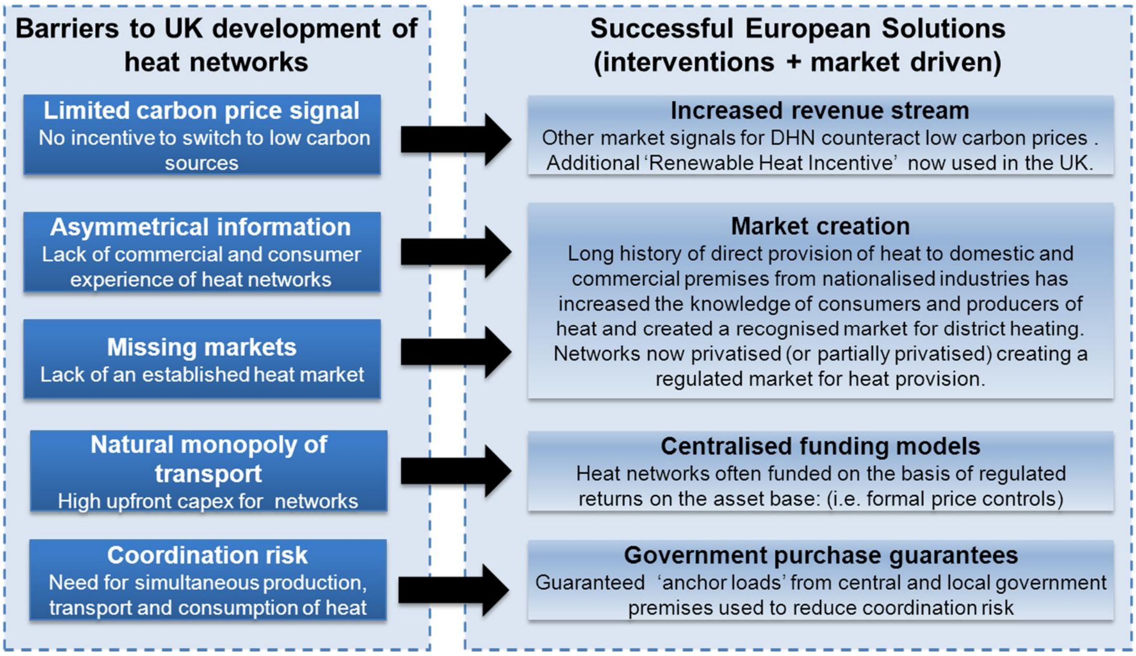
District heating networks (DHNs)

A heat network comprises production, transport and supply of heat. Whilst industrial heat networks, usually transmitting high grade heat, are relatively common (often involving Combined Heat and Power plants), wider district heating using lower grade heat in the UK is much less common – only 4% of UK floor space is currently connected to DHNs. In many European countries DHNs are much more common: 60% of heat supply in Finland and 50% in Denmark is via DHNs.



There is recognition in Government that in certain situations DHNs have the potential to contribute to both policy objectives on carbon emissions and cost savings due to their potential for higher thermal efficiency. However market failures create numerous barriers to the market adoption, many of which have parallels to CCS.

In Europe the barriers are much less important due to a differing policy, regulatory and financial landscape. Some elements of the landscape are direct intervention decisions from government and others are market driven arising from the fact that the DHN industry is at a much more advanced stage in Europe than the UK. The barriers currently faced by the UK industry and solutions that have been applied in Europe are summarised below.



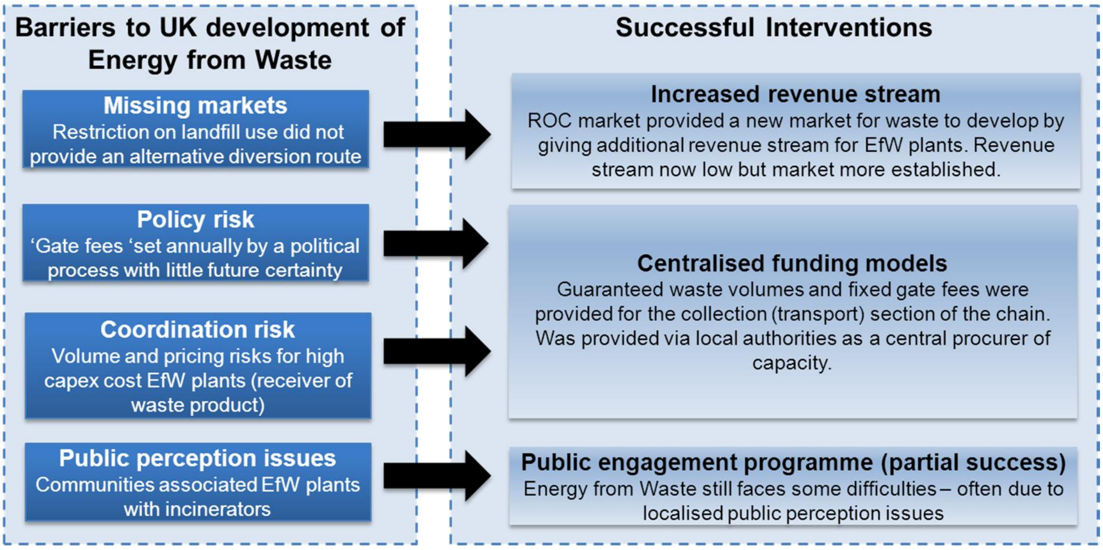
Waste Management (Energy from Waste)

The UK's waste sector was historically driven to deliver waste to land fill at least cost. However, as with CCS, it was widely recognised that there was a significant market failure in that there was a large **externality** – the disposal of the waste product did not fully price in the costs of landfill incurred by other parties:

- resource waste (i.e. it had a value in its own right);
- contamination of water courses and aquifers; and
- methane emissions (explosive risk and global warming potential)

An EU driven policy placed a restriction on landfill volumes aimed at reducing these externalities by forcing diversion of waste to other routes: reuse, recycling and energy recovery. It resulted in the introduction of a landfill tax in the UK to combat the market failure.

However the development of so-called Energy from Waste (EfW) technologies (in which the waste is burned to produce heat and/or electricity) was hindered in the UK by a series of barriers despite offering significant opportunities to aid with waste disposal. Further targeted interventions were introduced in the UK to counteract the barriers, which included the introduction of new revenue streams for generation and separate funding models for the transport element of the chain. The respective barriers and solutions are summarised below.



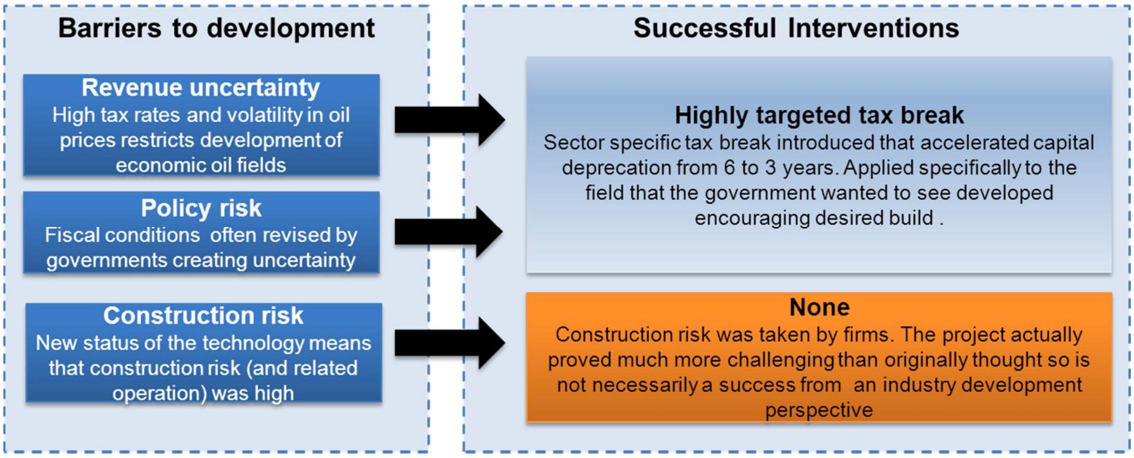
Since these interventions were introduced the market for EfW has developed considerably. Although take up was initially slow (incentives have been in place for more than 10 years) it is now a relatively common form of waste disposal, processing more than 3mt of waste per annum. EfW plants also contribute significantly to power sector decarbonisation generating around 1.5TWh annually of 'low carbon' power.

Offshore Oil & Gas

As Europe's oil and gas resources gradually deplete there is an ever increasing pressure on the hydrocarbon producing countries to maximise the utilisation of their remaining reserves. Part of this strategy involves exploitation of oil and gas resources in known but previously un-accessed fields through the application of new techniques and technology.

In general taxation for the oil and gas sector is one of extremely high marginal tax rates. Due to the higher costs, harder to access fields while economically valuable, are therefore not seen as financeable by oil companies.

A prime example of this is the development of the Snøhvit field on the Norwegian Continental Shelf. Snøhvit is the first gas project in the Baring Sea but in the late 1990's significant economic challenges hindered its development. They were not market failure related, but arose more generally from the risks arising from use of a highly novel technical approach that was necessary to extract the gas in such difficult conditions. As the Norwegian government was keen to progress the project (and open up corresponding industry in the Baring Sea) it introduced specific tax breaks to counteract part of the risk faced by the project developer.

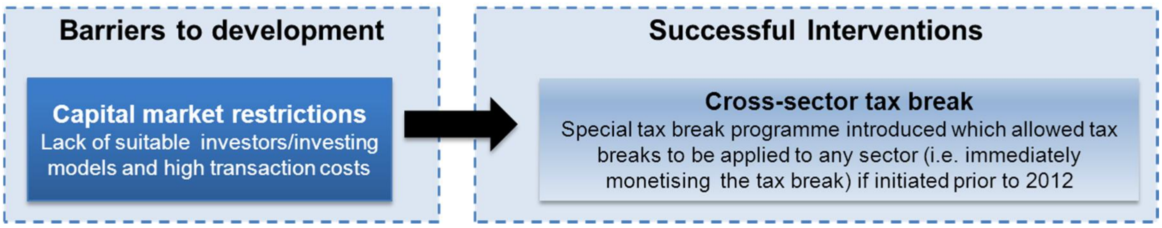


Ultimately, such an intervention was successful in achieving a positive investment decision because it allowed oil companies to offset high marginal tax rates from their current operations on the NCS. However, the project itself, whilst now in operation has faced significant technical challenges and has not been a positive investment for many of the parties – it has therefore not necessarily been a success from an industry development perspective.

US Renewable Energy

In the US there are both State and Federal initiatives to move towards more environmentally friendly energy sources. Although the processes are not as international in their basis as European initiatives (the US did not ratify the Kyoto Protocol), US energy policy still requires aggressive capital expenditure in developing renewable programs, clean fuels, smart metering and smart grids. There is no universal price applied to power sector CO_2 emissions in the US – although there are some state level carbon markets, where prices do exist they are generally insufficient as a sole measure to incentivise the take up of renewable energy.

The traditional approach for renewable energy incentives in the US has been to offer standard forms of tax credits but they have had limited success because of a restricted supply of tax equity based financing, high transaction costs and the barriers that tax equity can create for additional debt financing. The capital market restrictions meant that even where projects should be attractive to investors; there were restrictions on the speed of roll-out that could be achieved. To counteract this risk, a 'cross-sector tax' break was introduced to specifically try and increase the flow of capital into the clean energy sector.



Experience suggests that it was highly effective at driving additional equity investment and accelerating roll-out. In the US, clean energy investment in 2011 far exceeded the amount of financing that would have traditionally been available just in the tax equity market.

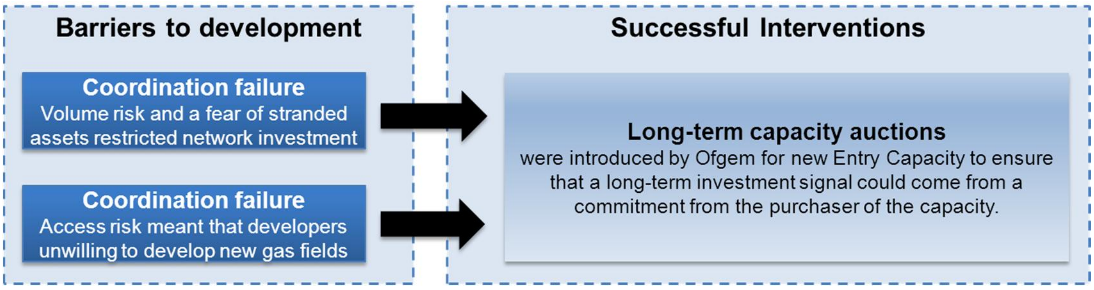
Natural Gas Transmission Network: Entry Capacity Auctions

Great Britain already had a well-developed gas transmission grid when liberalisation began in earnest in the late 1990's (Network Code developed in 1996). However, it quickly became apparent that the mechanism used by National Grid for developing new Entry Capacity at particular terminals (which was based on selling capacity at Long Run Marginal Cost levels) were not creating a suitable signals for investment.

As the development of the gas grid was needed in parallel with large investments in offshore gas fields, coordination failures were arising that hindered the effective development of the market:

- National Grid did not want to develop new capacity without certainty of new gas supply because of the risk of stranded assets (volume risk); and
- Conversely the offshore industry did not want to invest in new fields without some certainty over the volume and price of new entry capacity (access risk).

The problem can also be viewed as one of missing markets – at that time there was no market through which long-term capacity price signals could be effectively provided. The creation of a new market for long-term capacity came about through intervention by Ofgem which introduced long-term capacity auctions.



In practice the auctions scheme has been successful in developing new entry capacity at sites such as Milford Haven while still fitting with National Grid's other regulatory requirements.

3.2 Options for intervention

The previous examples show how thoughtful, timely and appropriate interventions can make a significant difference to growing an industry. In this section we now examine the range of possible options in the context of the problems that they need to address for CCS.

3.2.1 Mapping of risks to interventions

To enable an efficient and timely development of the CCS industry, each unaddressed risk and each market failure needs to be targeted by a suitable intervention. In the course of the project workshops, the industry stakeholders took the analogues and used their own experience to develop a series of intervention options to address the particular risks faced by the CCS industry.

All the intervention options from this process are summarised in Table 2 below. They fall into four broad categories:

- **Financial incentives:** Mechanisms that provide an alternative revenue stream (generally redirected from FiT payments under the current EMR 'trickle-down' approach). They include capital grants, payment guarantees and centralised or regulated funding approaches such as those seen in large natural monopolies like gas and power transmission.
- **Tax breaks:** Fiscal incentives applied using adjustments to the UK taxation system.
- **Market creation:** Regulatory or policy actions that seek to create a market for a product that is currently not available (due to market failures or barriers).
- **Knowledge generation:** Interventions focusing on actions such as R&D spending, health and safety and public engagement and guidance programmes.

Table 2 – Intervention options to target unaddressed CCS market failures

Current CCS risks/ failures	Intervention option considered	Intervention Description	Intervention Category
Capital market restrictions	Direct CTS revenues under 'EMR' framework	Lowers contract risks, potentially encourages hubs by encouraging specific business models.	Financial incentives
	Centralised funding models for T & S	Provides stable revenue stream and therefore enables low cost alternative finance structures.	
	Cross-sector tax breaks	Losses can be monetised easily encouraging equity investment by major companies.	Tax breaks
	EHR tax breaks	Encourages oil and gas majors to become involved in CCS.	
Missing Markets	CO_2 storage liability aggregation	Establishment of a pooled fund for liability aggregation	Market creation
	Long-term storage capacity auctions	Creates a long-term price signal for storage	
Public perception risk	Public engagement programme	Targeted public engagement programme to reduce delays in planning	Knowledge generation
Low non-power sector CO_2 price	TBC	Incentivise non-power sector to decarbonise using CCS where economically efficient. This paper does not considered specific options.	Financial incentives
Co-ordination failures: • Access Risk • Volume Risk • Development Risk	Option contracts for T & S	Provides signal and market for long-term transport and storage requirements.	Market creation
	Leasing rounds for AfLs	Give greater certainty over long-term storage accessibility and need.	
	Long-term storage capacity auctions	Creates a long-term price signal for storage	
	CO_2 purchase guarantee by government	Storage and transport partially paid on availability with shortfall guaranteed by government	Financial incentives
	Centralised funding models for T & S	Provides stable revenue stream and therefore enables access to lower cost and alternative sources of finance.	
	Grants for storage characterisation	Grant targeted at 'new' areas of storage or on incremental work at existing storage sites to overcome development risk	
	Targeted sector specific tax break	Grants for projects building on existing hubs or that will establish new hubs	Tax breaks
Local market power	Centralised funding models for T & S	Strong regulation to restrict negative market power	Financial incentives
Exploration spillovers	Grants for storage characterisation	Compensates for additional benefits from exploration that derive to other parties. Grant conditional on knowledge transfer arrangements.	Financial incentives
Imperfect & asymmetric storage information	Grants for storage characterisation	Improves storage data and information dissemination	Financial incentives
	R&D on CO_2 monitoring techniques	Improves data and information dissemination reduces storage development costs and risks	Knowledge generation

Table 3 summarises them by type. Each of them is described in more detail in the Sections 3.2.2 to 3.2.5 below.

Table 3 – Summary of intervention options by type

Intervention Type	Intervention Options
Financial incentives	Direct CTS revenues under EMR framework
	Centralised funding models for T & S
	Grants for storage characterisation
	Purchase guarantee by government
Tax breaks	Cross-sector tax breaks
	EHR tax breaks
	Sector specific tax breaks (targeting hubs)
Market creation	CO_2 storage liability aggregation
	Options contracts for T & S
	Leasing rounds for AfLs
	Long-term storage capacity auctions
Knowledge generation	Public engagement programme
	R&D on CO_2 storage and monitoring

3.2.2 Financial incentives

This category of interventions includes all those that provide a revenue stream (or capital grant) to elements of the CCS chain. They often provide an alternative to financial incentives from both the Commercialisation Programme and the CfD FiT mechanism 'trickle-down' approach.

Targeted financial incentives are a common intervention approach to address market failures. A financial incentive for a certain behaviour type (not currently encouraged by the market) can compensate for a market failure and lead to the more efficient development of an industry. Financial incentives can also be used to better reward developers by compensating them for risks faced in projects.

Not all financial incentive schemes perform equally well – if it is targeted correctly at a certain risk, it can provide an increased revenue stream and drive down required project returns. This will lower the overall cost of a project and mean that overall less subsidy is required.

Direct revenue subsidies for the carbon transport and storage system

As it stands, EMR requires all CTS infrastructure (beyond that established in the Commercialisation Programme) to be funded from payments made to the power station (a so called trickle-down funding approach). An alternative would be a direct revenue stream for transporting and storing CO_2, which results in removing (or at least lowering) one element of contractual risk for both the power station and the transport/store operator.

As all of the initial projects would by definition, need to be full chain, direct funding for the CTS infrastructure would not significantly impact the risk for early projects. Any payment to the Transport and Store would net directly off payments that would have been made to the power station under EMR. Once multiple CCS projects are operating in the UK direct funding can reduce risk for all parties by providing greater price certainty and lower contract risk. The eventual contracting structure that arises in the industry (and its ability to address risks) will partially dictate the impact of this intervention. We have not assumed that there is any capacity element to this payment (which would act as a form of volume guarantee and is therefore included under the heading of removing CO_2 volume risk).

Revenue would most likely come from the CfD FiT funding body that is paid via a levy on suppliers and be delivered in the form of a fee per tonne of CO_2. If the revenue would otherwise have been supplied by a CfD FiT such a scheme could be reasonably cost-neutral (versus the current policy regime).

Centralised funding model, particularly for transport system

Pipelines for CO_2 transport are a natural monopoly as significant economies of scale and long-lead times for planning and consenting of pipes create an obvious barrier to entry of competitors. They will therefore most likely be subject to regulatory scrutiny, on pricing and access for third parties. For point-to-point networks where the majority of capacity is used by a single project these risks are a relatively minor consideration.

Oversizing of pipes and sharing of transport infrastructure will lead to far lower industry costs and so must be encouraged in the longer term. As discussed in section 2.3, the trickle-down approach of CfD FiTs will not encourage sharing of pipeline infrastructure and so, as the industry develops, other funding models for transport need to be considered.

One alternative would be a centralised funding mechanism for all transport through a regulated returns model. Monopoly transport networks would have prices governed by a return on regulated asset base, creating a stable income stream and ‘guaranteeing’ some investment returns. ‘Gold-plating’ problems would need to be dealt with by appropriate regulatory oversight.

A more targeted funding model more suited to the independent development of large pipelines also has the potential to reduce risk for transport reducing the costs of CCS projects. It can also encourage CCS capture projects by establishing a separate entity which has responsibility for CO_2 transport and so remove one element of the CCS chain which may not be a core expertise of a typical power station investor.

Storage grants and subsidies

Information on most of the potential storage sites in the UKCS is still very sparse – certainly far less than needed to reach a final investment decision on an integrated project. Collection of the necessary data is time-consuming and at the later stages of site characterisation very costly. The gap between initial site screening and operation therefore puts significant capital at risk. Added to this, the long-term performance of any single storage well (and potentially the performance of the whole storage site) will not be fully known before significant operating data has been gathered. This will be most noticeable when developing new geological formations. Not surprisingly, storage is therefore currently regarded as the most risky part of the CCS chain for project developers.

Specifically targeted at early-stage development of the industry, this type of grant funding would focus on storage exploration subsidies. It could potentially target ‘new’ areas of storage or incremental work at existing storage sites (which would bring wider benefits). Each funded characterisation study is likely to cost in the region of £100-200m per storage site. The incentive could be relatively revenue neutral for government if it was associated with a project which would otherwise have required a higher CfD FiT (as is the case with the CCS Commercialisation Programme).

Such exploration subsidies could encourage early appraisal of storage and compensate for any additional benefits that fall to other parties both from information spill-overs and de-risking of the wider storage area. If structured correctly it can also help address information asymmetry issues by applying a knowledge transfer element to the grant. As both of these market failures should fall away as the industry matures and storage becomes more commonplace, this incentive is most appropriate only for the early stages of the industry.

Purchase guarantee by the Government

Under an availability fee regime the Government either underwrites or pays storage and transport developers directly for their availability rather than on the volume transported or stored. It would effectively compensate any shortfall in revenues from falls in CO_2 volumes.

The effect of such a guarantee would principally be transfer risk from industry to government and could be targeted at new hubs, or projects where oversizing appears to be particularly valuable (but would not be undertaken due to the risk profile). Arguably such a scheme would be a way of the government providing some backing to assertions that CCS will be developed in the UK in accelerated timescales than would otherwise happen.

This kind of mechanism could be implemented reasonably quickly. However it is probably not particularly feasible during the Commercialisation Programme when the funding mechanism (and some of the risk allocation) has already been decided. In the longer term a capacity payment route for funding could be implemented alongside other EMR arrangements – there is no indication that such a route is favoured by Government presently.

3.2.3 Tax breaks

Tax breaks are potentially applicable throughout the life of an industry with examples from the oil industry being a good starting point for how policy must adapt as an industry matures. The regularity of changes to the fiscal regime in the UK shows that such interventions would be fairly easy to implement by Government.

Tax breaks are relatively revenue neutral for government as an improvement in project economics through a tax break should enable a lower CfD FiT price to be paid to power stations offsetting the loss in tax revenue (although there may be more complex timing issues with cash flows). Tax breaks have an advantage over some other incentive mechanisms in that they can be more easily targeted at encouraging specific behaviours rather than being industry wide.

Cross-sector tax breaks

This structure allows losses or some form of 'allowances for investment' to be transferred from the CCS industry to other activities undertaken by the same company even if it's completely outside of the CCS sphere. For this reason it can have quite large revenue timing issues for the treasury.

It is perhaps the most generous form of tax break so it is unlikely to appropriate for a long period of time. However, the key benefit would be to encourage companies who would otherwise not be involved in CCS to get involved and provide equity at the early stage of the industry roll out. If an investor has a high marginal tax rate, the incentive is greater so that, in particular, oil companies (who due to their skills and expertise are seen as key stakeholders in promising storage sites but have no incentive to get involved at present) would see significant advantages. For an early stage industry such as CCS in need of both equity and many of the oil companies' skills, this could be of particular benefit (although limited by the appetite of tax equity investors).

Sector specific tax breaks

Sector or project specific tax breaks, defer or remove a portion of the tax liability in a specific project or sector, which results in improving the economics of that particular project or suite of similar projects. Unlike the cross-sector tax breaks the advantage is only realisable when the project pays tax or if the company owns a project in the same sector currently paying tax.

This type of tax break would have fewer treasury implications than the cross-sector tax breaks but it lacks the appeal to equity investors currently outside of the CCS sector. It seems most likely that it could be most usefully targeted at new hubs in the mid to long-term to improve the economics of socially beneficial solutions. It would however improve the economics of marginal projects without having to raise the CfD FiT price paid to CCS project developers if it was targeted at the whole of the CCS sector.

Enhanced Hydrocarbon Recovery (EHR) specific tax breaks

EHR could be one of the key mechanisms for getting scale in the CCS sector as it potentially provides an additional revenue stream to offset the costs of any CO_2 storage hub, as well as improving the UK Balance of Payments.

However the very high marginal tax rates in the oil industry work against EHR and actually create a barrier to CCS – these disincentives would have to be removed wherever possible (e.g. through the use of brownfield allowances for Enhanced Oil Recovery (EOR) and Enhanced Gas Recovery (EGR) schemes).

This will not only work to drive economic development of EHR (thereby providing a potential additional revenue stream to projects) but also encourage the large oil and gas companies to take a greater role in the development of the CCS industry.

3.2.4 Market creation

This section covers regulatory or policy actions that seek to create a market for a product that is currently not available (generally due to market failures or barriers).

CO_2 leakage liability

The industry will be expected to undertake continual improvements to minimise the technical risks of leakage liability. However there will continue to be a non-zero risk of CO_2 leakage from geological storage sites.

Section 2.1.4 describes how the EU CCS Directive currently creates a liability for CO_2 stores and a requirement for the provision of financial security to address pre and post-closure monitoring and CO_2 leakage. For the Commercialisation Programme projects there is expected to be some form of sharing of liabilities with governments to enable these projects to progress. There is currently no clear mechanism in place for risk sharing on longer term projects.

In theory, operational and long-term post operational risk could be partially mitigated for a project developer by taking out insurance against leakage (and indeed regulations may require the developer to do so) if suitable products were available on the insurance market. As CCS is a very new industry commercial insurance options for CCS projects are likely to be limited with bespoke terms required to match tenures etc. Where insurance is available it is likely to be relatively high cost, which along with the limited source of products available will discourage investors from undertaking storage exploration.

Intervention in the market to address such a scarcity could come in the form of clear guidance on the maximum leakage liability levels to be covered by projects with anything above these levels covered by Government. Alternatively or in addition, a pooled insurance system (with parallels in the nuclear industry) potentially initially funded via a levy could be used. This should enable lowering of costs as it would be on standardised terms and the communal risk of leakage should be much lower (low probability, high impact event). As the industry develops commercial products should develop and the need for this intervention will fall away

Payment for option contracts for pipes and stores

An option contract sold by a pipeline company would grant the purchaser the option of CO_2 capacity in a certain year at a pre-defined price (in exchange for a fee). Similarly an option contract sold by a storage company would grant the purchaser the option of storing a volume of CO_2 in a certain year at a pre-defined price. In some ways this mechanism is comparable to long-term capacity booking that currently takes by LNG shippers at regas terminals.

If long-term option contracts were offered and could be taken up sufficiently far in advance, they can provide good signals to pipeline and storage developers of the need for additional CO_2 capacity, give a level of price guarantee to both sides and also secure a revenue stream for the underlying pipeline of transport and storage development. However, it is likely to take some time for this form of contract to become established and would initially appear to be a longer term market development once some infrastructure is already in place. In addition, their scope to address the very large volume risks for CTS infrastructure may be limited and such contracts seem likely to form part of a package of solutions to address volume risks rather than a panacea.

Currently the development of such option contracts will be hindered by a lack of clarity on the future location of storage and capture projects as well as financial issues such as the credit worthiness of counterparties. Greater clarity on the need and location of sources and sinks for CO_2 as well as support through early government support for new projects (e.g. through early CfD FiT strike-price offers) would encourage growth of this particular form of risk reduction measure.

Agreements for Leases (AfL) leasing rounds

AfLs are currently offered by TCE, granting exclusive rights for potential permanent storage in certain blocks. Currently a developer would need to be participating in a public competition to be awarded an AFL and therefore demand for these have limited to entrants into the UK Commercialisation Programme.

There is the potential for TCE to drive further interest in storage and give greater certainty over long-term storage accessibility in the UK by creating leasing rounds (or other early competitive processes) for the award of AfLs in strategically important storage sites. This would most likely be used as part of a package of interventions that are targeted at reducing volume risk for developers.

Long-term capacity auctions for storage

Another option is to develop a long-term capacity auction that would grant storage rights for set capacity lots to the 'highest' bidder, through an auction process (in a similar way to those currently run for gas storage and gas pipeline capacity).

Assuming that there was demand for storage then this process could be run competitively – however this concept may also be regarded as market foreclosing and if this is the case Government support will be required for any auctions. The requirement for a clear underlying demand for storage (and a knowledge of bidders willingness to pay) means that this form of intervention is probably only applicable as a mid to late stage option for removing volume risk.

3.2.5 Knowledge generation

Knowledge generation interventions include R&D, health and safety and public engagement/guidance programmes. This section of the report describes two of the most promising interventions.

Public engagement programme

As discussed in Section 2.1.1, a national level public engagement programme will be required to overcome a very real barrier to CCS – public opposition. Furthermore, on a very local level CCS projects will be new to the places they are constructed, creating danger of additional opposition even if it is accepted as a route to lower UK carbon emissions. The most likely places where opposition could occur will be near capture plant locations and close to onshore pipelines. In other countries the greatest challenges for local public opposition have existed where storage sites have been planned onshore creating a real barrier and preventing projects proceeding. This should not be such a problem in the UK as storage will be offshore.

It would seem sensible to target a programme of local engagement in areas where clusters of CCS projects seem likely to develop. Cluster developments will lead to repeated interactions between local public and project developers – so likely increasing the strength of feeling on both sides. Adopting early proactive intervention has the potential to prevent knee-jerk reactions and achieve harmony by emphasising the well-documented local benefits of CCS (jobs, growth etc.).

R&D on storage (e.g. improved CO_2 storage monitoring techniques)

Perceived storage leakage risk is undoubtedly a large barrier to deployment of CCS at present. Monitoring of CO_2 after it is stored in the geological formation will be vital to proving that CO_2 is not leaking from a particular site (or indeed, dealing swiftly with the issue if it is). Such monitoring will likely be relatively costly for early sites as the best techniques are not yet known and initial projects will need to carry out far more monitoring than is strictly necessary. R&D activity that focuses on storage monitoring could help reduce perceived risks for storage and potentially decrease costs of monitoring.

The earlier this R&D is undertaken the more quickly it could feed into site selection and monitoring choices for future projects as well as regulations on CO_2 monitoring.

3.2.6 Intervention Options Summary

There are clearly many intervention options available to supplement the current regime with targeted interventions to address specific infrastructure risks. However they have quite different attributes – to understand better how they could fit together participants at the intervention options workshop were asked to give their opinion on the applicability of interventions to the CCS industry. Table 4 summarises the responses on the basis of the following dimensions:

- Feasibility of implementation – reflecting the ease of application and likelihood of such an intervention;
- Timeliness of deployment e.g.
  - Early: Technical proving;
  - Middle: Targeted deployment; and
  - Late: Commercial competitive deployment
- Which party is best placed to undertake the intervention (or which combination of parties); and
- The mechanism by which the intervention drives forward the market (toward the next gateway);

Table 4 – Intervention Options Summary

Intervention Intervention Type	Intervention	Feasibility of implementation	Likely Intervention 'stage'	Which party best placed?	Mechanism and Impact
Financial incentives	Direct CTS revenues under EMR framework	Medium	Mid	Government	Lower contract risk, encourages hubs
	Centralised funding models for T & S	Low	Mid/Late	Government/ Industry	Less risky business model so lower transport and storage hurdle rates
	Grants for storage characterisation	High	Early	Government, Industry	Lower risks on Storage, potentially encourages hubs
	Purchase guarantee by government	Low	Early/Mid	Government	Lower risk to T&S so strong impact on WACC
Tax breaks	Cross-sector tax breaks	Medium	Early	Government	Encourages more equity and faster build out. Potential for relatively large treasury impact
	EHR tax breaks	High	All	Government	More equity available so faster build out Negative tax impact short-term
	Sector specific tax breaks targeting hubs	High	Mid/Late	Government	Target at new hubs, cost neutral – lower strike price but lower tax revenue
Market creation	CO_2 storage liability aggregation	High	Early/Mid	Government / Industry	Lower insurance costs for store
	Options contracts for T & S	High	Mid	Industry	Lower of risk reduction and encourage investment
	Leasing rounds for AfLs	High	Early/Mid	TCE	Targeted at hub creation, reducing some risks to stores
	Long-term storage capacity auctions	Medium	Mid/Late	TCE / Industry	Lower risk for storage and potentially for generator so can reduce hurdle rate
Knowledge generation	Public engagement programme	High	Early	Government, Industry, TCE	Shorter lead times, lower risk/cost
	R&D on CO_2 storage and monitoring	High	Mid	Government, Industry, TCE	Lowers storage monitoring costs and storage risks

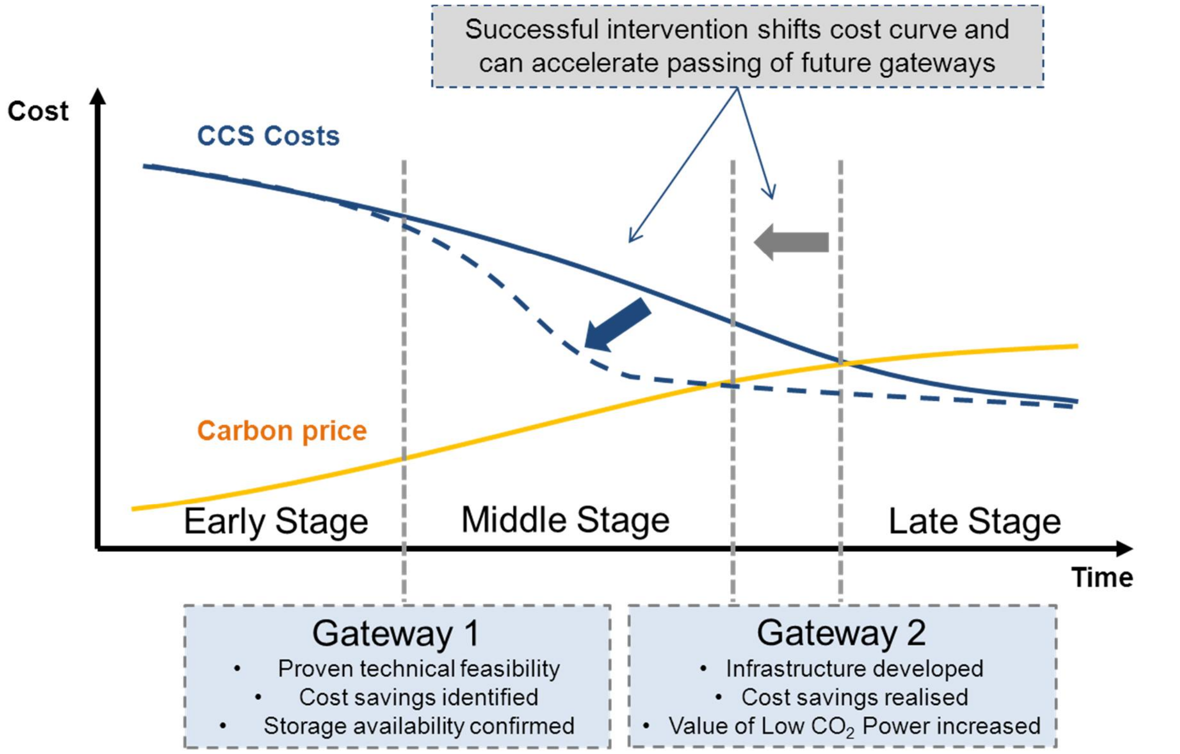
3.3 Implications of interventions for roll-out

3.3.1 Phasing of interventions

Optimal policy choices for CCS will need to develop in parallel with the industry as it evolves and matures. Whilst early policies should aim at removing technical and commercial barriers to CCS, later policies need to increasingly focus on incentivising the widespread deployment of CCS by minimising costs and incentivising optimal commercial behaviour.

Applied appropriately they could shift any deployment path of CCS by accelerating the speed with which CCS moves through its lifecycle.

Figure 4 – Potential for interventions to accelerate the industry lifecycle



In particular early phase interventions will help address current market failures in the CTS sector and all other things being equal, help CCS achieve the requirements of passing through the gateways by:

- Lowering the cost of CCS – either directly or indirectly through lowering of risk;
- Encouraging the development of the required infrastructure for long-run CCS deployment
- Help proving the required storage resource.

Although the costs may be similar for the earliest projects with or without additional early phase interventions (as full chain projects will be required by definition), actions taken now can set a landscape to drive to a lower cost path in future phases of deployment. They can also enable the quicker development of follow on projects and accelerating the point at which CCS support can be reduced as it becomes competitive with other low carbon generation sources.

Potential scenarios for the development of the CCS sector and the roll out of CCS are considered in Chapter 4.

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4. IMPACT OF INTERVENTION

4.1 Introduction

The regulatory and policy framework will determine the risk faced by all investors along the CCS value chain. Section 2.3 showed how the scope for the future roll-out of CCS will be limited by current risks and market failures. Unless additional interventions are made, these risks, especially in relation to transport and storage infrastructure, will not be effectively dealt with and will result in:

- a tendency to develop **smaller stand-alone projects** due to co-ordination failures and missing markets for providing shared transport and storage infrastructure;
- **slow roll-out of CCS** projects due to restrictions on available capital, delays caused by a lack of public knowledge and acceptance, and a lack of incentives to speculatively develop storage hubs; and
- **industrial CCS developing very slowly in non-power industrial sectors** in the absence of a strong carbon price signal (or other revenue signal).

Section 3.3 described a package of interventions that would address the risks and market failures. While the suite of intervention options would adapt to reflect the growing maturity of the industry, additional early phase interventions, occurring in parallel with current policies, could potentially lower costs and accelerate the progress of the CCS industry by:

- de-risking development of networks and so encouraging sharing of all infrastructure and creating a greater appetite for early development of large storage opportunities;
- stimulating novel business models and new markets that help to decouple power station investment (from transport and storage), and encourage participation from non-power industrial sectors; and
- improving access to capital for developers and addressing potential issues with public perception to lower the risk of project delays.

We initially examine the outlook for scenarios of CCS deployment in the absence of further intervention before addressing the scope for policy interventions to improve the outlook for CCS.

4.2 CCS development under the existing policy regime

4.2.1 Existing policy drivers of CCS development

At present, Government focus lies almost entirely on power sector decarbonisation, with the need for CO_2 transport and storage generally only being considered as a consequence of this aim. Without any intervention, the evolution of the CCS sector will be dependent on the incentives and risks inherent in the current policy and regulatory environment, notably:

- Core funding support is based on a ‘trickle-down’ approach, such that the CfD FiT is required to fund all the costs of generation, capture, transport and storage. The power station is generally assumed to develop a JV with transport and storage.
- The only additional financial incentive assumed is the £1bn grant from the CCS Commercialisation Programme (spread across projects developed from 2018 to 2020).

Section 2.3 highlights how current risks and market failures facing the CTS sector remain unaddressed by the existing policy and regulatory framework conditions, which mean that projects will be exposed to relatively high risk.

EMR as it stands looks to address only those failures impacting the Capture of CO2 and does not address the Transport and Storage market failures above directly. It seems unlikely to encourage the paradigm shift to a new view of CO2 but rather, may well drive a comparatively slow development of isolated single chain projects with individual solutions to their infrastructure. EMR thus potentially forgoes the opportunities to develop far more significant infrastructure which benefits from economies of scale and risk reduction as infrastructure grows in size and diversity.

At the moment there is a wide range of views within the stakeholders of the issues and failings: for example, industry opinions that there is a valuable business predicated on the availability of cheap and efficient CO2 storage, while DECC is taking an approach that the development of the CTS can be demand-driven from the generation side without further need for intervention.

It is already clear that the development timescales for the different components of a capture plant compared to pipeline infrastructure and storage facilities could form a major barrier to rapid deployment: while a capture facility could take as little as four years from development to operation, a storage site based on aquifer storage could have a development timescale closer to ten years. This could be a significant constraint on storage in the 2020's if nothing is done to address this mismatch.

4.2.2 Market drivers of CCS development

External market factors will also contribute to the speed of roll out of CCS. Primarily these can be thought of as external profitability drivers for CCS broadly outside the influence of UK intervention or policy.

Two of the most important drivers influencing this are:

- Commodity markets – Gas and coal prices will strongly influence the cost of thermal power projects in the UK and yet they are driven primarily by international factors. This is particularly relevant if wholesale electricity prices do not move in tandem with fuel price movements (such as the recent very large dark-spreads and the consequent increase in unabated coal fired power output); and
- Relative movements in costs of other low-carbon generation technologies such as renewables and Nuclear power. In a future where other forms of low carbon power have reduced costs below CCS-equipped power plants the growth of CCS would be significantly less.

A further example would be movements in carbon prices – however we have not examined this impact directly as we assume that Government's current plans for the Carbon Price Floor are maintained, starting at £16/tCO_2 in 2013 rising to £30/tCO_2 in 2020 and £70/tCO_2 in 2030. The carbon price outlook for the EU ETS is generally expected to be much lower than the carbon price floor and affects UK CCS only through a second order impact on European demand for CCS and knock-on longer term demand for CO_2 storage capacity in the North Sea from CO_2 captured in continental Europe.

This external market environment will determine the relative cost effectiveness of applying capture technology for industry and power compared to other abatement options.

4.2.3 *Non-intervention scenarios*

In order to understand the interactions between the policy and external drivers, described above we have expanded the CCS elements of The Crown Estate's own future energy sector scenarios and investigated these to examine the potential roll-out of CCS in the absence of further market intervention to address the market failures identified in the report. These have been evaluated through the ADAPT CCS model to produce two illustrative scenarios 'Island UK' and 'Gas/Wind Symbiosis' that typify the spread of likely outcomes for CCS. .

Baseline scenario assumptions

Both scenarios had a base set of capital and operating costs assumptions from the DECC sponsored May 2012 report by Mott Macdonald on potential cost reductions in CCS in the power sector. The Mott Macdonald "Low Cost" pathway was used as the basis of the scenarios that have high CCS technology development. To simulate the impact of higher costs in the slow technology development scenarios, an uplift of 30% on capex and opex was assumed (based on analysis of current TCE technology cost assumptions).

Baseline assumptions for expected rates of capital returns for power and capture plant investment were based on standard Pöyry assumptions. Assumptions for the returns of developing the transport and storage system are taken from work of the UK CCS Cost Reduction Taskforce interim report in November 2012[10] – these rates are assumed to decrease somewhat as the industry matures and moves through the industry lifecycle:

- Generation and capture plant projects have an average pre-tax real internal rate of return of 9-12%;
- Transport pipeline projects have a required pre-tax real internal rate of return of 10% (if funded via the current CfD FiT mechanism) falling to 8% as the CO_2 pipeline transport becomes more established in the early 2030's;
- Storage developments were regarded by the CRTF as being the most costly part of the chain to finance and are assumed to have differing return expectations depending on the storage type:
  - 15% IRR for depleted oil and gas field (DOGF) storage falling to 14% for projects in the early 2020's and 12% for projects commissioning in early 2030's.
  - 18% IRR for Aquifer[11] storage falling to 17% for projects commissioning in the early 2020's and 15% by the early 2030's

Fossil fuel prices in the modelling were based on the latest DECC 2012 fuel prices. In all scenarios carbon prices were assumed to rise in line with the carbon price floor trajectory.

Using the current market as a guide the policy and regulatory environment assumptions used for the Island UK and Gas/Wind symbiosis scenarios are:

- Funding is based on a 'trickle-down' approach with CfD FiT required to fund all the costs of generation, capture, transport and storage.

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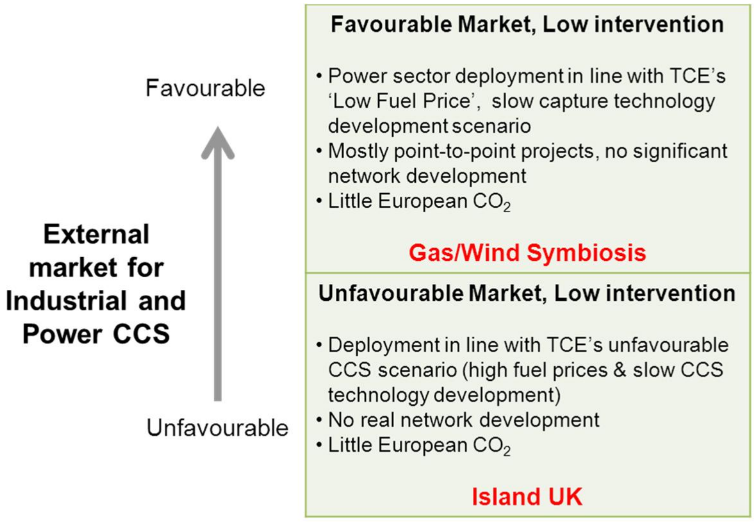
10 Where no assumptions were available Pöyry have supplemented with additional data based on internal Pöyry analysis.

11 Pöyry assume a 3% return expectation uplift for Aquifer storage due to additional exploration risk etc.

- £1bn grant from the CCS Commercialisation Programme (spread across projects developed from 2018 to 2020) only;

To capture the interaction between the policy and external drivers, we have expanded the CCS elements of two of The Crown Estate's own future energy sector scenarios, to produce illustrative scenarios that typify the spread of outcomes for CCS – 'Island UK' and 'Gas/Wind Symbiosis'. The two scenarios examined for roll-out of CCS without additional interventions span a range of fuel prices and technology development rates and are summarised in Figure 5 below. .

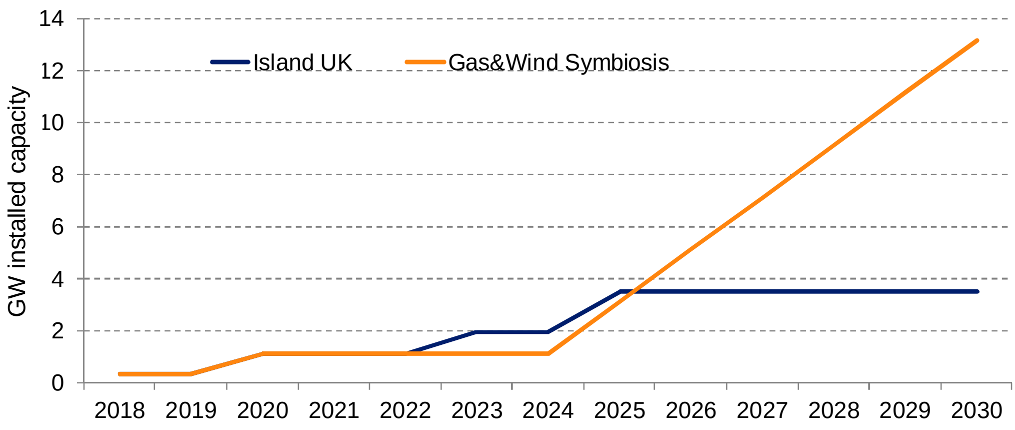
Figure 5 – Overview of scenarios without intervention



CCS deployment in the non-intervention scenarios

CCS roll out in each scenario is based on technology development work from TCE aimed at spanning a range of technology roll out scenarios for offshore wind, onshore wind, nuclear, unabated gas and CCS. Figure 6 shows the cumulative CCS build for the two non-intervention scenarios.

Figure 6 – CCS roll out under non-intervention scenarios



Both the Island UK and the Gas/Wind Symbiosis scenario assume that UK CCS Commercialisation Programme is successful in developing two full chain CCS projects before 2020.

The Island UK scenario has three more 1-1.5GW projects added in a second phase of pre-commercial construction so total capacity reaches 3.5GW by 2025. After that point, because the industry has not developed sufficiently to realise material cost reductions as envisaged in the transition to the second policy gateway, CCS cannot compete effectively against other carbon abatement options and no more is constructed.

The lack of relative competitiveness that stifles development in the Island UK scenario is as much a consequence of changes outside the CCS sector as it is of limited cost savings within the sector.

This situation could easily be reversed with significantly more positive implications for CCS development, as represented in the Gas & Wind symbiosis scenario. Here, while CCS build is slow to reach commercialisation, as in the Island UK scenario, a more benign external environment, characterised critically by low gas prices, means that CCS remains a competitive carbon abatement option despite limited technology cost improvements. Deployment therefore begins in earnest from 2025 onwards with around 2 GW of gas-fired CCS commissioned per year, enabling total CCS capacity to reach around 13GW by 2030

Even though both scenarios assume the successful deployment of the UK CCS Commercialisation Programme[12], capacity in the Gas/Wind symbiosis scenario ends up around 4 times that in the Island UK scenario. These scenarios demonstrate the wide range of possible CCS futures if the currently proposed market structure is left to its own devices.

As the roll out of CCS under the current policy regime is both slow and uncertain, there is an expectation that progress through the policy lifecycle will also be slow and uncertain. Figure 7 shows how these scenarios translate to an indicative timeline against the policy lifecycle above:

- In the case of the Island UK scenario the lack of progress in deployment and high relative cost of CCS in this scenario imply that progress is much slower through Gateway 1, from the first to the second phase of policy;
- Neither scenario completes the transition through Gateway 2 to the final commercial phase of deployment before 2030 as they both still require targeted interventions and significant subsidies in the form of CfD FiTs.
  - In the Gas/Wind symbiosis scenario, Gateway 2 can be assumed to be reached sometime beyond 2030, as the value of predictable low carbon generation increases and the cost of CCS continues to fall, albeit slowly, through technical learning;
  - The Island UK scenario will not necessarily reach the second gateway as infrastructure is not developed and cost savings are not realised. Commercial deployment is therefore severely restricted and alternative forms of Low Carbon Generation are installed.

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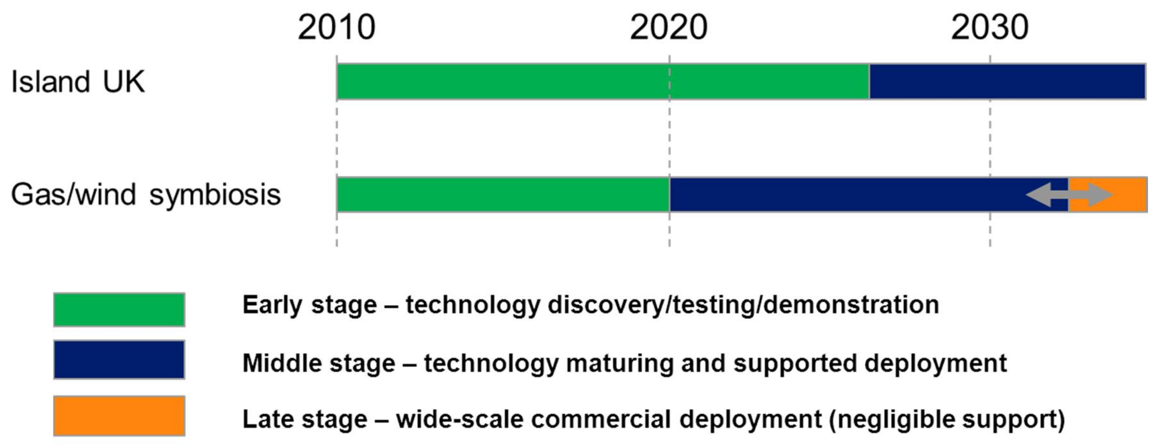
12 It should be noted that whilst we have considered a range of CCS roll-out scenarios, there is also the possibility that CCS roll-out could be lower even than the lower bound shown if for example the current CCS Commercialisation Programme is unsuccessful.

Figure 7 – No intervention scenarios: CCS development timeline



4.2.4 Implications for required CCS support levels

The external environment can also have a significant impact on the cost and effectiveness of the policy package. In a lower fossil fuel price world the required strike price for CCS will be correspondingly lower. In the Gas/Wind Symbiosis scenario, estimated CfD strike prices are in the range £95-£115/MWh, dependent on fuel type (gas or coal) and time of commissioning (taking account of improvements in cost). This contrasts with the Island UK scenario, where unfavourable market conditions make CCS generally expensive and estimated strike prices are in the range of £115-£145/MWh.

The difference payments made by government through the CfD and hence the expected cost of carbon abatement via CCS could therefore be very different unless fuel price variations are fully reflected in changes in the reference price for the CfD. If out-turn wholesale prices in both scenarios were consistent with DECC's central projections[13], this variation in support costs would be very stark. Under the Island UK scenario abatement costs would be around £150/tCO_2 abated, compared to £50/tCO_2 in Gas/Wind Symbiosis.

The figures above are illustrative and we would expect some reduction in this differential in reality, through variations in wholesale prices and/or elements of strike price indexation within the CfD. However, because the Gas/Wind symbiosis scenario advances through the first policy gateway more quickly and is able to achieve some benefits of scale through additional deployment in the 2020's, the unit abatement cost would still be expected to be lower.

[13] This study did not intend to model consistent wholesale price projections for each scenario and therefore has relied on latest existing data from DECC for wholesale power prices.

4.2.5 Summary of outcomes for Island UK and Gas/Wind Symbiosis

Island UK Scenario:

No new interventions
Unfavourable external market

In the Island UK scenario, the lack of movement to address risk from a policy and regulatory perspective combines with an unfavourable external market and slow CCS technology advancement to make CCS generally less attractive (on a risk/reward basis) than other forms of Low Carbon Generation. This severely limits the take up of CCS in the UK with CCS development restricted to two demonstration size plants by 2020 (through support in the UK CCS Commercialisation Programme) and three subsequent early commercial plants in the period to 2030.

Transport and storage networks use a point-to-point system as there is no separate market mechanism to drive independent transport and storage and the development of new projects is too slow and uncertain to drive networking behaviour.

Industrial sources of CCS do not develop due to a lack of incentive for them to decarbonise, and a lack of development in the Transport and Storage network. There is no CCS developed in Europe by 2030 due to the adverse market conditions.

Gas/Wind Symbiosis Scenario:

Favourable external market
no new interventions

A 'medium-paced' development scenario, illustrating the upper limit of CCS roll-out if there are no new interventions in the market.

Fossil fuel prices are low and the costs of alternative technologies are relatively high. CCS is therefore generally attractive compared to other forms of low-carbon generation despite slow progress on technology innovation and infrastructure sharing. Alongside wind, gas based CCS is a significant producer of low-carbon power in the UK.

This leads to a reasonably high-level of roll-out of CCS post-2025 to meet decarbonisation aims, in addition to the demonstration projects supported by the UK CCS Commercialisation Programme. Despite the prevalence of carbon capture projects, development is still along the lines of point-to-point networks with only limited sharing of infrastructure where very obvious benefits arise (to offset the increased contractual risks).

CCS in Europe develops slowly up to 2030 despite some signals provided by the market conditions for its development as European CCS regulation lags behind that in the UK. As in Island UK, Industrial sources of CCS do not develop due to a lack of incentives and a lack of 'spare' capacity in the Transport and Storage network.

Our CCS scenarios reflect the general characteristics of sector development that are likely to occur without intervention.

We conclude that in response to the risks we have identified, our expectation is that project developments are more likely to proceed on a stand-alone basis, meaning that:

- the sector may fail to realise many of the economies of scale that can be achieved in the transport and storage activities, resulting in increased capital and operational and contingency costs of around 30% compared to an optimum development path[14];
- transport and storage will evolve on a point-to-point basis; and
- projects will generally be smaller as access to funding will be harder and the risk of oversizing will be higher.

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14 Based on analysis from Mott MacDonald and The Crown Estate future energy scenarios on divergence of technology costs with different technology development assumptions.

4.3 Impact of additional intervention on the CCS sector

4.3.1 An alternative policy intervention framework for CCS

In Section 3.3 we concluded how a more tailored package of targeted interventions may be desirable to mitigate the risks and market outcomes described above. These interventions included:

- Financial incentives focused on individual segments of the value chain to ensure funds reach targeted activities, reducing reliance on the 'trickle down' support via the FiT payment and potentially bringing forward the timing of support payments to reduce barriers to raising capital.
- Fiscal incentives (tax breaks) applied using adjustments to the UK taxation system to improve returns for projects and encourage new sources of capital.
- Regulatory or policy actions that seek to create markets for products that cannot currently be traded (due to market failures or barriers). These will focus on enabling efficient provision of leakage liability insurance and establishing markets for CO_2 storage and transport capacity.
- Knowledge generation actions such as R&D spending, health and safety and public engagement and guidance programmes to remove misperceptions surrounding the technology and improve access to information for all potential developers.

Within this framework, we propose an alternative policy and regulatory structure that addresses the risks and market failures but also adapts as the CCS industry develops over time.

4.3.1.1 Early Stage interventions

In the early stages of development, interventions should focus on reducing the risk associated with developing transport and storage to mitigate the impacts of long lead times, imperfect information or knowledge transfer, high capital costs and coordination failures. The actual suite of policies would be in addition to the current policy regime rather than replace it and include the following elements.

- The £1bn grant from the CCS Commercialisation Programme is applied to projects in the period 2018-2020.
- CfD FiT funding provided to Generation and Capture plants to ensure a return on investments.
- Providing targeted grants to storage developers before 2025 during the pre-construction and construction phases to encourage the characterising of stores (particular saline large aquifer storage), lowering risks to storage developers and compensating for knowledge and risk spill-overs from developments.
- 'Cross-sector' tax breaks to encourage new sources of capital to enter the market – helps to lower the cost of equity finance.
- Centralised provision of leakage liability insurance in the short-term to medium-term to reduce the costs to stores.
- Provision of government volume guarantees to reduce the risks for new storage and transport development in the short-term and medium-term and enable more speculative investment in additional storage and transport capacity.
- Public engagement programmes and government R&D programmes help drive down the investment costs and risk of CCS.

For the Transport and Storage sectors this package of new interventions offers investors and developers alternative business models for CTS and enables them flexibility to develop the CTS chain as separate activities, broadening the range of services and players in the market. As a consequence of the measures proposed the target IRRs for developers should fall – in the modelling target IRRs are assumed to fall by 3% for storage and 1% for transport[15].

4.3.1.2 Middle stage interventions

As the sector evolves, the form of intervention should adapt to reflect the growing maturity of the system and the establishment of viable hubs and transport networks. The focus should shift to deployment of capture projects utilising shared network and storage infrastructure. This will also imply a greater emphasis on the operation of the networks and issues such as codes of practice and Third Party Access. As the system moves through the second gateway, the policy instruments required should:

- Continue CfD FiT funding for to Generation and Capture plants to ensure a return on investments.
- Target reduction of the corporation tax burden for all stages of the CCS for projects developing new capture clusters, storage hubs and/or integrated networks.
- Target R&D spending to drive down capital and operational costs (e.g. through step change CO_2 capture techniques and CO_2 storage monitoring).
- Drive the development of long-term signals for storage and transport requirements via storage capacity auctions and/or options markets.

4.3.1.3 Late stage interventions

Though it is a much longer horizon, as the sector evolves, we would envisage much of the direct financial support to become less relevant as CCS is stimulated by a technology neutral price instrument. Focus should shift further towards ensuring the efficient and competitive operation of the CTS infrastructure for cost competitive capture opportunities in industrial and power generation applications across the UK and Europe. It is anticipated that:

- CfD FiT funding falls away as power and carbon prices rise (falls almost to zero in the Greener Gas scenario by late 2020's as the overall required tariff level falls close to the level of DECC Central wholesale prices).
- Centralised funding business models for the transport network and (potentially) storage hubs as industry maturity and scale develop.

Adding in the current interventions from 2.2.1 to the options for additional intervention above, Table 5 below summarises the options by their likely stage for application in the market.

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[15] Resulting Transport sector target IRRs are restricted from being much lower than this level as they are moving towards a 'floor' level for IRR expectations in a regulated asset base business.

Table 5 – Phasing of interventions

	Early Stage (Technical proving)	Middle Stage (Targeted deployment)	Late Stage (Commercial or enduring regime)
Financial incentives	• Power sector FiT • Direct grant to start initial hubs (e.g. Commercialisation Programme) • Grants for storage (especially for aquifers) • Government purchase guarantee	• Power sector FiT • Separate tariff for CO_2 storage – relevant if a large volume being stored	• Carbon price only • Centralised direct funding model for transport (regulated monopoly) • Centralised direct funding model for Storage (regulated monopoly)
Tax breaks	• Tax breaks for EHR • Cross-sector tax breaks to encourage participation from more companies.	• Tax breaks for EHR • Sector specific (e.g. accelerated depreciation) encourages hubs	• Sector specific (e.g. accelerated depreciation) to encourage new hubs only (addresses specific enduring barrier to entry)
Market creation	• Storage liability aggregation • Options contracts for AfLs	• Storage liability aggregation • Option contracts for Transport and Storage hubs • Storage capacity auctions	• Insurance industry provides aggregation • Storage capacity auctions
Knowledge generation	• Public engagement programme	• R&D on storage and monitoring	

4.3.2 Scenarios with strong intervention

By implementing a suitable package of incentives and regulatory regime that reduces industry risks CCS development should accelerate. While there will still be some residual exposure to the external market, the de-risking will reduce costs for CTS and make scale economies more achievable.

Our modelling of the implied transport and storage costs in response to these additional interventions illustrates the materiality of this shift. Whereas without intervention (Island UK and Gas/Wind Symbiosis) transport costs were around £10/tCO_2 over the period 2013-2030, the additional intervention options lower this substantially. Lower capital and contingency costs and reduced IRR requirements result in transport costs around 40% lower at £5.5/tCO_2.

A similar effect is seen in the storage costs. Storage costs in the non-intervention scenarios are £16-17/tCO_2 over the period 2013-2030. With intervention, targeted de-risking of storage sites and leakage liability insurance aggregation lead to lower return requirements and the development of storage hubs with lower capital costs per unit of CO_2. The average cost of storage falls as a consequence to around £11/tCO_2.

As a result we will see a shift – the 'Island UK' outcome will be improved as demonstrated in the 'Localised World' scenario, and the 'Gas/wind symbiosis' scenario would shift as described below to a 'Greener Gas' scenario.:

Localised World Scenario:

Strong CTS interventions
Unfavourable external market

Localised World is a scenario which illustrates how timely and targeted market interventions that reduce costs and risks, can lead to acceleration in CCS industry development and a reasonable level of roll-out even if the external market is less favourable.

Despite high fossil fuel prices the package of targeted and timely interventions drive forward the CCS industry decreasing risks and lowering the capital costs of CCS. Other technologies also develop quickly in this scenario meaning that there is strong competition for the provision of Low Carbon Power.

The roll-out of 2 demo-sized projects before 2020 is supported by the UK Commercialisation Programme. Post 2020, shared pipeline and storage hub development is accepted as standard wherever possible, with the networks building out from opportunities created by the initial demonstration projects. New hubs and networks are enabled by specific targeted interventions creating markets and removing volume risk. A total of 6 GW of coal & gas CCS capacity is connected to networks by 2025 with 11 GW installed by 2030.

Despite the increased availability of storage capacity in the North Sea (due to the de-risking of storage development), European CCS does not send significant volumes to the UKCS in this scenario due to the limited European appetite for CCS.

Greener Gas Scenario:

Strong CTS interventions
Favourable external market

The final scenario, Greener Gas assumes that an optimal package of interventions combines with favourable market conditions to create a much accelerated development of the CCS industry.

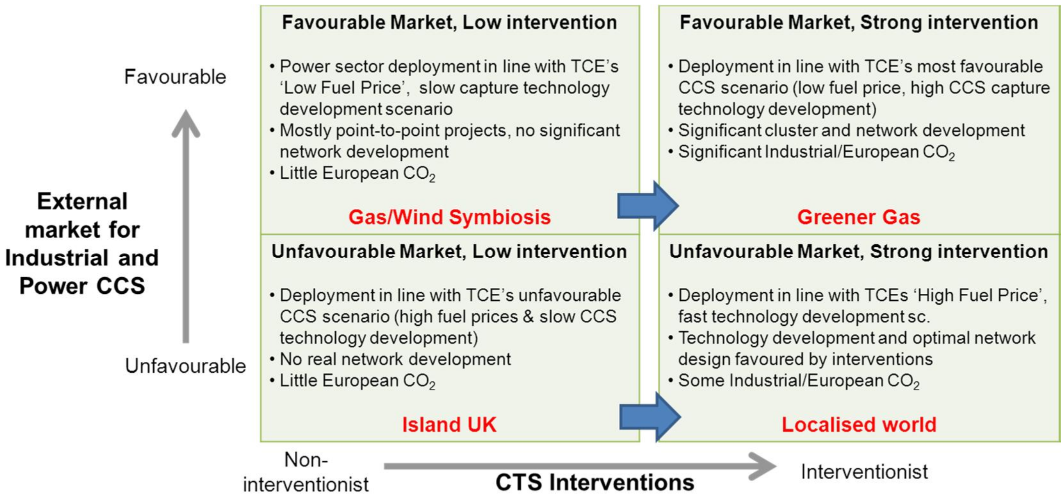
Fossil fuel prices are low and alternative technology costs are relatively high creating a strong market driver for CCS as they key option for decarbonising the UK power sector. Interventions in this scenario are focused on quickly driving down costs and progressing the industry meaning that the industry moves quickly through the development stages.

Roll-out of 4 demo-sized projects before 2020 is supported by the UK Commercialisation Programme and follow up support from the CfD Fit mechanism. Significant new gas CCS capacity is installed by 2025 and 2030 connected to a very extensive network of pipelines and storage hubs. This network of transport and storage enables the participation of non-power industrial CO_2 sources where incentives to decarbonise these sectors are provided.

European appetite for CCS storage in the North Sea is high in this scenario as CCS is established in Europe and the North Sea is developed and is internationally attractive for widespread CO_2 storage.

The interactions between these four scenarios are illustrated in Figure 8 which shows the effect of the two drivers of CCS development highlighted in the previous discussion (external market conditions and existence of CTS intervention).

Figure 8 – Overview of scenarios

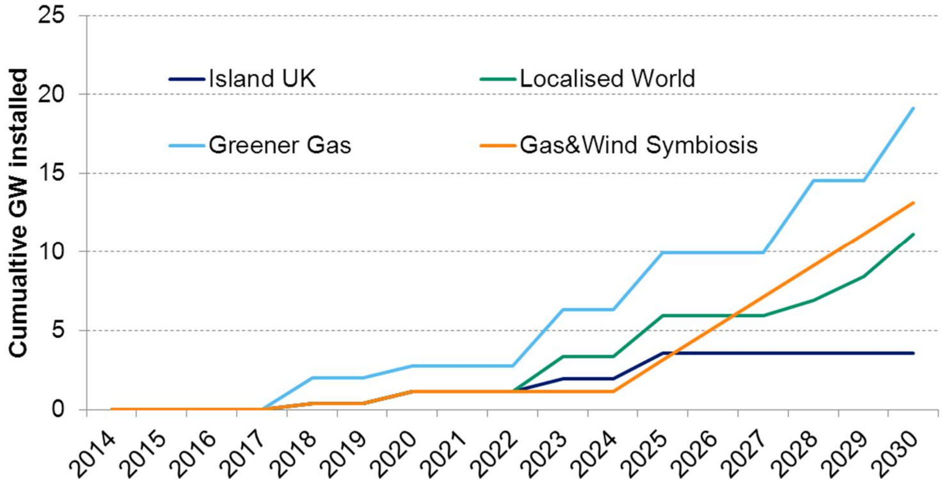


CCS deployment in the strong intervention scenarios

The cumulative deployment of CCS for both the non-intervention scenarios and strong intervention scenarios are shown in Figure 9.

The impact of the additional interventions is to increase the development of CCS. In unfavourable external market conditions, the lower cost and risk result in an increase in total installed capacity from 3.5GW (the Island UK scenario) to 11.5GW in the 'Localised World' scenario by 2030. In the 'Greener gas' scenario roll-out reaches 19GW by 2030. The interventions combine with the favourable market conditions to push the deployment path forward significantly in time from that seen in Gas & Wind Symbiosis scenario (favourable market, non-intervention scenario). Both of these scenarios are gas CCS dominated.

Figure 9 – Cumulative GW roll out of CCS by scenario



The combination of interventions decrease risks and costs, combat market failures and improve access to finance for the CCS industry to the extent that, even with adverse external market conditions, CCS development is sufficiently strong to step through the policy gateways and begin to establish a viable industry in the 2020's. Figure 10 illustrates the impact of the interventions on the progression through the policy lifecycle of all four scenarios.

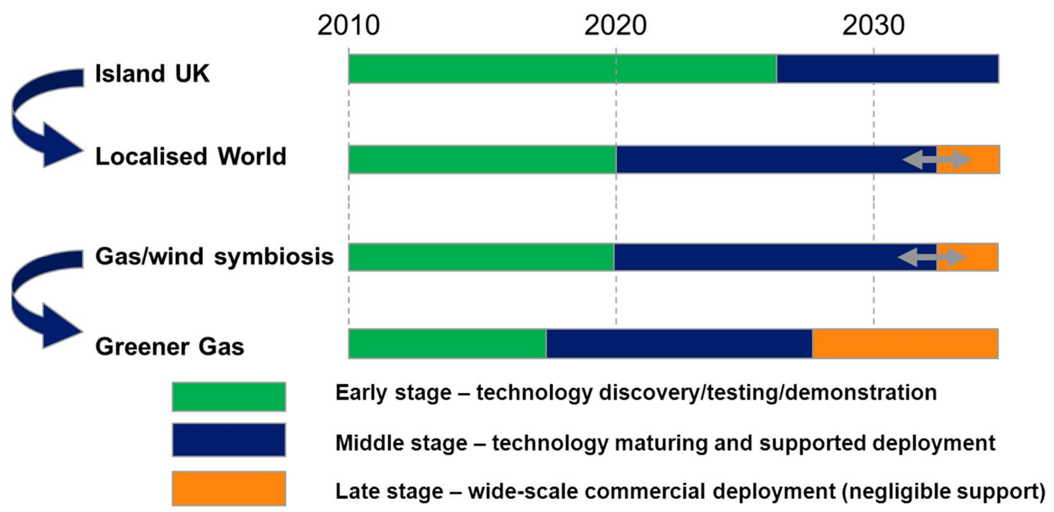
Both the 'Localised World' scenarios and the 'Gas/Wind symbiosis' scenarios progress through the Gateways at similar points (the first around 2020 and the second Gateway in the early 2030's) albeit for different reasons:

- The strong influence of external market conditions in 'Gas/Wind symbiosis' means that it develops with point-to-point transport and bespoke storage solutions as a standard business model. Any cost savings are largely due to low fossil fuel prices and risks discourage development of shared transport and storage. In the long run low fossil fuel prices and slow development of other low-carbon technologies increases the value of stable low-carbon power to the point where CCS becomes a viable commercial proposition.
- In contrast the 'Localised World' benefits from the targeted interventions and de-risking of the full chain of CCS. So transport networks and storage hubs develop

and lead to cost savings for CCS projects despite the higher fuel prices. Even though other low-carbon technologies are also comparatively low cost, CCS is able to steadily progress through progressive interventions such that it is able to deliver competitive low carbon power in the early 2030's.

Finally, in the 'Greener Gas scenario, it passes through Gateway 1 before 2020 as a second phase of small scale CCS projects benefits from the lessons of the UK CCS Commercialisation Programme. Interventions to de-risk infrastructure sharing encourage the growth of a core of networks and hubs around existing infrastructure. By the late 2020's de-risking of CCS, low fossil fuel prices, sharing of infrastructure and relatively fast CCS technology development combine and Gateway 2 is reached in the late 2020's. By this point CCS is commercially viable such that very little specific project support is required (in the form of government subsidies) to deliver a continued commercial roll-out of CCS in the UK.

Figure 10 – CCS industry development timeline by scenario



4.3.3 Comparison of key scenario results

Using the full-chain CCS discounted cash flow model "ADAPT CCS" developed for this project[16], key sector performance metrics for the sector have been projected for each of the four scenarios. Full details on the results for each scenario are contained in Annex C, and Table 6 summarises some of the main financial and cost outputs including:

- Weighted Average Cost of CO_2 transport for all CO_2 pipelines developed over the period 2013-30;
- Weighted Average Cost of CO_2 Storage based on all CO_2 storage sites developed in the UK between 2013 and 2030;

16 Details of ADAPT CCS structure and methodologies are summarised in Annex B.

- A measure of the cost to Government[17] of CO_2 abated using CCS; and
- The implied strike price under the CfD FiT approach in £/MWh for coal and gas fired CCS in each scenario for 2018-2020, 2021-2025 and 2026-2030.

Table 6 – Cross scenario comparison of results

Scenario	Abatement cost to Gov. [£/tCO_2]	Weighted Av. Trans. Price [£/tCO_2]	Weighted Av. Storage Price [£/tCO_2]	FiT for Gas CCS [£/MWh]			Fit for Coal CCS [£/MWh]		
				2018-20	2021-25	2026-	2018-20	2021-25	2026-
Island UK	151.3	9.2	17.0	130	115	115	125	145	145
Localised World	104.7	5.2	11.1	115	104	104	105	123	120
Gas & Wind Symb	50.5	9.0	16.2	110	96	96	113	N/A	N/A
Greener Gas	42.6	5.9	10.6	92	85	85	110	105	105

Transport and Storage Costs

As we have already commented, transport and storage costs in the intervention scenarios (‘Localised World’ and ‘Greener Gas’) are materially lower than those in the non-intervention scenarios (Island UK and Gas/Wind Symbiosis). The differences arise because the intervention scenarios enable developers to benefit from lower risk (lowering contingency and IRR requirements) and encourage the development of shared infrastructure, giving rise to greater economies of scale. In addition, for storage developers, leakage liability insurance aggregation also serves to de-risk projects and reduce insurance costs.

One point worth noting is that in some cases transport costs may increase as the overall market grows. The Greener Gas scenario (which has the highest deployment) has a transport cost of £5.9/tCO_2 compared to £5.5/tCO_2 in the Localised World scenario. As the CCS market expands and transport networks get larger there are benefits of economies of scale as larger diameter pipelines are built, but also average transport distances for CO_2 may increase as the closest capture sites are developed and focus moves to capture plants located further from storage sites. In Greener Gas average distance to store is 500km, whereas it is 350km under Localised World. This highlights the fact that rising transport costs may effectively define the limits of the geographic CO_2 market that UK storage operators may be able to serve cost effectively, even with the benefits of scale.

17 NPV of net government expenditure (in 2012 at 10% discount rate) divided by total volume of CO_2 abated, measured against equivalent electricity generated by an unabated CCGT. This covers CCS plant built until 2030 only, but accounts for operation of plant up to 2060.

Support costs for CCS

The intervention scenarios provide targeted support to storage and transport that include grants for projects developed to 2025 and a variety of interventions to directly reduce risk and cost.

Consequently, the required strike price in the CfD falls whilst still maintaining the same level of pre-tax returns (and potentially somewhat higher returns post-tax due to the targeted tax breaks encouraging new hub development). The strike price for Gas CCS is £10-20/MWh lower with intervention and beyond 2020, more than £20/MWh lower for Coal CCS.

The alternative financing models are not just a diversion of support from the CfD to other mechanisms. Calculating the total cost of support payments (through grants, tax breaks and CfD difference payments) ADAPT CCS projects that, under comparable external market environments, intervention reduces the cost of abatement for government. The abatement cost (on a £/tCO_2 basis) to government for investing in CCS falls by:

- 30% in the unfavourable market scenarios (from £150/tCO_2 to £100/tCO_2); and
- 15% in the favourable market scenarios (from £51/tCO_2 to £43/tCO_2).

4.3.4 Impact of increasing European and non-power sector Industrial CO_2 flows

Increased CO_2 flow from Industrial CCS and from Europe was not directly modelled in the scenarios but would most likely bring down the storage costs, particularly in the Greener Gas scenario, by increasing the volume stored and size of the hubs. It could also serve to reduce the risks for storage owners (and therefore further reduce costs) by diversifying supply sources.

In a carbon constrained world, the chief benefit for the early adoption of CCS in the industry sector would be that UK industry should have a competitive advantage over their more carbon intensive counterparts. However, industrial CO_2 is unlikely to be a major source of CO_2 for storage (even with interventions to drive take-up) until CO_2 transport and storage is more commonplace[18] from 2020 onwards. Estimates from the CO_2 sense study of the Yorkshire and Humber region suggest that 3.6mtpa of CO_2 is available from medium sized [Tier 1] industrial players in that area.

Estimating the potential for CO_2 flow from Europe is challenging – the total generated emissions are very large but it is unlikely that significant percentages of this will be captured and stored in the North Sea until at least well into the 2020's. In addition the large distances between the North Sea storage resource and European CO_2 emissions may create a natural geographic limit to economic quantities – at some distance shipping of CO_2 may become more attractive but this is currently regarded as a very high cost transport solution.

However as an indicator, if just 2% of current European CO_2 large point source emissions were stored in the UKCS this would equate to around 40m tonnes per annum additional storage demand.

18 A caveat to that is high CO_2 gas sources which may be developed earlier than power CCS.

Essentially European or Industrial CO_2 volumes are not needed to drive CTS roll-out in the UK (and there may be limitations to those volumes) but the potential for CTS infrastructure to drive forward European and Industrial CO_2 capture creates a large upside for the sector.

5. CONCLUSIONS

Current challenges for the CCS sector

Despite its potential, the CCS industry still remains in the early stages of its development. The development of the industry to deliver a timely and efficient roll-out of CCS requires coordinated deployment of all elements of the CCS chain (capture, transport and storage).

This project examined how the existing policy and regulatory framework supports this aim and concludes that under the current regulatory and policy framework sector, development of the industry is likely to be slow, relying on relatively uncoordinated deployment of full chain integrated CCS-equipped power generation projects that do little to promote a common transport infrastructure or the development of storage hubs.

The current regulatory and policy framework already recognises that there is a need for intervention in CCS. The government is seeking to address these issues for CCS by providing specific support under the UK CCS Commercialisation Programme and the Electricity Market Reform (EMR) process.

The CCS Commercialisation Programme (CCS CP) is aimed at incentivising demonstration of the full chain of new CCS technologies and gathering operational experience, both of which will help reduce the perception of construction and operational risk. The EMR process will form the enduring regime under which CCS will operate and has two principle components relevant for CCS developers – an underpinning of the carbon price (CPS) and a revenue stream for low carbon power (CfD FiTs). Both of these measures are directed at the power station and capture end of the chain and do not directly address the key risks and market failures faced by the transport and storage sectors. In addition these measures do not address the feedback and impact from the transport and storage market failures that of itself creates a barrier for decisions on power generation and capture.

The project identifies and concludes that there are a number of risks and market failures facing the CO_2 Transport and Storage sector. Capture, Transport and Storage of CO_2 differ by industry type, risk/return profile and their development stage, and must therefore be tackled appropriately. Unless addressed these risks and market failures effectively combine to severely restrict the development of CTS infrastructure and hence the viability of CCS as a future decarbonisation option.

The requirement for swift decarbonisation of the power sector means that the multi-billion pound investments in developing capture, transport and storage solutions must begin while technologies, markets and regulations are still immature and evolving rapidly. Facilitating the development of CCS therefore requires a shift from interventions focused on generation and capture only, to targeted interventions that overcome the specific risks and issues faced at each point of the chain.

Priority requirements for facilitating development

Analysis of feedback from key industry stakeholders collated through workshops undertaken for the project show that interventions options are diverse and that they:

- should be targeted at specific sectors;
- will require all stakeholders to be involved in their delivery (not just government); and

- may vary at each stage of the industry but should do so in predictable way.

Our analysis concludes that early phase interventions that look to tackle the industry's current challenges are the priorities. Interventions that focus on the specific risks faced by the sector will need to be addressed immediately to ensure that projects currently in the pipeline can continue and the CCS industry can continue to develop. Choices made for the initial package of interventions will have a strong influence on whether or not the industry can progress through the policy gateways enabling it to be deployed at scale.

Identified early stage intervention actions include the following:

Financial incentives

Financial incentives include mechanisms that provide alternative revenue streams for development of the CCS chain (generally redirected from FiT payments under the current EMR 'trickle-down' approach). Financial incentives considered for the early stage of industry development include:

- Capital grants targeted at storage characterisation which can:
  - Lower investment risk for storage developers to counteract coordination failures;
  - Encourage the exploration and development of larger or shared storage sites by compensating for spill-overs from exploration that derive to the wider market; and
  - Enhance access to information on storage sites to address current issues of imperfect and asymmetric storage site information.
- Provision of CO_2 purchase guarantee by government to help overcome the potential coordination failures faced by early transport and storage developers and encourage the development of shared transport and storage infrastructure.

Tax breaks

Tax breaks are fiscal incentives applied using adjustments to the UK taxation system. Tax breaks are potentially applicable throughout the life of an industry with examples from the oil industry a good starting point for how policy must adapt as an industry matures. At the early stage of the industry tax breaks are recommended that encourage new capital investors (such as oil and gas majors) to invest in CCS to lessen capital market restrictions:

- broad tax breaks whereby tax credits can be used against tax paid outside the CCS sector; and
- targeting tax breaks for enhanced hydrocarbon recovery.

Market creation

Regulatory or policy actions that seek to create a market for a product that is currently not available. Intervention is only usually required when market failures or entry barriers prevent the market from forming naturally.

Market creation interventions applicable to early stage development of CTS include:

- either directly or indirectly creating a market for leakage liability insurance (such as through a pooled insurance similar to that in the Nuclear industry) to lower risks and insurance costs for storage site owners; and

- running competitive commercial leasing rounds (for AfLs on storage sites) analogous to those in the offshore wind industry to start to establish demand and greater certainty for storage;

Knowledge generation

Knowledge generation interventions focussed on actions such as R&D spending, health and safety and public engagement and guidance programmes

One near-term knowledge generation action that appears to have clear longer-term benefits is an organised public engagement programme to ensure that public opposition does not unnecessarily delay projects.

No single measure alone will be sufficient to deliver the necessary development of the CTS sector in the UK and a number of interventions are required to facilitate this.

Summary of early stage risks and interventions

Table 7 below summarises the key early stage intervention options, the risks and barrier that each intervention helps to tackle and the potential market led outcome if left unaddressed.

Our analysis and the outputs of the stakeholder workshops conclude that delivery of the interventions requires a coordinated effort amongst a range of stakeholders. While Government has a key role to play, industry and The Crown Estate have an important role to play in implementing the interventions identified.

Table 7 – Priority Interventions to address key risks/market failures

Early Stage intervention. Option	Intervention description	Intervention Category	Intervention. Party	Risk addressed	Potential 'market led' outcome of risk	Current regime ability to address risk
Grants for storage characterisation	Grant targeted at 'new' areas of storage or on incremental work at existing storage sites to overcome development risk. Compensates for additional benefits from exploration that derive to other parties and can improve storage data and information dissemination.	Financial incentives	Government, Industry	Co-ordination failures	Discourages speculative investment in stores. Required assurances for access to T & S come from building JV end-to-end projects.	Low CCSCP helps early projects only
				Exploration spillovers	Volume of storage appraisal likely to be less and later than would be optimal for long-term development of the industry.	Low CCS R&D incentivises limited exploration
				Imperfect & asymmetric storage info	Project developers are likely to be cautious when developing a site as the performance and long-term viability of the site is unknown.	Medium CCSCP helps develop some capacity
CO_2 purchase guarantee by government	Storage and transport partially paid on availability with shortfall guaranteed by government	Financial incentives	Government	Co-ordination failures	Discourages speculative investment in stores or in oversized pipes. Assurances for access to T & S come from building JV end-to-end projects.	Low CCSCP helps early projects only
Cross-sector tax breaks	Losses can be monetised easily, encouraging equity investment by major companies	Tax breaks	Government	Capital market restrictions	Limited availability of both equity and debt. Significantly increased financing costs.	Low/Medium CCSCP helps early projects only
EOR/EHR tax breaks	Encourages EHR led finance and oil and gas majors to become involved in CCS	Tax breaks	Government	Capital market restrictions	Limited availability of both equity and debt. Significantly increased financing costs.	Low/Medium CCSCP helps early projects only
Option contracts for AfLs	Targeted at hub creation, reducing some risks to stores. Gives greater certainty over long-term storage accessibility and need.	Market creation	TCE	Missing markets	Developers only use integrated projects models for financing.	Low/Medium CCSCP partially addresses
			TCE	Co-ordination failures	Discourages speculative investment in stores or in oversized pipes. Assurances for access to T & S come from building JV end-to-end projects.	Low CCSCP helps early projects only
CO_2 storage liability aggregation	Establishment of a pooled fund for liability aggregation	Market creation	Government, Industry, TCE	Missing markets	High insurance costs for leakage liability.	Low/Medium CCSCP partially addresses
Public engagement programme	Targeted public engagement programme to reduce planning delays	Knowledge generation	Government, Industry, TCE	Public perception risk	Lack of public knowledge and acceptance may create significant delays for projects.	Low

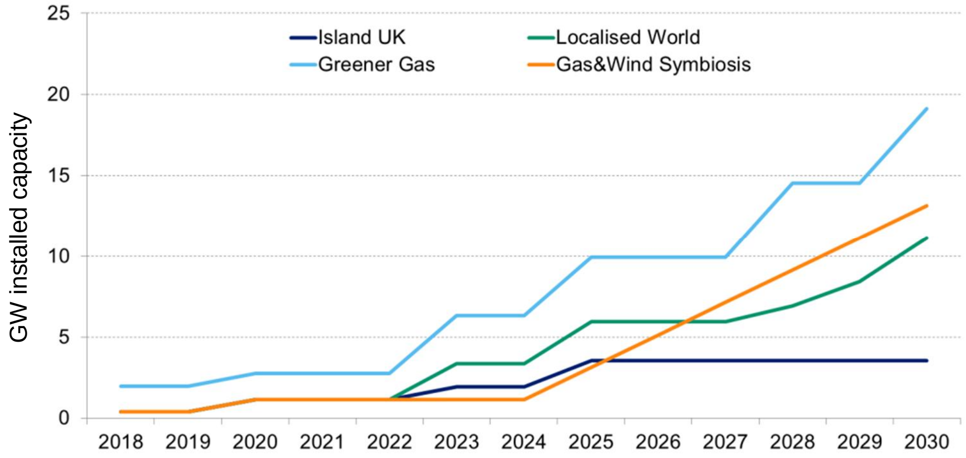
Potential benefits of intervention

Work undertaken by DECC, the CCC and The Crown Estate (among others) examines the range of scenarios for the future delivery of CCS and shows the considerable uncertainty for the future roll-out of CCS in the UK.

Without action to address the current market failures the scope for roll-out of CCS is limited driven primarily by external factors. Primarily these can be thought of as external profitability drivers for CCS broadly outside the influence of UK intervention or policy. Two of the main examples are movements in commodity prices and relative changes in the cost of other low-carbon technologies.

Figure 11 shows the cumulative installed capacity of CCS in four illustrative scenarios[19] analysed as part of the project which span a range of CCS deployment. These show the impact on deployment rates of both external market factors and interventions introduced to address the risks faced by CTS.

Figure 11 – Overview of scenarios and roll-out



By comparing the performance of these scenarios we can draw conclusions on the potential roll-out and materiality of benefits the package of interventions brings. Key results are show in Table 8 and highlight several effects of the additional interventions.

- Transport and storage costs are materially lower – lower capital and contingency costs and reduced IRR requirements result in transport costs around 40% lower and targeted de risking of storage sites. Leakage liability insurance aggregation leads to lower return requirements and the development of storage hubs with lower capital costs per unit of CO_2.
- Support costs are reduced – the required strike price in the CfD falls whilst still maintaining the same level of pre-tax returns (and potentially somewhat higher returns post-tax due to the targeted tax breaks encouraging new hub development)

19 These scenarios were analysed using the ADAPT CCS model, detailed analysis of these scenarios is contained in Chapter 4.

and intervention reduces the cost of abatement through CCS (on a £/tCO_2 basis) for government by 15% to 30%.

Table 8 – Key scenario results

			Scenario			
			Island UK	Localised World	Gas & Wind Symb	Greener Gas
Weighted Av. Trans. Price		£/tCO2	9.2	5.2	9.0	5.9
Weighted Av. Storage Price		£/tCO2	17.0	11.1	16.2	10.6
FiT for Gas CCS	**Before 2020**	£/MWh	130	115	110	92
	2021-2025	£/MWh	115	104	96	85
	2026 onwards	£/MWh	115	104	96	85
FiT for Coal CCS	**Before 2020**	£/MWh	125	105	113	110
	2021-2025	£/MWh	145	123	N/A	105
	2026 onwards	£/MWh	145	120	N/A	105
Abatement cost to Government		£/tCO2	151.3	104.7	50.5	42.6

If interventions are successful in addressing the key barriers that prevent the efficient development of CO_2 infrastructure, there is the potential to influence the markets towards an overall higher pathway of CCS development.

While there will still be some residual exposure to the external market, higher deployment is driven by:

- increased demand for CCS due to a reduction in the risks and costs;
- encouraging the development of shared infrastructure, lowering costs particularly for projects developing in the longer-term;
- reducing other barriers which enhance the likelihood of successful projects (e.g. improving the availability of capital and information and reducing delays caused by public opposition);

Our analysis concludes that although the costs may be similar for the earliest projects with or without additional early phase interventions (as full chain projects will be required by definition), actions taken now can set a landscape to drive to a lower cost path in future phases of deployment. They can also enable the quicker development of follow on projects and accelerate the point at which CCS support can be reduced as it becomes competitive with other low carbon generation sources.

We would therefore anticipate that there is the potential for direct feedback between interventions that lower costs and the roll out of CCS. Lower cost can create a positive feedback cycle – lower costs leads to higher demand for CCS and higher roll-out. This, in turn, leads to lower costs through decreased investor risks and economies of scale which again leads to increased demand for CCS. However the opposite is also true, if few of the risks are addressed, costs are likely to stay high and roll-out will be slow. There is therefore a clear advantage to the utilisation of a package of interventions to maximise positive feedback.

ANNEX A – REFERENCES

Publications

Carbon Capture and Storage: Realising the potential?: UKERC Research Project, 2012

A Policy Strategy for Carbon Capture and Storage: OECD/IEA, 2012

A Proposal for Greenhouse Gas Storage Exploration Incentives: Carbon Storage Taskforce, 2010

Business and regulatory Models for offshore CO_2 transport and storage in the late 2020s and beyond: ETI and Element Energy Ltd, 2012

Interim Report - The Potential for Reducing the Costs of CCS in the UK: UK CCS Cost Reduction Task Force, November 2012

Potential cost reductions in CCS in the power sector, Discussion Paper: Mott Macdonald May 2012

IEA Technology Roadmap Carbon Capture and storage: OECD/IEA 2009

The Global Status of CCS: Update, January 2013: GCCSI January 2013

Workshop Attendees

The Crown Estate

Pöyry

Shell

Carbon Capture and Storage Association

Societe General

Energy Technologies Institute

National Grid

Premier Oil

Taqa

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ANNEX B – DESCRIPTION OF ADAPT CCS

ADAPT TCE is an advanced financial analysis tool developed to analyse the feasibility of the companies in the Carbon Capture Transport and Storage sector as well as the gains of/costs to the Government and the Crown Estate (TCE).

ADAPT TCE is a flexible model in terms of using the pre-set data in the model or manually entering the data for companies of interest. Built in MS Excel and using a calculation engine rather than macros/VBA, ADAPT TCE can evaluate each individual entity (e.g. an individual company or a subsidiary of a bigger company) as well as assessing a tax-entity (e.g. a holding) which owns a number the individual entities entered into the model,. Within this context, ADAPT TCE iteratively processes the entities to produce the required outputs simultaneously.

ADAPT TCE is designed to evaluate the feasibilities of individual capture/transport/storage entities and/or group companies composed of more than a single entity, as well as the cost of the carbon capture/storage (CCS) sector to the government and the revenues that TCE can earn by renting its storage sites.

The model can accommodate up to 10 capture, 10 transport and 10 storage entities.

In this regard, the user

- enters the data required for each single entity,
- defines the contractual relationship among entities (i.e., which company/companies transport(s) and store(s) the carbon captured by which capture unit(s)), and
- non-ring-fences the entities which belong to the same group company, if any.

The model first organises the input data, and then processes the outputs via a two-stage calculation engine in an iterative manner:

- The first-stage is dedicated to process each single entity and is loaded with one entity's data at a time. This produces the CAPEX, OPEX and revenues of each entity, as well as the grants allocated and the revenues of TCE, but does not require financial modelling.
- The second stage runs the financial model (i.e. financing of the corporation, forming the financial statements and calculating the feasibility ratios such as IRR, NPV and DSCR), using the results obtained in stage 1

Consequently, outputs include the following financial metrics for each entity and group company (i.e. a group of non-ring-fenced entities) defined by the user:

- Financial statements (P&L, balance sheet, cash flow statement)
- Project Internal Rate of Return (IRR), before and after tax,
- Debt-Service Coverage Ratio (DSCR),
- Project NPV after tax

The model also generates the net cost of the CCS sector, i.e. all the entities entered into the model, to the Government as well as the revenues of TCE.

The model is based on the principle that capture units pay transport and storage fees (per tonne of CO_2 transported/stored) to relevant companies. In other words, there are transport and storage costs for capture companies, which form the revenues of transport and storage companies. Within this process, the model provides the user with two alternatives:

- The user can define the target IRR for the transport/storage company, and the model calculates an average transport/storage fee per tonne-CO_2 to ensure that the transport/storage company have the targeted IRR ±1%. This approach provides the opportunity to find out what transport/storage fees should be applied to have desired profitability.
- The user can set the transport/storage fee, so that the model runs and the IRRs are calculated based on these prices. This approach provides the opportunity to assess the profitability of companies with a given set of prices.

ANNEX C – DETAILED SCENARIO MODELLING RESULTS

C.1 Overview

All scenarios had a base set of capital and operating costs assumptions from the DECC sponsored May 2012 report by Mott Macdonald on potential cost reductions in CCS in the power sector[20]. The Mott Macdonald "Low Cost" pathway was used as the basis of the scenarios that have high CCS technology development. To simulate the impact of higher costs and higher contingency requirements in scenarios with slow technology development, an uplift of 30% on capex and opex was assumed (using analysis of the range of current TCE technology development paths).

Baseline assumptions for expected rates of capital returns for power and capture plant investment were based on standard Pöyry assumptions. Assumptions for the cost of capital for developing the transport and storage system are taken from work of the UK CCS Cost Reduction Taskforce interim report in November 2012[21]:

- Capture plant projects have an average pre-tax real internal rate of return of 10%;
- Transport pipeline projects have a required pre-tax real internal rate of return of 10% (if funded via the current CfD FiT mechanism) falling to 8% as the CO_2 pipeline transport becomes more established in the early 2030's;
- Storage developments were regarded by the CRTF as being the most costly part of the chain to finance and are assumed to have differing return expectations depending on the storage type:
  - 15% IRR for DOGF storage falling to 14% for projects in the early 2020's and 12% for projects commissioning in early 2030's.
  - 18% IRR for Aquifer[22] storage falling to 17% for projects commissioning in the early 2020's and 15% by the early 2030's

Fossil fuel prices in the modelling were based on the latest DECC 2012 fuel prices. In all scenarios carbon prices were assumed to rise in line with the carbon price floor trajectory.

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20 Potential cost reductions in CCS in the power sector, Discussion Paper, May 2012 http://tinyurl.com/c3cj9e8

21 Where no assumptions were available Pöyry have supplemented with additional data based on internal Pöyry analysis.

22 Pöyry assume a 3% ROR expectation uplift for Aquifer storage due to additional exploration risk etc.

All scenarios assume that the currently announced funding mechanisms are still in existence including:

- The CfD FiT mechanism for the funding of baseload CCS generation; and
- The £1bn Commercialisation Competition subsidising the funding of the first few projects (prior to 2020).

Rental Incomes for TCE in the model are based on a simplified model of changing of a percentage of the prevailing carbon floor price in the year of storage plus a low annual fixed charged to cover the post-operational period. The rental incomes projected by the model are therefore highly related to the amount of CO_2 being stored – they are useful for comparison between scenarios but if another rental structure was chosen the overall numbers could alter somewhat.

For each scenario we report below the following key outputs from the modelling:

- Weighted Average Cost of CO_2 transport based on all CO_2 pipelines developed in the UK between 2013 and 2030;
- Weighted Average Cost of CO_2 Storage based on all CO_2 storage sites developed in the UK between 2013 and 2030;
- Contract for Difference Feed in Tariff level (in £/MWh) required for the average Gas CCS project (inc. Transport and Storage costs) over different time periods;
- Contract for Difference Feed in Tariff level (in £/MWh) required for the average Coal CCS project (inc. Transport and Storage costs) over different time periods;
- NPV of net government expenditure (in 2012 at 10% discount rate) which comprises:
  - costs of capital grants;
  - cost of Cfd FiTs (above wholesale electricity price);
  - less any tax receipts from CCS;
- NPV of net government expenditure divided by total volume of CO_2 abated
  - Where abated CO_2 is measured against the benchmark of the CCS generated electricity being generated by an unabated CCGT.

C.2 Island UK

The key model outputs for the Island UK Scenario are shown in Table 9 below. This scenario involves no new interventions and CCS generally remains less attractive (on a risk/reward basis) than other forms of Low Carbon Generation limiting the take up of CCS in the UK.

CCS roll-out is restricted to 2 demonstration size plants and ~3 subsequent early commercial plants (no large scale commercial plant rolled out before 2030). To this end CCS Capacity increases to 1.1 GW in 2020 to 3.5GW by 2030 through a mixture of coal and gas CCS capacity. Total CCS volume transported and stored increases to around 15mtpa by 2030 total CO_2 stored reaching 130mt in 2030 and 276mt by 2040.

Pipelines and storage develops generally along the lines of point-to-point networks with relatively small pipes developing. Pipeline capacity is 23mtpa (pipelines are around 65% full in this scenario) with a total pipeline length of 1000km in 4 separate pipeline networks.

The key metrics for the Island UK scenario are shown in Table 10 below. Weighted average transport and storage costs are around £9/tCO_2 and £17/tCO_2 respectively.

NPV of Government spend on CCS is £4.7bn which converts to an NPV cost per unit of abated CO_2 of £151/tCO_2. FiT levels for Gas CCS fall from £130/MWh to £115/MWh. FiT levels for CCS rise in this scenario as costs do not fall rapidly enough to offset the loss of the capital grants for Projects in the 2020s.

Table 9 – Key scenario assumptions and results: Island UK

	2020	2030	2040
Total CCS installed capacity (GW)	**1.1**	**3.5**	**3.5**
Total volume of CO_2 delivered (mtpa)	**5.8**	**14.7**	**14.7**
Total transport capacity (mtpa)	**9.1**	**23.3**	**23.3**
Pipeline length (km)			
Onshore	200.0	400.0	400.0
Offshore	300.0	600.0	600.0
Total pipeline length	**500.0**	**1,000.0**	**1,000.0**
Annual Storage Capacity (mtpa)			
Depleted Oil & Gas Fields	10.0	15.0	15.0
Saline Aquifers	0.0	5.0	5.0
Total Annual Storage Capacity	**10.0**	**20.0**	**20.0**
Total Storage Capacity (mt)			
Depleted Oil & Gas Fields	220.0	350.0	350.0
Saline Aquifers	0.0	150.0	150.0
Total Storage Capacity	**220.0**	**500.0**	**500.0**
Annual CO_2 Flow to Storage Fields (mtpa)			

Depleted Oil & Gas Fields	5.8	10.6	10.6
Saline Aquifers	0.0	4.1	4.1
Total Annual Storage Capacity	**5.8**	**14.7**	**14.7**
Cumulative Volume of CO_2 stored (mt)			
Depleted Oil & Gas Fields	7.8	104.1	210.1
Saline Aquifers	0.0	24.9	66.3
Cumulative Annual Storage Capacity	**7.8**	**129.0**	**276.4**

Table 10 – Key result metrics: Island UK

Metric	Value		
Weighted Average Cost of CO_2 transport (£/tCO_2)	£9.2		
Weighted Average Cost of CO_2 Storage (£/tCO_2)	£17.0		
NPV of net government expenditure (£m)	£4,670		
NPV per unit of CO_2 abatement (£/tCO_2)	£151.3		
	2018-2020	**2021-2025**	**2026-2030**
FiT level req for Coal CCS (inc. Transport & Storage) (£/MWh)	£125	£145	£145
FiT level req for Gas CCS (inc. Transport & Storage) (£/MWh)	£130	£115	£115

C.3 Gas and Wind Symbiosis

The key model outputs for the Gas and Wind Symbiosis Scenario are shown in Table 11 below. This scenario involves no new interventions however the market moves in favour of CCS due to low fossil fuel prices and CCS becoming generally attractive (on a risk/reward basis) compared to other forms of Low Carbon Generation.

CCS roll-out is restricted to 2 demonstration size plants before 2020 with minor early commercial scale roll-out before 2025 leading to 3.1GW of CCS installed by 2025. Around 2GW of gas-based CCS per year is installed from 2025 so CCS capacity reaches 12.3GW by 2030, supported by government FiTs as gas-CCS is generally competitive with other forms of Low Carbon Generation.

Total CCS volume transported and stored increases to around 37mtpa by 2030, with total CO_2 stored reaching 173mt in 2030 and 539mt by 2040. Pipelines and storage develops generally along the lines of point-to-point networks and only limited sharing of infrastructure where very obvious benefits arise (despite increased contractual risks). Pipeline capacity is more than double that in the Island UK scenario with 37mtpa (pipelines are around 70% full in this scenario) with a total pipeline length of 2400km in 8 separate pipeline networks.

The key metrics for the Gas/Wind Symbiosis scenario are shown in Table 12 below. Weighted average transport and storage costs are around £9/tCO_2 and £16/tCO_2 respectively.

NPV of Government spend on CCS is £4.3bn which is similar to the Island UK scenario but which converts to an NPV cost per unit of abated CO_2 of £51/tCO_2 due to the much higher levels of CCS in this scenario. FiT levels for Gas CCS fall from £110/MWh to £96/MWh. CCS Coal is only built with a capital subsidy prior to 2020 and a FiT level of £113/MWh.

Table 11 – Key scenario assumptions and results: Gas/Wind Symbiosis

	2020	2030	2040
Total CCS installed capacity (GW)	**1.1**	**13.1**	**13.1**
Total volume of CO_2 delivered (mtpa)	**5.8**	**36.5**	**36.5**
Total transport capacity (mtpa)	**9.1**	**51.8**	**51.8**
Pipeline length (km)			
Onshore	200.0	1,000.0	1,000.0
Offshore	300.0	1,400.0	1,400.0
Total pipeline length	**500.0**	**2,400.0**	**2,400.0**
Annual Storage Capacity (mtpa)			
Depleted Oil & Gas Fields	10.0	28.0	28.0
Saline Aquifers	0.0	18.0	18.0
Total Annual Storage Capacity	**10.0**	**46.0**	**46.0**
Total Storage Capacity (mt)			
Depleted Oil & Gas Fields	220.0	610.0	610.0
Saline Aquifers	0.0	450.0	450.0
Total Storage Capacity	**220.0**	**1,060.0**	**1,060.0**
Annual CO_2 Flow to Storage Fields (mtpa)			
Depleted Oil & Gas Fields	5.8	21.1	21.1

Saline Aquifers	0.0	15.4	15.4
Total Annual Storage Capacity	**5.8**	**36.5**	**36.5**
Cumulative Volume of CO_2 stored (mt)			
Depleted Oil & Gas Fields	7.8	111.5	322.5
Saline Aquifers	0.0	61.8	215.9
Cumulative Annual Storage Capacity	**7.8**	**173.3**	**538.5**

Table 12 – Key result metrics: Gas/Wind Symbiosis

Metric	Value		
Weighted Average Cost of CO_2 transport (£/tCO2)	£9.0		
Weighted Average Cost of CO_2 Storage (£/tCO2)	£16.2		
NPV of net government expenditure (£m)	£4,252		
NPV per unit of CO2 abatement (£/tCO2)	£51		
	2018-2020	**2021-2025**	**2026-2030**
FiT level req for Coal CCS (inc. Transport & Storage) (£/MWh)	£113	N/A	N/A
FiT level req for Gas CCS (inc. Transport & Storage) (£/MWh)	£110	£96	£96

C.1 Localised World

The key model outputs for the Localised World Scenario are shown in Table 13 below. This scenario assumes that interventions are made in the market and that they are both correctly targeted and timely, helping the industry overcome costs, risks and barriers.

Roll-out of 2 demo-sized projects before 2020 is supported by the UK Commercialisation Programme with 6 GW of coal & gas CCS capacity installed by 2025 and 11 GW installed by 2030. The roll-out programme is driven by targeted interventions leading to networking and lower Transport and Storage costs. Take up of the technology is hindered somewhat by higher fuel costs and consequentially limited European appetite for CCS storage in the North Sea.

Total CO_2 volume transported and stored increases to 53mtpa by 2030 with total CO_2 stored reaching 254mt in 2030 and 781mt by 2040.

Pipelines and storage develops optimally with hubs developing and general sharing of pipeline and storage infrastructure wherever feasible. Pipeline capacity is high as there is at 53mtpa (large appetite to oversize pipes to create option value for the future) with a total pipeline length of 2450km in 4 relatively large scale pipeline network companies (with many companies owning multiple transport pipes).

Table 13 – Key scenario assumptions and results: Localised World

	2020	2030	2040
Total CCS installed capacity (GW)	**1.1**	**11.1**	**11.1**
Total volume of CO_2 delivered (mtpa)	**5.8**	**52.6**	**52.6**
Total transport capacity (mtpa)	**9.1**	**80.2**	**80.2**
Pipeline length (km)			
Onshore	200.0	1,050.0	1,050.0
Offshore	300.0	1,400.0	1,400.0
Total pipeline length	**500.0**	**2,450.0**	**2,450.0**
Annual Storage Capacity (mtpa)			
Depleted Oil & Gas Fields	10.0	33.0	33.0
Saline Aquifers	0.0	32.0	32.0
Total Annual Storage Capacity	**10.0**	**65.0**	**65.0**
Total Storage Capacity (mt)			
Depleted Oil & Gas Fields	220.0	780.0	780.0
Saline Aquifers	0.0	970.0	970.0
Total Storage Capacity	**220.0**	**1,750.0**	**1,750.0**
Annual CO_2 Flow to Storage Fields (mtpa)			
Depleted Oil & Gas Fields	5.8	25.9	25.9
Saline Aquifers	0.0	26.7	26.7
Total Annual Storage Capacity	**5.8**	**52.6**	**52.6**
Cumulative Volume of CO_2 stored (mt)			
Depleted Oil & Gas Fields	7.8	151.5	410.5
Saline Aquifers	0.0	102.7	370.0
Cumulative Annual Storage Capacity	**7.8**	**254.2**	**780.5**

The key metrics for the Localised World scenario are shown in Table 14 below. Weighted average transport and storage costs are around £5/tCO_2 and £11/tCO_2 respectively.

NPV of Government spend on CCS is very high in this scenario due to the large roll-out of CCS at £7.5bn which converts to an NPV cost per unit of abated CO_2 of £115/tCO_2. FiT levels for Gas CCS fall from £115/MWh in 2020 to £104/MWh after 2025. FiT levels for Coal CCS rise in this scenario (from £105/MWh to £123/MWh) as costs do not fall rapidly enough to offset the loss of the capital grants for Projects in the 2020s.

Table 14 – Key result metrics: Localised World

Metric	Value		
Weighted Average Cost of CO_2 transport (£/tCO_2)	£5.4		
Weighted Average Cost of CO_2 Storage (£/tCO_2)	£11.1		
NPV of net government expenditure (£m)	£7,484		
NPV per unit of CO_2 abatement (£/tCO_2)	£105		
	2018-2020	**2021-2025**	**2026-2030**
FiT level req for Coal CCS (inc. Transport & Storage) (£/MWh)	£105	£123	£123
FiT level req for Gas CCS (inc. Transport & Storage) (£/MWh)	£115	£104	£104

C.2 Greener Gas

The key model outputs for the Greener Gas Scenario are shown in Table 15 below. This scenario assumes that interventions are made in the market that are targeted and develop quickly to and contribute to the much accelerated deployment of CCS we see in this scenario. Roll-out of 4 demo-sized projects before 2020 is supported by the UK Commercialisation Programme with significant new gas CCS capacity installed by 2025 and 2030 driven by both interventions, and rapidly falling CCS costs with favourable market conditions.

European appetite for CCS storage in the North Sea is high in this scenario as CCS accelerated in Europe and the North Sea is a desirable place for widespread CO_2 storage. Total CO_2 volume transported and stored increases to 71mtpa by 2030 with total CO_2 stored reaching 378mt in 2030 and more than 1Gt by 2040. Pipelines and storage develops optimally with hubs developing and general sharing of pipeline and storage infrastructure wherever feasible. Pipeline capacity increases quickly to 71mtpa with a total pipeline length of 3500km in 3 very large scale pipeline network companies (with all companies owning multiple transport routes). Large storage hubs develop with three CO_2 storage companies owning storage sites with around 2GT of capacity and more than 70mtpa injection capacity by 2030.

Table 15 – Key scenario assumptions and results: Greener Gas

	2020	2030	2040
Total CCS installed capacity (GW)	**2.7**	**19.1**	**19.1**
Total volume of CO2 delivered (mtpa)	**10.1**	**70.9**	**70.9**
Total transport capacity (mtpa)	**16.0**	**112.0**	**112.0**
Pipeline length (km)			
Onshore	600.0	1,650.0	1,650.0
Offshore	500.0	1,850.0	1,850.0
Total pipeline length	**1,100.0**	**3,500.0**	**3,500.0**
Annual Storage Capacity (mtpa)			
Depleted Oil & Gas Fields	15.0	46.0	46.0
Saline Aquifers	0.0	31.0	31.0
Total Annual Storage Capacity	**15.0**	**77.0**	**77.0**
Total Storage Capacity (mt)			
Depleted Oil & Gas Fields	350.0	1,130.0	1,130.0
Saline Aquifers	0.0	800.0	800.0
Total Storage Capacity	**350.0**	**1,930.0**	**1,930.0**
Annual CO_2 Flow to Storage Fields (mtpa)			
Depleted Oil & Gas Fields	10.1	40.7	40.7
Saline Aquifers	0.0	30.2	30.2
Total Annual Storage Capacity	**10.1**	**70.9**	**70.9**
Cumulative Volume of CO_2 stored (mt)			
Depleted Oil & Gas Fields	20.9	221.0	627.6
Saline Aquifers	0.0	156.5	458.4
Cumulative Annual Storage Capacity	**20.9**	**377.5**	**1,086.0**

The key metrics for the Greener Gas scenario are shown in Table 16 below. Weighted average transport and storage costs are around £6/tCO_2 and £11/tCO_2 respectively. Average transport costs are slightly higher in this scenario than in Localised World as the higher volume of CO_2 drives longer networks which offset the economies of scale of the larger diameter pipes.

NPV of Government spend on CCS is £5.8bn which converts to an NPV cost per unit of abated CO_2 of £43/tCO_2. FiT levels for Gas CCS fall from £92/MWh in 2020 to £85/MWh between 2021 and 2030 (with coal FiT levels at £105/MWh). After 2025 the wholesale price rises to £80/MWh - very close to the FiT level for Gas CCS implying that CCS projects would start considering whether to invest using the wholesale market rather than the FiT mechanism. This indicates that the market in this period is moving into a full commercial phase of operation.

Table 16 – Key result metrics: Greener Gas

Metric	Value		
Weighted Average Cost of CO_2 transport (£/tCO_2)	£5.9		
Weighted Average Cost of CO_2 Storage (£/tCO_2)	£10.6		
NPV of net government expenditure (£m)	£5,805.9		
NPV per unit of CO_2 abatement (£/tCO_2)	£42.6		
	2018-2020	**2021-2025**	**2026-2030**
FiT level req for Coal CCS (inc. Transport & Storage) (£/MWh)	£110	£105	£105
FiT level req for Gas CCS (inc. Transport & Storage) (£/MWh)	£92	£85	£85

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