Report's unique identifier: 2016/346

A STRATEGIC APPROACH FOR DEVELOPING CCS IN THE UK

A report to The Committee on Climate Change

May 2016

EXECUTIVE SUMMARY

Withdrawal of funding from the Commercialisation Programme in 2015 left the UK without any explicit funding mechanism for developing CCS in the UK. With CCS now facing a highly uncertain future the Committee on Climate Change (CCC) has commissioned Pöyry to provide a short report exploring the options for commercialising Carbon Capture and Storage (CCS) in the UK.

While CCS is one option for decarbonising the power sector, it is the only available option for decarbonising many industrial processes. In the longer term, CCS combined with biomass could be a source of negative carbon emissions, allowing cost savings by reducing the need to decarbonise elsewhere. Analysis by the CCC indicates that developing a CCS industry is essential to decarbonising the UK industrial sector, and work from the ETI suggests that CCS infrastructure needs to be in place by the late 2020s or early 2030s.

The Commercialisation Programme has left the UK with well characterised storage ready for development, a detailed appraisal of capture technologies and costs and a significant body of knowledge around the creation of successful commercial arrangements for CCS. These assets create the opportunity for rapid development of CCS within the UK if appropriate support is put into place. Recent falls in expected UK gas prices also make CCS more cost-effective when compared to technologies that are not dependent on fuel prices.

In this report, we explore the key steps required to establish a CCS industry in the UK, and the costs of doing so. Critically, we consider that one of the most important lessons to learn from the commercialisation is the difficulty of funding CCS on a "full-chain" approach, where a single payment rewards the construction and operation of capture, transport and storage. We suggest that any cost-effective CCS strategy will require the Government to absorb cross-chain risks via "part-chain" funding mechanisms, where transport and storage are supported either via a second funding scheme, or a risk sharing arrangement.

Our broad view of how to achieve cost reductions is unchanged from our 2015 report to the CCC. Development should be focused around capture and storage hubs, reducing costs by sharing transport and storage infrastructure. As far as possible, and subject to cost targets, continuous rollout of CCS power generation will drive savings via lower financing costs and development of supply chains. Finally, optimal technology choice, location choice and knowledge transfer will be crucial to access learning by doing and risk reduction cost savings.

We consider that industrial CCS should be considered a critical part of the overall CCS strategy, but we do not believe that CCS should be developed around industry alone. The requirement for CCS for industry provides a framework for considering necessary investment that could drive the development of at least one CCS hub. Once a hub is in place, cost estimates suggest that power CCS is a valuable source of low-carbon generation, and immediate development of power CCS helps drive cost reductions and captures significant volumes of carbon that be used to securely drive the development of a transport and storage network.

Exploring timelines for the roll-out of CCS, we conclude developing low cost CCS by the early-2030s requires immediate progress on a new strategy for UK based CCS. Even with immediate development, we consider it very challenging to get CCS operating in the early 2020s, and expect that second generation power CCS would begin operation around 2030, around 5 years later than in our 2015 report. To drive this schedule, some key steps need to be taken:

- Making an early decision on a preferred region(s) from which capture facility bids will accepted, ideally accompanied by a decision on which storage facility to develop.
- Committing to making funding available for carbon capture units, provided that cost targets can be met.
- Choosing an initial business model to support transport and storage, with the Government absorbing a significant part of four key risks:
  - Cross chain funding risks
  - Carbon volume flow risks
  - Long term storage liabilities
  - Fuel price risk
- Allocating responsibilities within the business model to existing bodies where possible, and creating new bodies if required.
- Establishing a mechanism that will support the development of carbon capture from industrial processes.

In addition to exploring the objectives of a CCS strategy, and the steps required to meet them, we have updated the cost estimates from 2015 to take into account recent developments, and separation of funding for capture units from transport and storage. Using fuel prices from the 2015 DECC Reference Scenario, and engineering estimates from the 2013 Cost Reduction Task Force we calculate that post-combustion gas CCS, commissioning in the mid-2020s, could be developed with a 15 year Contract for Difference (CfD) at around £115/MWh, and that once learning, development and economies of scale are taken into account, costs would reduce to £85-90/MWh in the 2030s.

Driving this investment, in addition to CfDs for capture units, will require the creation of a transport and storage network. A minimum transport and storage investment of around £600m is likely to be required, dependent on the geographical choice of the initial hub, and the storage facility used. At the high end of our rollout estimates, with significant support for CCS power generation and industrial capture, we estimate that around £2.5bn of investment by 2035 could support 7.5 GW of power generation and 5 Mtpa of industrial capture.

1. INTRODUCTION

1.1 Background

The international community reaffirmed at COP21 in Paris the global commitment to tackling climate change by reducing carbon emissions in line with a target of limiting global warming to at most 2°C. In almost all credible scenarios, the combination of renewables, energy storage and nuclear energy will not be sufficient to reach this goal. Research from the IEA and IPPC has indicated that the global cost of reducing emissions from the energy and industrial sectors will be much higher without CCS, leading to a strong incentive for CCS to be developed worldwide.

Within the UK, work by the ETI has indicated that we have a plentiful supply of offshore sites suitable for carbon storage. Utilising these is the only viable route to decarbonising many industrial processes, while the ETI has indicated expected savings of up to £30bn per year, in 2050, from deploying CCS in the UK to support both industry and power generation. The UK also possesses some of the best potential sites for carbon storage in Europe, and may be able to export some of this capacity to support the potential £1 trillion in savings across the EU that the Zero Emissions Platform has estimated that CCS can bring.

This report focuses on how the UK can successfully commercialise CCS, rather than on the case for doing so. However, we note that work by the CCC, the ETI, and others including those referenced above, has created a compelling case for the development of CCS in the UK.

In our 2015 report to the CCC[1], we examined the cost drivers for the entire CCS value chain and then considered the alternative development paths' pros and cons before suggesting a minimum target to drive cost reductions of 4GW of CCS projects based on one technology or 7GW on two, which would deliver costs below £100/MWh. This analysis was based on the premise that at least one of the Commercialisation Programme projects under consideration at the time would be approved.

The Autumn 2015 Comprehensive Spending Review withdrew capital support for both Commercialisation Programme projects and this has led the CCC to commission a review of the development pathways we set out in our 2015 report. While the events of the last six months set the implementation programme back, the evidence of a requirement for CCS in the longer term has not changed. In addition the cancellation of the previous demonstration programme provides an opportunity to review the UK's approach to supporting the commercialisation of CCS, and allow choice of a more favourable route. Meanwhile, the fall in oil and gas prices has created a situation where the expected costs for CCS are significantly lower than a year ago, and the downturn in the offshore industry means there should be no shortage of available labour and expertise for exploiting offshore carbon storage.

1 "Potential CCS Cost Reduction Mechanisms Report", published by the CCC, Pöyry and Element Energy.

1.2 Methodology and report structure

To develop a proposal for a feasible high-level approach to establishing a CCS industry, we undertook a review of events in 2015, and developed ideas for how the UK could develop CCS in light of recent events. These ideas were discussed with the CCC and an expert advisory group, and subsequently refined. We then undertook a similar process to develop, present and refine cost estimates for the development of CCS under selected business models.

This report presents the outcome of this process, and sets out a proposal for a feasible high-level approach to establishing a CCS industry. It seeks to identify a low-cost viable route to develop CCS, in a manner that will attract the required investment while minimising the costs to consumers and treasury. We finish by providing an updated estimate of the costs involved.

2. ELEMENTS OF A STRATEGIC APPROACH FOR DEVELOPING CCS

This section outlines our view on the elements required in a strategic approach to developing CCS in the UK. We outline what we consider to be the target of a successful approach, and then present the principal considerations necessary to allow this target to be met. We follow this with a timeline, discussing when we think that CCS could be delivered, and a high level consideration of two financing models for CCS.

2.1 The strategic target

Based on our work for the CCC in 2015[2], a successful CCS policy should:

- **Develop the support models, commercial funding, supply chains and shared learning necessary to enable initial projects and then reduce the costs of power-based CCS:**

  Costs of carbon capture from power generation are expected to fall quickly over time. While the forecast costs of established CCS are competitive with nuclear and offshore wind, CCS policy should be shaped to assist in reducing costs. For example, Government support and appropriate funding models are critical to producing interest from the financial community. Continuous rollout, rather than "stop-start" build of CCS plants, supports both interest from the finance community and the development of a supply chain. Support mechanisms that encourage the sharing of knowledge and gradual rollout of CCS help to reduce both costs and risks.

- **Develop transport and storage infrastructure focused initially around one to two hubs to minimise investment costs and capture economies of scale:**

  Our work for the ETI and the CCC in 2015[3], as well as other research, has identified the importance of supporting networks that connect multiple capture and storage sites to reduce the transport and storage costs associated with CCS. A policy approach that encourages geographically diverse capture sites will not access these savings. Broadly speaking, hubs that accept at least 5-10 million tons of CO_2, transported via shared infrastructure, will access most of the economies of scale that can be achieved from shared transport. We consider that this should mean the UK initially focusses support around one, or possibly two, hubs.

- **Include support for industrial CCS:**

  CCS for power generation has been the focus of the UK commercialisation program to date, and produces large volumes of captures CO_2 that can act as a backbone for the formation of CCS networks. Meanwhile, industrial CCS is, in many cases, the only option for reducing industrial emissions while keeping industry in the UK. We therefore consider it essential that any policy framework supports the development of carbon capture from both power generation and industry.

---

2 "Potential CCS Cost Reduction Mechanisms Report", published by the CCC, Pöyry and Element Energy.

3 "CCS Sector Development Scenarios in the UK", published by the ETI, Pöyry and Element Energy, and "Potential CCS Cost Reduction Mechanisms Report", published by the CCC, Pöyry and Element Energy.

- **Create the option to roll out both industrial and power CCS at scale in the 2030s, where costs are competitive with other decarbonisation options:**

  The long-run value of CCS lies in the ability to capture significant volumes of carbon from both power and industry. The lack of CCS development to date means that we are still in an early 'discovery' phase of the full costs involved, and it makes sense to focus spending on "least regrets" infrastructure, i.e. that we know there is a strong case to develop at some point, while also keeping "optionality" by supporting the development of a CCS industry that can be scaled up if future deployments are competitive with other decarbonisation options.

2.2 Principal considerations for CCS strategy

There are many different business models by which the commercialisation of CCS could be supported. In evaluating the merit of different models, a higher level strategy is useful to evaluate what structures will work effectively. Four key factors determine any choice:

- where the risks are borne;
- how funding is allocated to the three elements of the CCS chain;
- which sectors to initially support in carbon capture; and
- where to begin initial developments.

The remainder of Section 2.2 considers each of these factors in turn to identify key steps and decisions within a CCS strategy, and does not focus on specific business models. Section 2.4 outlines the implications of this strategy for business models choices.

2.2.1 Where the risks are borne

As with all investments, there is a level of risk associated with developing a CCS industry. The level of financial support that needs to be provided to the CCS industry will depend on how the risks are separated between the private and public sectors. In general, risks should be borne where they are best managed, which will typically be in the private sector. However, attracting private finance at reasonable rates requires limiting the private sector risk to those that commercial finance is willing to fund. Based on our experiences to date, there are four categories of risk present in the commercialisation of CCS that are particularly difficult for the private sector to deal with. We suggest that these must be at least partially underwritten by the Government for CCS development to take place at reasonable cost:

- **Cross-chain funding risks:**

  Cross-chain funding risks occur if the developer of one part of the CCS chain, e.g. a storage facility, will not receive its expected income due to a failure elsewhere in the CCS chain, such as a transport network. For example, under the competition model payments would only be made based on successful delivery and performance of the capture facility, transport network and storage site. This requires each element of the chain to evaluate and build into their pricing the risk of failure elsewhere in the chain, adding significant levels of complexity and risk to the funding of each element. We discuss options for reducing cross-chain funding risks in Sections 2.2.2 and 2.4.

- **Volume risks for the initial transport and storage operators:**

  Pipeline networks achieve significant economies of scale when built to transport larger volumes of CO_2. For example, a 16 million tons per annum (Mtpa) pipe is expected to cost substantially less than twice the cost of a 1 Mtpa pipe. This makes it vastly preferable to build pipes that are large enough to support future carbon capture facilities, rather than just those committed when the pipeline is developed. However, there is also substantial uncertainty regarding the demand for CO_2 transport as it is heavily dependent on future Government policy. We consider it unlikely that industry will bear this risk at a price that is acceptable to the public purse.

- **Long term liabilities from storage:**

  Storage operators must be incentivised to establish safe, secure long-term storage of CO_2 at their site. However, the risk of carbon leakage via failure of the store, while small, cannot be eliminated at this stage. Whilst CO_2 leakage from well characterised stores is seen as very unlikely, the exposure under the EU CCS Directive to potential payments for ETS certificates for leaking CO_2 is uncapped, and therefore potentially large, and has no expiry date beyond which the liability will cease. This very low likelihood, high consequence risk in an immature industry is difficult for either developers or the insurance market to absorb.

- **Fuel price risk:**

  Fuel price risk arises when power CCS is paid a fixed price for the electricity it produces, but is subject to uncertainty over the cost of coal or gas used as fuel. For gas CCS, the fuel cost forms around half of the levelised cost of electricity, and the volumes of fuel needed, coupled with the long time periods over which gas is required, make hedging this risk difficult. Our preferred option is to allocate CfDs that are indexed to the fuel price, which also reduces the public expenditure risk under a levy control framework, as the correlation between gas and electricity prices is high and so indexation decreases uncertainty around CfD spend.

Cross chain, storage liability and transport volume risks, in particular, are difficult for industry to absorb, and requiring industry to cover them would require costs that seem out of proportion to the risks involved. We therefore consider that cost-effective delivery of CCS will require the Government to absorb some or all of these risks.

2.2.2 How funding is allocated to the three elements of the CCS chain

Any CCS industry can naturally be broken up into a chain involving three elements:

- carbon capture;
- carbon transport; and
- carbon storage.

A successful industry requires developers to attract finance for, and construct, all three elements of the chain. Funding for them to do so can be provided either through a single revenue stream that rewards operation of all three elements (full chain funding), or via two or three revenue streams that reward operation of only part of the chain (part chain funding). Full chain funding appears attractive as it ensures that payments will only be made if carbon is both captured and stored. Part chain funding has the potential for “white elephant” developments, for example, if a transport and storage network is built and not utilised.

One of the lessons to come out of the UK CCS competition is the difficulty of financing on the basis of full chain funding[4]. Carbon capture and carbon transport and storage are quite different businesses, requiring different expertise and risks. Financing each element with full chain funding adds significant complexity to business planning, and the pricing in of risk for all parts of the chain into the financing for each element. A single developer, owning all parts of the chain, and financed primarily with equity funds and sufficient contingency funding, would be best placed to absorb the risk of failure of one part of the chain on another. This arrangement was present for one of the competition projects, but was nonetheless still insufficient to reach agreement on funding. We do not anticipate that such an arrangement is likely to occur again, nor is it efficient for it to do so.

Separating funding for capture from the funding for transport and storage, and absorbing some or all cross-chain risk (such as by making funding for each asset dependent only on the performance of that asset), will reduce financing and support costs, lower the barriers for entrants in each sector, and reduce the complexity and timescales of project development.

It is less clear whether there is a benefit to separating funding and removing cross-chain risk between transport and storage, which are more closely related than is capture. We consider either choice possible, likely dependent on the business model chosen to deliver CCS, and it may be that different solutions are appropriate for the short and long term.

2.2.3 Which sectors to initially support in carbon capture

Interest in developing carbon capture has emerged from a number of sectors, for example the recent competition involved both coal and gas fired power generation, while several industrial sites have expressed interest in industry-led CCS. While any CCS network should support both industrial capture and cost-efficient capture from the power generation, it remains an open question whether CCS development in the UK should initially focus around capture units from power generation or from industry, or from both simultaneously, and to what scale and with which technologies initial developments should be built.

A dual power and industry approach could work, but comes with additional complexity and hence additional risk compared to beginning CCS development with either industry or power alone. In selecting between a primarily industry-led or power-led approach three points favour a power-led approach:

- The volume of non-combustion CO_2 emissions from most industrial sites (or indeed clusters of sites) is too small to fill a significantly sized hub without additional CO_2 input – even a small power station can capture more carbon (~1-2 Mtpa) than most industrial emitters, providing greater initial volumes of carbon over which to share transport and storage costs.
- A support mechanism (CfD) is already in use that could easily be applied to power-CCS, while the support mechanisms for industrial capture still need to be developed.
- The income risk of CfD funded CCS power generation is likely to be lower than for industry CCS due to risks associated with the host sites' primary business. For example, recent experience in the UK iron and steel industry demonstrates the high level of uncertainty in the future profitability of an industrial sites.

We acknowledge that opinions on these points vary and there is no clear-cut priority, but on this basis we assume for further analysis that the initial CCS rollout will contain a

[4] See also "A need unsatisfied - Blueprint for enabling investment in CO_2 storage", published by Deloitte and the Crown Estate in February 2016.

significant component of power-CCS. We reiterate that a decision must be made on which sector(s) to fund initially, and that whichever decision is made, developing both sectors is valuable. Once initial sites are approved and a CCS network is funded and under construction, supporting carbon capture from both sectors will help to realise the full value of the associated storage network.

Within the power sector, a number of technologies are available that could be used in early power stations. While there is optionality value in deploying a range of technologies, helping to develop gas, coal and biomass CCS, current cost estimates vary significantly between technologies and the additional cost of supporting a range of technologies is likely to be high. We therefore take the view that selecting the cheapest capture facilities – which likely means natural gas CCS based on current cost estimates – is the best way to begin CCS deployment at reasonable cost. Likewise, initial plants need to be built to sufficient scale to clearly demonstrate the technology, but the expectation of falling costs suggests that the UK should not immediately commit to GW-sized power stations even if economies of scale allow a marginally cheaper strike price. We consider 300-500 MW, i.e. around the scale of the competition projects, to be a good compromise, but expect that the final decision must assess the value of any projects that compete for funding.

2.2.4 Where to begin initial developments

Our recommendation that funding should initially support the development of one or two hubs leads to the question: where? The location could be decided by Government before negotiating contracts for initial capture sites, or could be decided afterwards, via the result of contract negotiations or an auction. Based on previous work by The Crown Estate[5], ETI[6] and others, there is significant evidence to support a direct and early decision by Government as to which storage site to develop. This will reduce capture development risks and hence costs, and allow the early development of transport and storage while capture FEED studies are ongoing.

A number of factors are significant in any decision about initial network locations:

- Proximity to cheap, appraised storage sites.
- The extent to which the store and pipeline routes have already appraised (e.g. as part of the commercialisation programme).
- Proximity to industrial emissions, the likelihood of capturing current industrial emissions and desired future industrial developments.
- Suitability for development of new power stations with carbon capture, or proximity to existing power stations with capture retrofit capability.

Recently, the ETI's Strategic UK Storage Appraisal Project has assessed the status of UK storage sites, and concluded that there are plentiful storage options available, with some of the most promising options shown in Figure 1. We refer to their report for more details, but note that there are promising storage options available near most industrial centres in the UK.

---

5 See, e.g., "Options to incentivise UK CO2 transport and storage", 2013, and CO2 stored.

6 "Progressing Development of the UK's Strategic Carbon Dioxide Storage Resource", published by the ETI in 2016.

Figure 1 – Map of promising storage sites from ETI's storage appraisal project

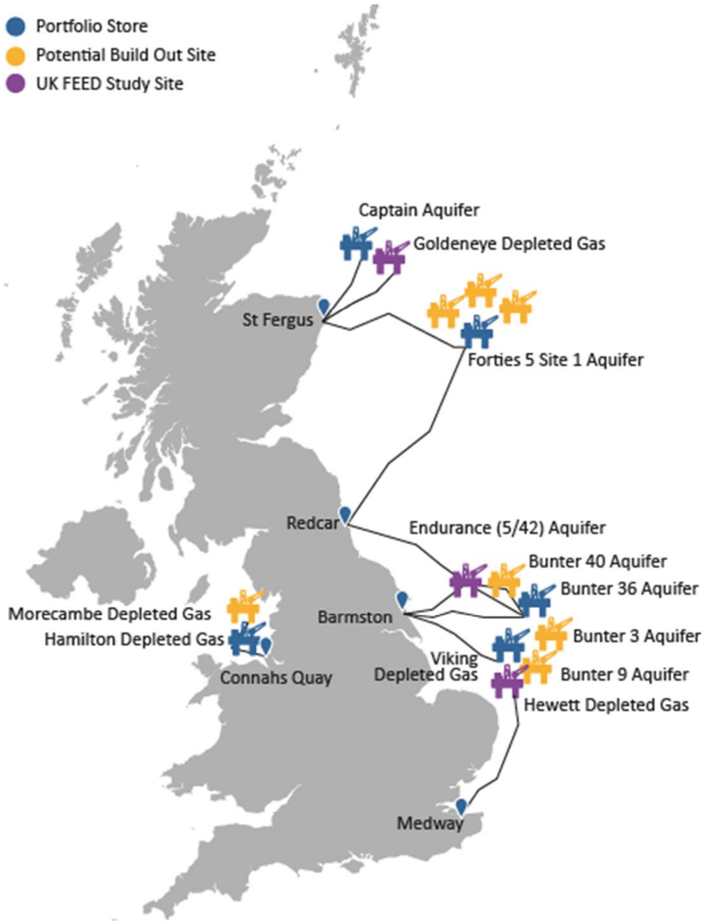


Image reproduced with permission from the ETI's Strategic UK Storage Appraisal Project

For evaluating the costs of CCS development later in this report, we assume that initial developments are based around Endurance in the Southern North Sea, as this is one of the best understood stores and leaves the option of supporting capture from Teesside, the Humber or the Thames Estuary.

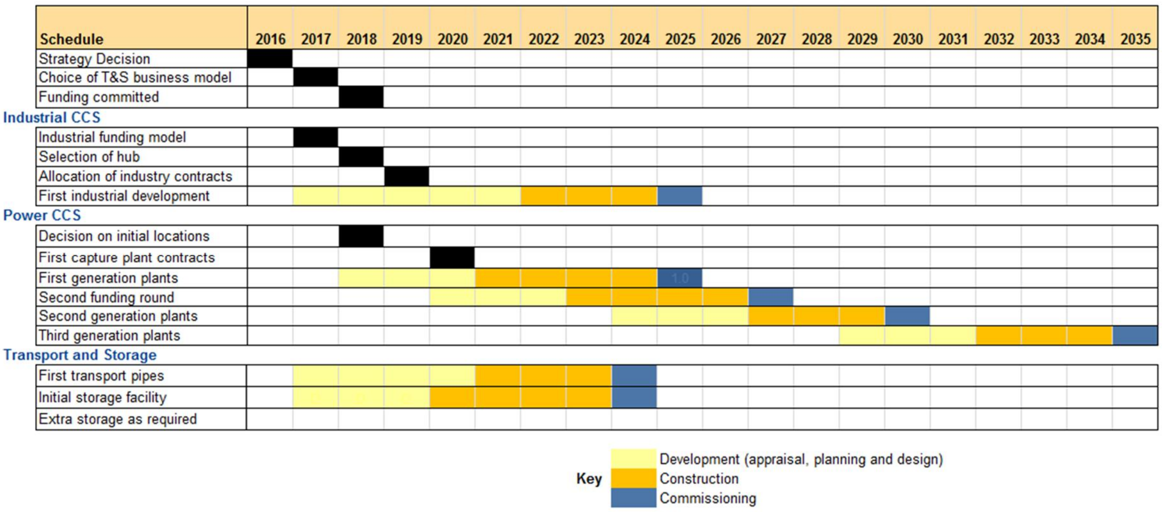
We recommend the Government evaluates the merits of different locations, leading to an early decision on which storage facility to develop first. This will allow likely transport routes to be mapped out, and will identify a region, or regions, in which capture projects will be considered for initial funding.

2.3 Implications for CCS development timeline

Based on the above considerations we developed indicative timelines showing how power and industrial CCS might develop in the UK[7] if the UK Government were to support immediate development. Figure 2 shows a timeline for simultaneous development of both industrial and power CCS. For either sector the business model is time-critical, so a decision to simply focus on one would delay rollout of the other by around 2 years.

7 Our time estimates are based on a range of sources, including the Cost Reduction Task Force, the Teesside collective, the IEA-GHG report on CO_2 pipeline infrastructure and estimates on storage development from a range of ETI reports.

Figure 2 – Timescales for deploying industrial capture, power capture, transport and storage



This timeline is based on an anticipation of a Government strategy decision made in 2016, followed by a number of key milestones in the following years:

- a decision on the business model to adopt for supporting capture, transport and storage;
- a decision on a region, or region(s), from which capture facility bids will accepted, ideally accompanied by a decision on which storage facility to develop;
- development of a funding model for industrial capture sites; and
- legislation to commit to funding of all elements of the CCS chain.

To develop power-CCS, we anticipate a two year period for FEED studies between the committing of funds and allocation of contracts, leading to a FID around 2021, and operation around 2025. To develop industrial CCS, the first industrial contracts might be allocated on an indicative level in 2019, but our time estimates suggest that the development time for a sizable industrial hub is significant and industrial capture operation would also begin around 2025. In both sectors, we conclude that provided the current work on appraising storage is built on and the most promising stores are progressed to FID, transport and storage can be constructed before carbon capture facilities are operating. Indeed, we have indicated commissioning of transport and storage in the year prior to operation of capture facilities enabled by the assumed separation of funding; while this creates some cost inefficiencies, it seems prudent to err on the side of delivering storage before the earliest possible commissioning date of capture facilities.

While we consider the timescales in Figure 2 realistic, we note that that we have received feedback from various parties indicating that shorter timescales are possible. For transport and storage, we have used average estimates based on a range of sites, while some sites, for example Endurance (5/42) which has already had significant appraisal work conducted, could be ready in the early-2020s. For power generation, we have built in a delay between contract award and FID, and some construction time contingency into our first generation of plants, and acknowledge that trouble-free financing and construction could lead to commissioning one to two years earlier than shown. The lead time on industrial developments will be case-specific, and some could complete significantly earlier than we have shown, but we assume that any industry led policy would look to develop multiple sites in the "first round" in order to capture sufficient volumes of CO_2 to justify investment in transport and storage.

We have also assumed that the power-CCS industry, having experienced recent changes of policy in this area, will not commit significant money to FEED and project planning until the Government enacts legislation to commit to new funding. If such planning and funding were to begin from the announcement of a new CCS strategy – perhaps supported by strong Government guarantees or development funds – then the timescales shown could be reduced by a further one to two years. We note in particular that there are capture projects in development in the UK which may be willing to progress faster than the timescales shown if sufficient support from Government was forthcoming. The feasibility of such acceleration has not been investigated more fully with either Government or project developers at this stage.

More generally, these timescales have been developed with the aim of a realistic representation of what is possible, and should not be considered as a target. Any support or actions that can bring forward the early development of all three elements of the CCS chain, i.e. capture, transport and storage, would assist in accelerating the rollout of CCS and bring forward the potential delivery times of larger scale carbon capture.

2.4 Business model options

In the previous sections, we identified the principal considerations in deciding how to fund CCS development. A number of different models are available which could be adapted to align with the recommendations from Section 2.2. These include, but are not limited to:

- two pre-FID and two post-FID models described in a recent report from The Crown Estate[8];
- three frameworks, suitable for different levels of maturity in the market, advanced by the Zero Emissions Platform (ZEP)[9];
- four models examined in a Societé Génerale report for the Teesside Collective[10]; and
- the National Carbon Storage Authority model proposed by the NCSA Working Party[11].

The initial model that is chosen to support the CCS industry need not be a permanent arrangement: the ZEP frameworks explicitly discuss how it could evolve over time. In the interests of minimising costs and delays, we recommend using existing infrastructure and knowledge where possible within the constraints of any chosen business model. For example, Contracts for Difference are an established funding mechanism for low carbon electricity sources, and therefore suitable for funding baseload CCS generation as well. Likewise, where organisations are required to manage allocations, operations or funding, it may be preferable to involve existing organisations, such as DECC, National Grid or the National Infrastructure Commission, rather than create new organisations from scratch.

8 "A need unsatisfied - Blueprint for enabling investment in CO_2 storage", published by Deloitte and the Crown Estate in February 2016.

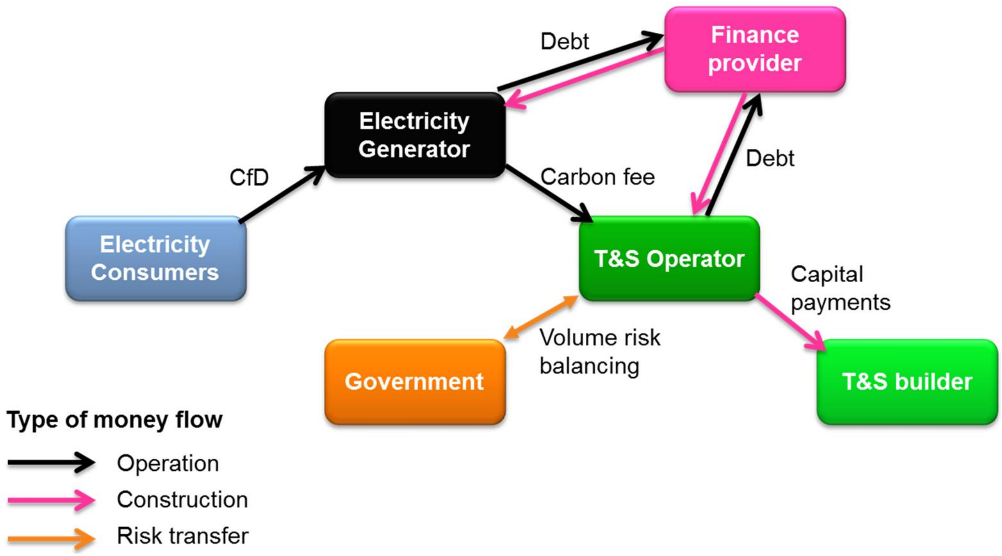
9 "Business models for commercial CO_2 transport and storage", published by the Zero Emissions Platform in June 2014.

10 "Development of an Incentive Mechanism for an Industrial CCS Project", prepared by Societe Generale for the Teesside Collective in 2015.

11 "Working Party Report on the Arrangements Needed to Develop the Infrastructure for Carbon Capture and Storage in the UK", from the NCSA Working Party in December 2009.

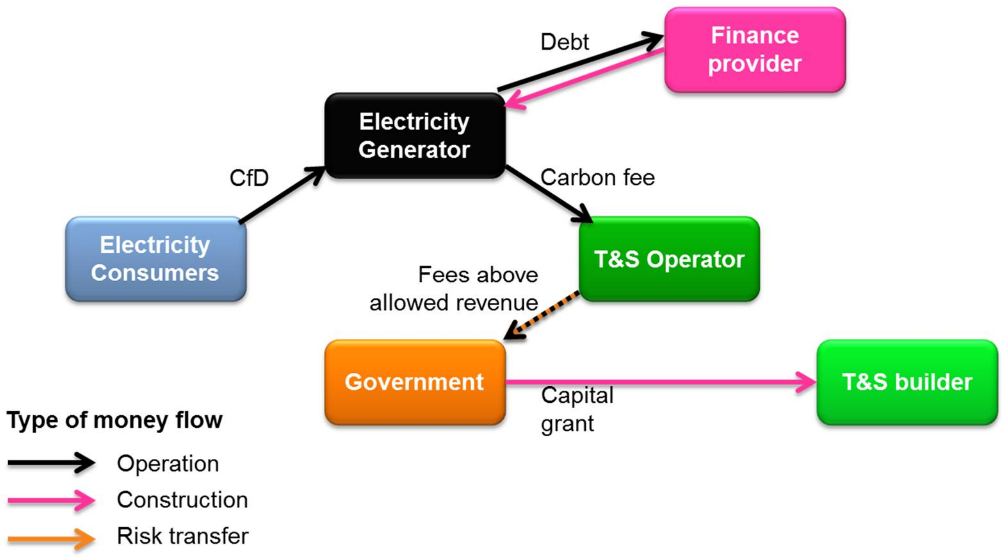
In seeking to understand the differences between proposed business models, and the likely costs of each, we investigated the flows of debt, cash and risk under a range of different models. Two common arrangements represent about two thirds of the business models that we considered. They mainly differ in whether capital funding of transport and storage is provided by private debt and equity, or a grant from Treasury. Figure 3 shows the money flows for the former, and Figure 4 shows the money flows for the latter.

Figure 3 – Business model and money flows for private funding of storage



Money flows for a CCS industry based on private funding of transport and storage. Resulting transfers of assets are not shown. T&S represents transport and storage. Initial funding for capture facilities and T&S networks are provided by a mix of debt and equity. Investment in capture is then repaid via a Contract for Difference (CfD), while investment in T&S is repaid by a carbon storage fee paid by the capture facility. Government absorbs some or all of the volume risk associated with T&S, which may result in flows of money either to, or from, the Government depending on the carbon flows that occur.

Figure 4 – Business model and money flows for grant funding of storage



Money flows for a CCS industry based on grant funding of transport and storage. Resulting transfers of assets are not shown. T&S represents transport and storage. Initial funding for capture facilities is provided by a mix of debt and equity, while T&S facilities are funded by a Government grant. Investment in capture is repaid via a Contract for Difference (CfD), while T&S operation is funded by a carbon storage fee paid by the capture facility. Depending on the carbon fee levied, the T&S operator may repay the initial grant from Government, with repayments dependent on the carbon flows that occur.

Broadly speaking, the private funding model overview describes money flows for the Crown Estate model #1, is an option for all three ZEP frameworks, and also represents the storage equivalent of the so-called Thames Tideway funding model. The grant funding model overview describes money flows for the Crown Estate model #2, the NCSA model, and is an option for the first two ZEP frameworks (i.e. prior to a mature industry).

In both models, power-CCS is built based on debt and equity funding, and then repaid via a Contract for Difference (CfD), in line with funding for alternative low carbon technologies. Payment would primarily be based on generation, with the Government absorbing either most or all cross-chain risk. The mechanism for industrial funding is yet to be determined, but it is likely that Government funding will be required.

Depending on the particular business model, transport and storage assets may be operated by the entity responsible for their construction, or may be transferred to a single operator for the operational phase. In either case, we have shown the ultimate operator of the asset as the “T&S operator”.

Under private funding of T&S, its operator would be paid a regulated fee by capture facilities that would ultimately be funded by CfD payments and industrial funding. The regulated fee would be set to allow full cost recovery of the full lifecycle of transport and storage assets, calculated with a certain volume flow assumed. To allow private funding at reasonable rates, volume risk would be partially or fully underwritten by Government, such as by setting a regulated revenue, or agreeing cap and floor revenues. In a low-volume flow case, the Government would then be liable to topup the revenue of the T&S operator, while in a high-volume flow case, the Government would receive excess payments, which could go to treasury or optionally be re-distributed to offset CfD costs to electricity consumers.

Under grant funding of T&S the operator would only be liable for operational expenses and future abandonment costs. In this case there is less volume risk associated with T&S, although some volume risk sharing between the operator and HMG might still be preferable to ensure certainty on fees and liquidity of the operator. The fee paid by capture units could either be fixed to cover the revenue required by the operator, or could cover the full lifecycle cost of T&S, which would result in the operator recovering excess revenue that would be passed on to Government to repay the initial grant.

While the two groupings of potential business models are far from exhaustive, and leave many underlying options unspecified, they fairly represent the two classic cases of private or Government funding of transport and storage infrastructure. In the next section, we estimate the costs associated with developing CCS under these two options.

3. IMPLICATIONS FOR THE COSTS OF CCS

To evaluate indicative costs, we have adapted our work from 2015[12], with four significant differences:

- Developed two updated deployment scenarios, Low and High, based around the timetable shown in Figure 2.
- Updated our assumptions to reflect events that occurred in 2015. Specifically, we have used DECC's commodity price forecasts from their 2015 updated energy and emissions projections, and based on feedback from the competition process we have increased the hurdle rates assumed for the first two capture sites from 12% to 14%.
- Based our cost estimates on the part-chain approach, where capture is funded and contracted separately from transport and storage. Capture costs therefore include a charge from the transport and storage operator, rather than an inflated cost to recoup the majority of the transport and storage investment.
- Used more recent cost estimates from the ETI's Strategic UK Storage Appraisal Project[13] instead of the ones we used in 2015. The ETI has assumed a lower cost of capital than we used in 2015, in line with assuming an improved funding structure as outlined in the previous chapter.

3.1 Deployment scenarios

Low and High deployment scenarios demonstrate a reasonable range of ambition within the confines of the target declared in Section 2.1. On the Low deployment side, we primarily build power CCS in line with our view on the minimal rate of "continuous rollout" required to keep financial and industrial interest along with healthy supply chains. On the High deployment side, we express our view of an ambitious rollout pathway that deploys significant CCS capacity.

In both scenarios, we keep to the generational learning approach used in our 2015 work: learning from doing allows design improvements, risk reduction and cost reductions in the second (FOAK) and third (NOAK) generations of capture plant. We also make generic assumptions about the net output of capture plants, assuming that the first generation of plants are 375-500 MW, the second generation 750 MW, and the third generation 1 GW, and assume that all plants are built to the cheapest technology available, which in the engineering estimates we have used is post-combustion gas. Costs assume that all plants are new-build; we do not consider the economics of retrofitting existing plants explicitly but note that the cost structure of such plants could differ somewhat from a pure new-build.

Table 1 contains summary data for the two scenarios, while Figure 5 and Figure 6 display detailed timelines of the rollout of capture units. The associated transport and storage build required is detailed in Section 3.3.

12 "Potential CCS Cost Reduction Mechanisms Report", published by the CCC, Pöyry and Element Energy in 2015.

13 "Progressing Development of the UK's Strategic Carbon Dioxide Storage Resource", published by the ETI in 2016.

Table 1 – Scenario summary

	Low deployment	High deployment
Generation in 2030	2.0 GW	3.0 GW
Generation in 2035	3.8 GW	7.3 GW
Industrial capture in 2035	3 Mtpa	5 Mtpa
Total capture in 2035	16 Mtpa	27 Mtpa
Assumed number of hubs	1-2	2-3

Figure 5 – Timeline for Low deployment scenario

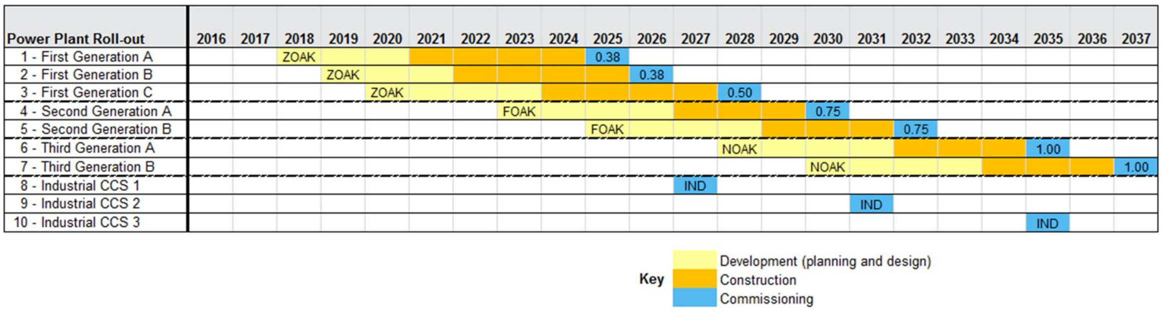
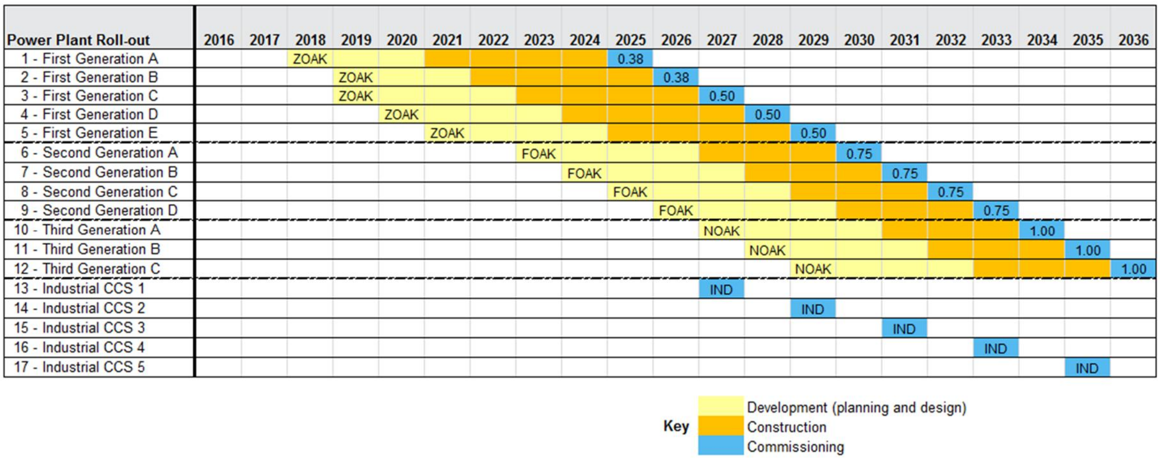


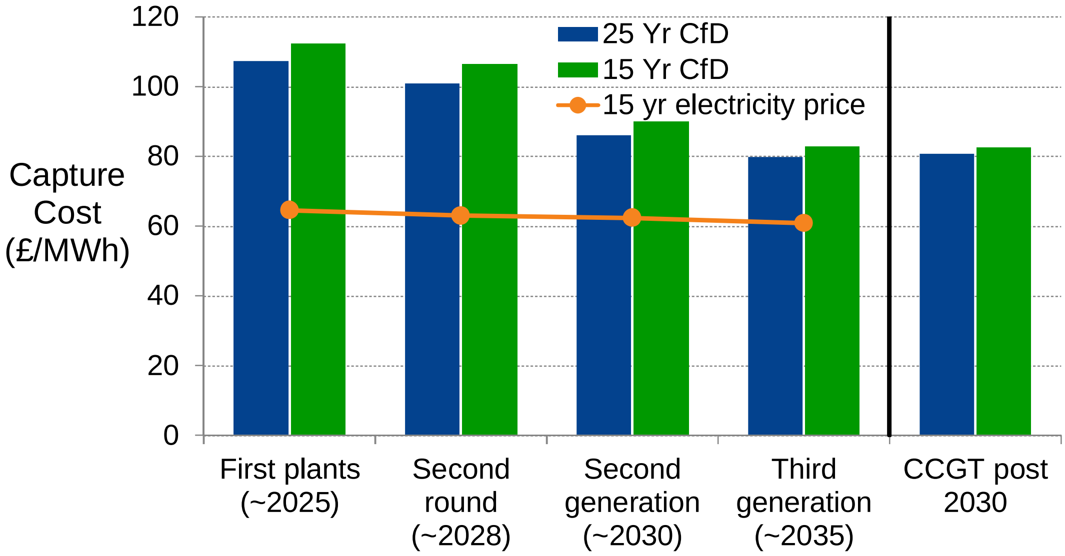
Figure 6 – Timeline for High deployment scenario



3.2 Capture costs

We have calculated capture costs, based on the engineering estimates used in the CCS Cost Reduction Task Force for post combustion gas[14], for each wave of projects assuming that power generation is funded by a CfD, and that fuel prices are as per the reference scenario in the DECC 2015 projections[15]. Figure 7 shows the strike prices[16], excluding transport and storage costs, necessary to fund construction of power CCS, alongside the cost under equivalent assumptions to fund a baseload CCGT via a CfD. The latter shows that, excluding transport and storage, third generation CCS is expected to be cost-competitive with unabated baseload gas power generation given DECC's projected gas and carbon floor prices.

Figure 7 – Capture plant cost estimates under CfD regime (post combustion gas) based on data from Cost Reduction Task Force



Capture component of required strike prices under a 25 year CfD (blue) or 15 year CfD (green), assuming fuel prices as in the DECC reference scenario. Transport and storage costs are additional to the costs shown here. The first four categories are based on cost-estimates for post-combustion gas capture CCS; the last category shows the equivalent calculation for a CCGT not fitted with carbon capture. The orange line shows the average electricity prices in the 15 years following plant commissioning, according to the DECC reference scenario.

14 "CCS Cost Reduction Task Force Final Report", published May 2013. Post combustion gas was the cheapest capture plant technology examined in this study.

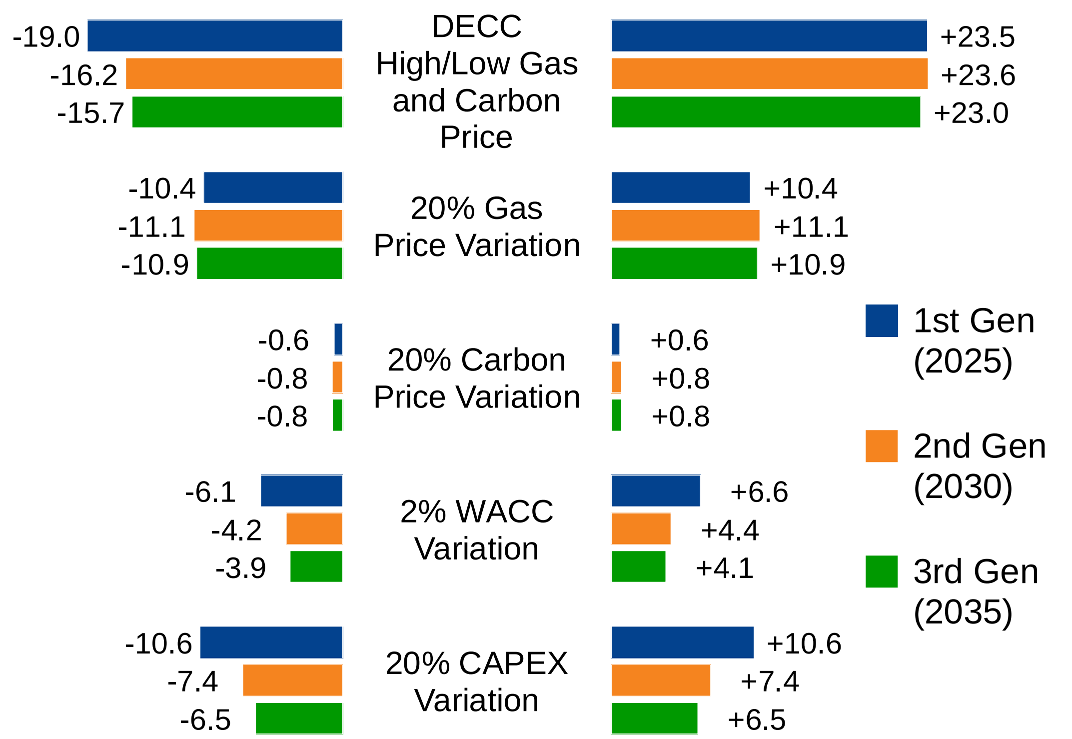
15 The DECC projections provide prices to 2035 only. We have hence assumed flat real prices for gas, carbon and electricity post-2035. We have also assumed that all plants use post-combustion gas capture technology, pay TNUoS charges in line with National Grid forecasts for North East England, do not receive capacity payments during their CfD lifetime, and run baseload for any technical lifetime remaining after their CfD if it is profitable to do so with a capacity payment of £30/kW. We have increased the hurdle rates from the original CRTF report, assuming 14% for the first two plants, 12% for subsequent first generation (ZOAK) plants, 11% for second generation (FOAK) and 10% for third generation (NOAK). All costs are in real 2015 money. For comparison with a CCGT we have assumed CCGT availability of 90% (compared to 80% for the CCS plants) and hurdle rate of 9%.

16 Note that the analysis provides estimates of CfD strike prices and payments, and not the levelised cost of energy, which does not factor in the policy risk associated with CfDs.

While Figure 7 shows our best estimates of the costs, substantial uncertainty remains over the final competitive strike prices that would be signed: it comes from several sources, including a dependence on the final risk profile of the investment, actual costs estimated by FEED studies, and future commodity prices.

Figure 8 displays the impact that changes to some of these factors would have on the eventual strike price, including the impact of changing gas or carbon prices either directly or using the High and Low price DECC scenarios, as well as the impact of the cost of capital and the use of different engineering estimates. One striking feature is the sensitivity of the CfD to gas prices: fuel costs account for roughly half the levelised cost of gas CCS.

Figure 8 – Sensitivity of strike prices for post combustion gas CCS to commodity, finance and engineering estimates (£/MWh)



Variation in CfD prices under different cost assumptions, including the DECC High and Low Price Scenarios, 20% changes to gas price, carbon price or CAPEX assumptions, or a 2% increase or decrease in the weighted cost of capital. All price changes are in £/MWh. The effect of each sensitivity is shown for 1st, 2nd and 3rd generation plants (blue, orange and green, respectively).

3.3 Transport and storage costs

To evaluate the options available for developing offshore storage in the UK, and their costs, we have used preliminary results from the ETI's Strategic UK Storage Appraisal Project[17]. We have used these figures as the most up to date available, recognising their inherent uncertainties. However, because we have worked from partial preliminary results, we have had to combine them with our own assumptions and recommend referring to the ETI's final report.

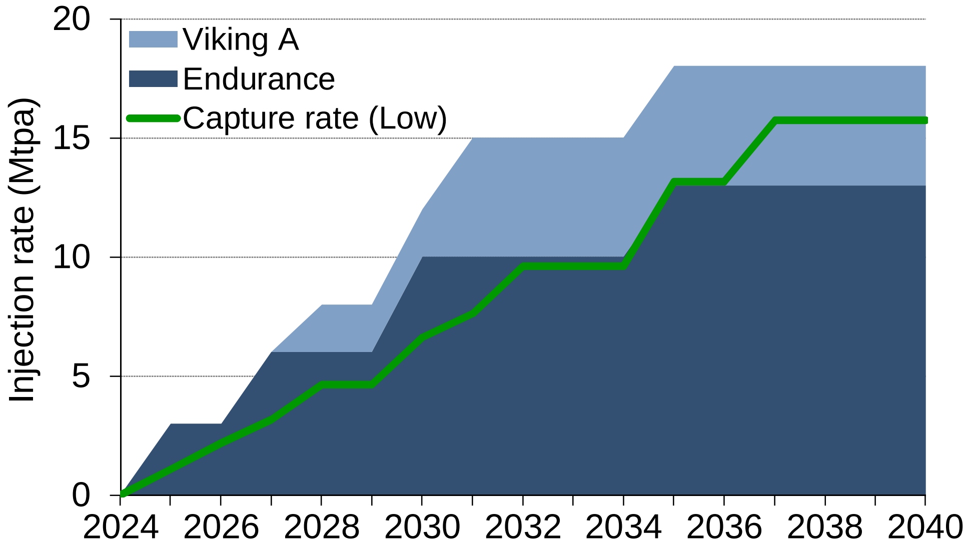
The ETI have shared with us forecast capital expenditure and lifetime cost estimates for developing eight storage sites around the UK; four in the Southern North Sea, three in the Central North Sea, and one in the East Irish Sea, as shown earlier in Figure 1. For both our High and Low deployment scenarios, we have assumed that only the Endurance site is developed in time for the first capture facilities, but that once the CCS industry is progressing, a second site, Viking A, is developed three years later to provide redundancy and further experience. The injection capability of these sites develops over time, within the limits analysed by the ETI, to meet rising capture volumes with capacity to spare.

In our Low deployment scenario, developing these two sites to the levels suggested by the ETI (13 Mtpa and 5 Mtpa injectability respectively) provides sufficient injection capacity to support all capture sites developed, as shown in Figure 9.

In our High deployment scenario, Endurance and Viking only provide sufficient injection capacity to the early 2030s. While numerous expansion options are possible, we have assumed the development of Goldeneye and Captain X in the Central North Sea, and Hamilton in the East Irish Sea, leading to the formation of three storage hubs each with a capacity of at least 5 Mtpa. This is shown in Figure 10.

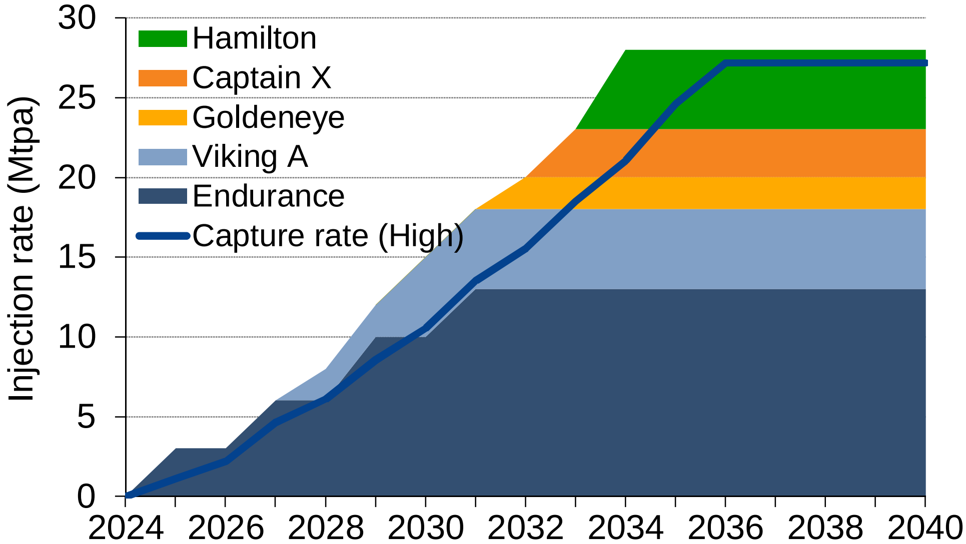
17 "Progressing Development of the UK's Strategic Carbon Dioxide Storage Resource", published by the ETI in 2016.

Figure 9 – Storage development assumed for Low deployment scenario



Storage development assumed for Low deployment scenario. The green line shows total captured carbon emissions in the Low deployment case, while the shaded areas show the injection capacity of developed storage sites. We assume a two year delay from initial development (3Mtpa) of Endurance and subsequent expansion. Viking is developed initially as a backup/reserve to Endurance, but is required for injection capacity from the mid 2030s. While this figure shows injection capacity, these sites also provide more than sufficient storage volume for lifetime capture from all plants in the scenario, with the storage being "half full" of carbon in 2052.

Figure 10 – Storage development assumed for High deployment scenario



Storage development assumed for High deployment scenario. The dark blue line shows total captured carbon emissions in the High deployment case, while the shaded areas show the injection capacity of developed storage sites. The High scenario follows the same initial deployment as the Low scenario, but from 2029 Endurance is expanded more quickly, and additional storage sites are developed to meet higher capture rates. While this figure shows injection capacity, these sites also provide more than sufficient storage volume for lifetime capture from all plants in the scenario, with the storage being "half full" of carbon in 2047.

In line with the main business model options, we examine two methods of funding storage development:

- private finance to cover initial construction costs, which is then recovered via a utilisation fee; or
- grants to cover initial construction costs, and then a utilisation fee to cover operational and abandonment costs.

The ETI has estimated the lifetime cost of carbon storage, in £/tCO_2, that would be required to recover costs for each of the storage facilities used in our scenarios. The estimates account for construction, operation, abandonment, post-closure and insurance costs, a 30% construction contingency, and assume a 10% weighted average cost of capital (WACC) and full utilisation of storage injection. Costs include construction and operation of all offshore pipes, but exclude onshore pipes.

For our two deployment scenarios, the injection-weighted average cost of carbon is £11/tCO_2 and £13/tCO_2 for Low and High respectively, indicating the average fee that capture sites would need to pay in order for offshore transport and storage operators to recover their costs over the complete lifetime of a storage facility. Based on analysis conducted for the UK CCS CRTF onshore transport costs will typically add less than an extra £1/tCO_2 to these figures for well sited capture projects. The ETI figures come with three significant caveats:

- A 10% WACC is reasonable if volume risk is underwritten by Government via a risk sharing arrangement that guarantees revenues, or establishes a revenue cap-and-floor. Without underwriting of volume risk, facilities are likely to be funded based only on committed capture projects, and fees are likely to exceed £50/tCO_2.
- Utilisation rates will typically be less than 100%, increasing costs, due to timing differences between storage and capture development, and the need to be able to inject at peak, rather than average capture rate.
- Our 2015 work emphasised the importance of cost savings via the construction of hubs and transport networks. The ETI cost estimates allow for a separate offshore pipe to each storage facility; appropriate network planning should reduce transport costs.

We therefore expect that requiring capture facilities to pay a fee in the range of £15-20/tCO_2 is reasonable to fund storage and transport, with a built-in volume risk premium, provided that the Government underwrites volume risk at a utilisation level around 70% or higher. This fee is equivalent to requiring an additional £6-9/MWh to be added to the capture strike price.

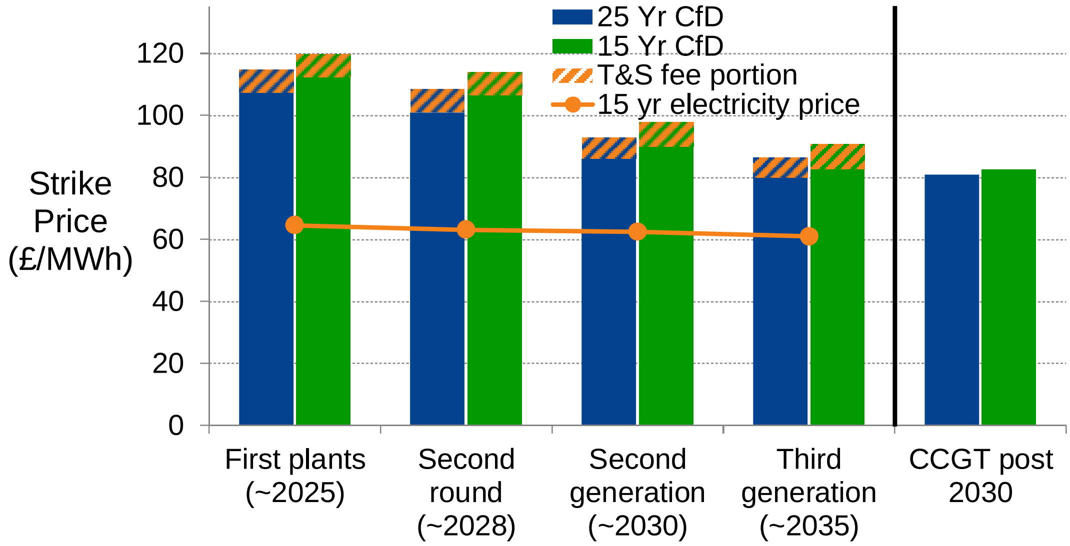
Alternatively, under a grant model, the initial capital expenditure would be funded by Government grants, and operational expenditure by a carbon fee on capture sites. The carbon fee could either be sufficient for the transport and storage operator to recover operational costs only, perhaps £5/tCO_2, or could be levied at the £15-20/tCO_2 required for full lifetime cost recovery, with the Government then recouping fees in excess of operational costs in return for the initial grant funding. Total cumulative capital expenditure for offshore transport and storage to 2035 is estimated at £2.1bn in the High deployment scenario, and £1.3bn in the Low deployment scenario, with an additional £0.2-0.4bn being required for onshore transport. Final transport costs will depend on the locations chosen for capture facilities.

Hybrid models, such as grant funding of the first developments followed by utilisation fee funding for later expansions, are also possible. Under grant funding for a "least regrets" framework, around £600m would fund the development of Endurance with an injection capacity of 6 Mtpa. This would be sufficient to store carbon from two initial power-CCS facilities, plus 3-4 Mtpa from industrial emissions, to absorb a further 7 Mtpa if the power or industrial based CCS industry continued to expand.

3.4 CfD strike prices

Based on the analysis of capture costs and transport and storage costs above, Figure 11 sets out the CfD strike prices we expect to be sufficient to develop power capture plant, including sufficient revenue to cover the transport and storage fees they would pay to the transport and storage owner. In this example we assume a fee of £18/tCO_2, based on full transport and storage cost recovery over the lifetime of the transport and storage assets, and a volume risk premium based on the average utilisation of our scenarios before 2035. This fee would support either the business model in which investment in transport and storage is privately financed, or in which it is grant funded, but lifetime costs are charged and the Government receives repayments for the initial grant. If transport and storage fees were to cover only operational and abandonment expenses, then transport and storage fees, and therefore strike prices, would be significantly lower.

Figure 11 – Capture plant strike prices (post combustion gas CCS) based on Cost Reduction Task Force estimates and including £18/tCO_2 T&S fee



Required strike prices under a 25 year CfD (blue) or 15 year CfD (green), assuming fuel prices as in the DECC reference scenario. The first four categories are based on cost-estimates for post-combustion gas capture CCS; the last category shows the equivalent calculation for a CCGT not fitted with carbon capture. The striped orange section shows the contribution to the strike price required to cover transport and storage fees at £18/tCO_2. The orange line shows the average electricity prices in the 15 years following plant commissioning, according to the DECC reference scenario.

With a strategic approach to developing CCS, CfD strike prices could be as low as £115/MWh for the first plants, falling to £85-95/MWh for second- and third-generation plants, i.e. strike prices comparable to those envisaged for new nuclear. Note, as discussed earlier, that these estimates are subject to a range of uncertainties, some of which were shown in Figure 8.

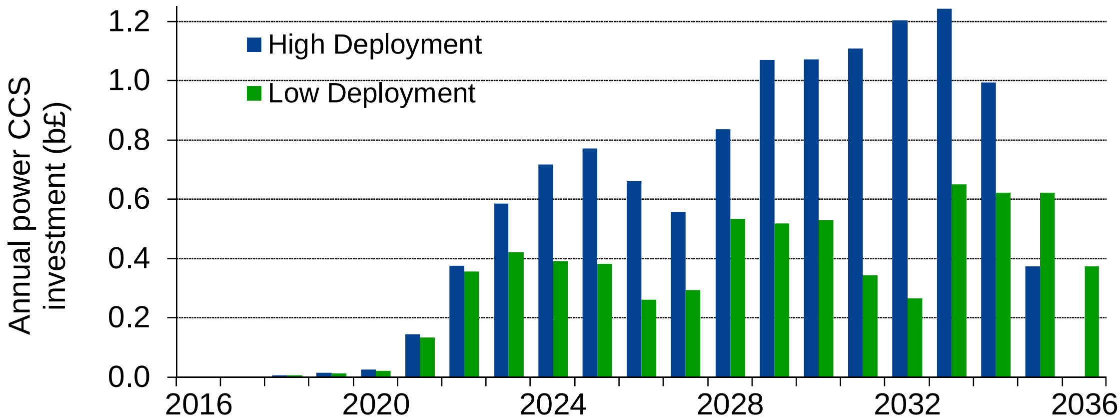
3.5 Total incidence of costs

This section details the incidence of capital costs, CfD expenditure under a Levy-type framework, and direct cash payments by, or to, treasury, under the two main business models identified in Section 2.4.

3.5.1 Investment costs

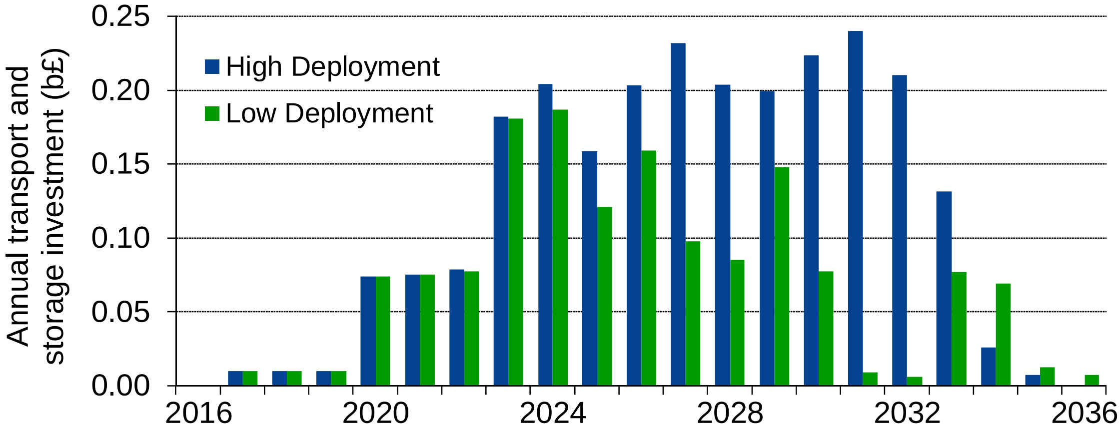
Total investment costs for CCS capture facilities are £6.7b in the Low deployment scenario (4.75 GW by 2037), and £11.7b in the High deployment case (8.25 GW by 2036), and the incidence of these costs is shown in Figure 12. Total investment in onshore and offshore transport, and storage, is £1.5b and £2.5b in the Low and High deployment scenarios, and the incidence of capital expenditure is shown in Figure 13. Development of industrial CCS would require investment in addition to the capital expenditure shown.

Figure 12 – Investment in CCS power generation



Capital investment estimates for the High deployment (blue) and Low deployment (green) scenarios, based on development and construction costs from the Cost Reduction Taskforce and an assumed profile of how costs are incurred during construction.

Figure 13 – Investment in carbon transport and storage



Capital investment estimates for developing the transport and storage networks developed in the High deployment (blue) and Low deployment (green) scenarios. Costs for offshore transport and storage are based on ETI work, with Pöyry assumptions about when the costs are incurred prior to commissioning. Costs for onshore transport are based on Cost Reduction Task Force estimates.

We assume that the capital expenditure for CCS power generation is covered by private finance, as are the storage costs in the case of private-funding of storage. In the case of grant-funding of transport and storage, the outlay required from treasury is equal to the investment shown in Figure 13.

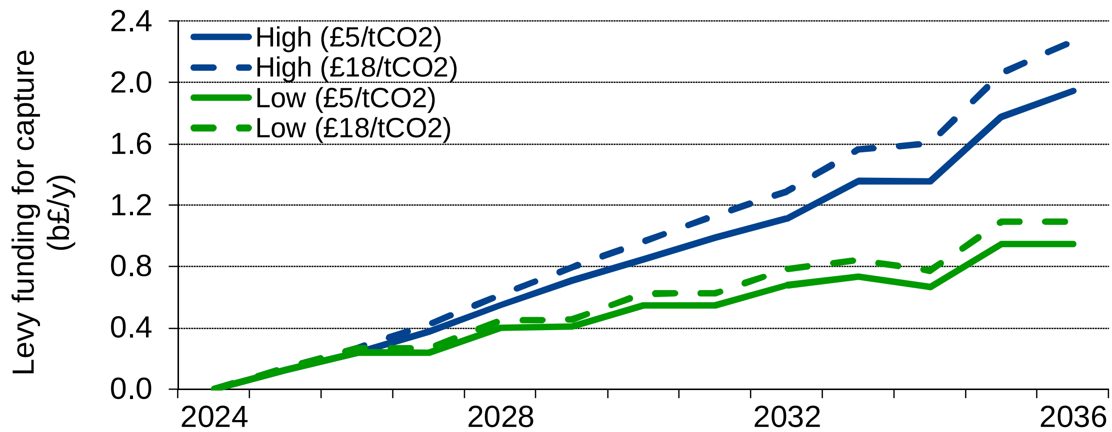
3.5.2 Cost recovery

Investment in CCS power generation is ultimately funded by consumers via CfD payments. We assess this cost under a Levy Control Framework; that is, the cost of the CfD strike price less the cost of the same volume of electricity on the wholesale market. Annual costs are not incurred by consumers until generation starts in 2025; costs incurred after this date are shown in Figure 14, with the solid lines showing the costs incurred if storage is grant funded and capture units pay £5/tCO_2, while the dotted lines show the cost incurred if the CfD covers the full lifetime costs of transport and storage, estimated at £18/tCO_2, including a volume-risk allowance for under-utilisation of infrastructure (based on the average utilisation to 2035 in our scenarios).

Under either business model, assuming transport and storage fees of £18/tCO_2 to cover the investment costs in full, costs are expected to reach £1.1bn per year in 2035 for 3.75 GW of power generation in the Low deployment scenario, and £2.1bn per year for 7.25GW of power generation in the High deployment scenario.

If investment in transport and storage is grant-funded, with transport and storage fees set at around £5/tCO_2 to cover operational and abandonment costs only, costs are expected to reach around £0.9bn per year in 2035 for 3.75 GW of power generation in the Low deployment scenario, and £1.8bn per year for 7.25GW of power generation in the High deployment scenario.

Figure 14 – Levy funding for power generation CCS



Costs incurred for CCS power generation CfDs under a Levy Control Framework, in the High deployment (blue) and Low deployment (green) scenarios. Solid lines show the costs incurred if capture units pay £5/tCO_2

4. CONCLUSIONS

Following the withdrawal of funding from the Commercialisation Programme in 2015, the UK is without an explicit policy for commercialising CCS. In this report, we have explored the key steps in a strategic approach to establishing a CCS industry in the UK that is capable of delivering CCS as a low-cost option for decarbonisation.

We consider that a critical step required in establishing a CCS industry is to allocate the risks appropriately. We conclude that four key risks need to be borne, in full or part, by Government, which in turn influences the potential options for funding and business models. Cross-chain risks and volume risks can be absorbed either by establishing separate direct revenue streams to capture and to transport and storage, or by guaranteeing a minimum (or fixed) revenue for a transport and storage operator. We expect that private storage liabilities will also need to be limited, and indexation of CfDs to fuel prices reduces risk to both private industry, and the levy spend borne by consumers.

More broadly, our view of how to achieve cost reductions for CCS is unchanged from our 2015 report to the CCC. Development should be focused around capture and storage hubs, reducing costs by sharing transport and storage infrastructure. Savings from financing and supply costs can be driven by continuous rollout of CCS power generation, and optimal technology choice, location choice and knowledge transfer will be crucial to access learning by doing and drive cost savings.

We consider that capture and storage hubs should be developed which allow for both power and industrial CCS. Power CCS can capture significant volumes of carbon, and act as the backbone to the development of a hub that is also capable of decarbonising British industry. The choice of how best to support each sector and part of the CCS chain, and where to build the network, is critical. Delivering CCS on the timeframes anticipated by ETI and CCC modelling of the UK energy sector requires that these choices be made quickly, with funding committed to encourage continued interest and development.

Even with immediate development, we consider it very challenging to get CCS operating in the early 2020s, and expect that second generation power CCS would begin operation around 2030, around 5 years later than anticipated in our 2015 report. Keeping to, or beating this schedule will require the Government to make a choice of initial sector and business model, a decision on the initial location, committing of funds and allocation of responsibilities to new or existing bodies within the next 2-3 years.

We consider that beginning this strategy will require a commitment to an initial investment in capture plants, transport and storage. Assuming a power CCS led approach, based on fuel prices from the 2015 DECC Reference Scenario and engineering estimates from the 2013 Cost Reduction Task Force, we calculate initial costs for capture facilities to be around £105-115/MWh. In addition, to fund transport and storage would require either a £600m grant, or an additional £8/MWh on the capture CfD (to cover T&S fees around £18/tCO_2) and the government absorbing volume risk. This transport and storage would be available for both power and industry CCS. In our Low deployment scenario, by 2035, CfD prices exclusive of T&S reduce to £85-90/MWh, and a total of £1.5bn investment in T&S must also be supported either via grants or additional CfD payments (at around £8/MWh), to support 3.75GW of power CCS. Our High deployment scenario delivers 7.25GW of CCS in 2035, with similar strike prices and around £2.5bn of investment in T&S.

[This page is intentionally blank]

Contact details

Name	Email	Telephone
Stuart Murray	stuart.murray@poyry.com	+44 207 932 8244
Bradley Steel	bradley.steel@poyry.com	+44 1865 722 660

Pöyry is an international consulting and engineering company. We serve clients globally across the energy and industrial sectors and locally in our core markets. We deliver strategic advisory and engineering services, underpinned by strong project implementation capability and expertise. Our focus sectors are power generation, transmission & distribution, forest industry, chemicals & biorefining, mining & metals, transportation, water and real estate sectors. Pöyry has an extensive local office network employing about 6,000 experts. Pöyry's net sales in 2014 were EUR 571 million and the company's shares are quoted on NASDAQ OMX Helsinki (Pöyry PLC: POY1V).

Pöyry Management Consulting provides leading-edge consulting and advisory services covering the whole value chain in energy, forest and other process industries. Our energy practice is the leading provider of strategic, commercial, regulatory and policy advice to Europe's energy markets. Our energy team of 200 specialists offer unparalleled expertise in the rapidly changing energy sector.

The leading advisor to the world's capital and resource intensive industries.
Clients choose us for the sharpness of our insight, deep industry
expertise and proven track record – because results count.

Pöyry Management Consulting

Pöyry Management Consulting (UK) Ltd
King Charles House
Park End Street
Oxford, OX1 1JD
UK

Tel: +44 (0)1865 722660
Fax: +44 (0)1865 722988
www.poyry.co.uk
E-mail: consulting.energy.uk@poyry.com