A BUSINESS CASE FOR A UK INDUSTRIAL CCS SUPPORT MECHANISM

A Pöyry report on behalf of and in partnership with Teesside Collective

February 2017
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PÖYRY MANAGEMENT CONSULTING

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EXECUTIVE SUMMARY

- Carbon Capture and Storage (CCS) is a technically proven technology for application to industrial emissions currently operating at sites worldwide, and the only option for deep emissions cuts for many UK industries.
- Total lifetime cost for capture, transport and storage for an industrial CCS hub is £60/tCO\(_2\) – appears good value in comparison to cost of carbon used for policy development which stands at £78/tCO\(_2\) by 2030, and other contracts aimed at decarbonising the energy system.
- Building on Lord Oxburgh report recommendations, a commercially feasible industrial CCS business model has been identified and tested through broad stakeholder input that potentially meets needs of both industry and Government.

Introduction

Large manufacturing industry is a major contributor to the British economy: in 2015, for example, nationally it accounted for 2.6 million jobs, £160 billion Gross Value Added and contributed around half of UK exports. However, it also has around 70 million tonnes (mt) annual direct CO\(_2\) emissions. As the UK Government formulates its industrial strategy, it is inevitable that the impact of legally binding carbon budgets form part of that consideration – including the provision of necessary infrastructure to reduce industrial emissions. Beyond further energy efficiency, deep emissions reduction for many industries is only possible through Carbon Capture and Storage (CCS) technology.

During the most recent UK competition for CCS on power, modest funding was provided by Government to scope CCS for industry, as represented by Teesside Collective. Following the cancellation of the CCS Commercialisation Programme in 2015, and an evident need to gain industry confidence after a number of failed competitions, there is a need to revitalise this effort in a more structured approach.

This report proposes a business model that could make cost-effective, near-term investment in CCS attractive to the Government and to Energy Intensive Industries (EIIs) and so form a basis to enable the Government and industry to jointly to take forward delivery of Industrial CCS.

Costs of industrial CCS

A comprehensive analysis of the costs and benefits of supporting industrial CCS would take a number of factors into account, including the value of jobs created, future value of infrastructure and learnings developed, and the value of supporting the retention of EII industry in the UK. Here, we address only one part of the cost-benefit analysis: investigating the abatement cost purely from the perspective of direct cost-to-government per tonne of CO\(_2\).

Figure 1 presents the cost per tonne of CO\(_2\) abated by supporting three sample projects from Teesside Collective – CF Fertilisers, BOC Linde and Lotte – comprising a total potential CO\(_2\) volume of 0.73 million tons per annum (mtpa) permanently stored. These three projects sum to a total cost, including payment for accessing a shared T&S network, of £58 per tonne of CO\(_2\) (tCO\(_2\)). The blue bars represent different cost elements of the business model proposed in this report. The projected monetary carbon value from captured carbon is £41/tCO\(_2\) based on Government EU ETS price projections, some of which will be netted off on-going capital and operational support cost commitments for Government under the proposed business model.
These costs, totalling around £17m of pre-FID costs, £110m for construction and £16m per year of operational costs (excluding T&S), would reduce emissions by 11 million tons of CO₂ over a 15 year support lifetime.

We emphasise that the three sample projects are a limited subset of the industrial CCS opportunity on Teesside, particularly when accounting for new potential investments. For example, further work completed in 2010 for an additional three pre-existing sites on Teesside, delivers very similar cost estimates per tonne of CO₂ for capturing an additional 1.7mtpa (2.4mtpa total when combined with the three sample Teesside Collective projects). Additional existing and new opportunities at the Teesside hub alone may capture a further 5-10mtpa.

It is likely that many more sites around the UK could capture carbon at similar cost to these first projects shown on Teesside where developed through a hub approach. While some sources will undoubtedly require more expensive engineering solutions, total non-electricity related industrial emissions in the UK are around 70mtpa, so the potential for emissions reduction, based only on existing industry, is significant.

**Developing a successful business model for Industrial CCS**

**Aligning perspectives on industrial CCS**

A model which drives industrial CCS must create an attractive proposition to many stakeholders with different outlooks and success criteria. We group these into three principal ‘perspectives’, shown in Figure 2 below.
Figure 2 – Aligning perspectives on industrial CCS

- **EIIs – building a compelling investment case:**
  - Decarbonisation is a strategic goal for many EIIs, but the realities of international competition need to be accounted for. The key target must be to create a compelling business case for the national or international management in comparison to other investment opportunities. From an EII perspective the model embraces the underlying commercial realities of industry by providing a reasonable rate of return and carbon exposure benefit for the first movers.

- **Government – aligning with industrial strategy:**
  - From a Government strategic perspective, upgrading UK industry to help it increase competitiveness and position for operating in a carbon-constrained future aligns well with the developing industrial strategy and Emissions Reduction Plan in the UK. This ICCS Business Model protects and generates jobs, attracts inward investment, grows GVA, provides a competitive advantage to UK operations, and develops UK supply chains. Industrial CCS also delivers decarbonised UK industry in line with wider objectives such as the Climate Change Act carbon budgets, while the need for provision of explicit support for CCS is recognised by EU state aid rules.

- **Government – providing value-for-money decarbonisation:**
  - From a Government value-for-money perspective, effective industrial CCS support can be judged to deliver cost-effective decarbonisation through:
    - generating growth in industrial regions and significant decarbonisation at a potential cost that is much lower than other decarbonisation options, including current subsidies in the energy sector; and
    - minimising the overall cost of support for industrial CCS to the public by avoiding the risk of over-reward of the EII undertaking the capture.

**Transport and Storage**

Building on previous work for developing CCS in the UK – most notably the 2015 Teesside Collective Blueprint work and the 2016 Lord Oxburgh Parliamentary Advisory Group report – this report supports the necessity of the separation of the business of CO₂
capture from that of CO₂ Transport and Storage (T&S). The risks, drivers and required expertise for offshore T&S are very different from those of capture sites; whose primary business is the production of goods. Where the business case for capture and T&S has been strongly linked, cross-chain risk between the parties is a very real deal breaker and creates an unacceptably high risk of failure.

The business model in this report therefore focuses on driving the adoption of industrial CCS, while linking in to a CO₂ transport and storage network that is developed and backed separately by the UK Government. A process for developing the transport and storage network hub and carbon capture will need to ensure the transport infrastructure can be brought online before, or concurrently with, the first capture project(s). Pursuing a model that also works alongside support for power based CCS will maximise the opportunity to access economies of scale from a large well utilised transport and storage network.

**Proposed industrial CCS business model**

Five main challenges need to be addressed in any industrial CCS contract:

1. Upfront capital investment for CO₂ capture.
2. On-going costs for operating the CO₂ capture plant.
5. A clear solution for the CO₂ once it leaves the boundary of the capture site.

Fundamentally the proposal is a fixed-term contract between the EII and Government which supports development of CO₂ capture at the industrial site.

A Government owned company would be responsible for CO₂ T&S – and the EII will have a contractual relationship governing the transfer of CO₂, including the transfer of all storage long-term liabilities, and any associated payment of transport and storage fees.

Figure 3 summarises the business model structure, the main money flows within the contract and the key parties: the EII company capturing CO₂ at the site; the Government body assumed as tasked with delivering CCS (the CCS Delivery Company or CCSDC); and T&SCo – the company developing CO₂ transport and storage.

**Figure 3 – Overview of proposed ICCS Business Model**

Note: We assume here that CCSDC is the responsible body within Government for delivery of UK CCS including contracting of Industrial CCS. Figures in brackets are parameters to be negotiated between parties and are subject to change.
This proposed model needs to be an attractive proposition to both EIIs and Government. In the following sections we describe the proposed model from each party’s viewpoint.

**Given the current stage of UK CCS development, we focus on the business model features required to establish the first industrial CCS projects at a new hub in the UK. The level of support provided to the EIIs may decrease between the initial contracts developed before the hub is operational and those developed later, as the risks of developing CCS change. Early adopters will particularly need to see enhanced benefits within this framework to encourage them to participate.**

**Energy Intensive Industries:**

- EII makes a capital investment in the capture plant. It then receives repayment of that capex from Government with an agreed return on their investment. This payment stream from Government is shaped such that the majority of the original capital outlay is recovered by the EII in the first few years of operation to fit with EII restrictions on investment return periods. Payments from Government relating to capital are much lower in the later years of the contract, but ensure that the EII will only earn a higher return on capital if it continues to operate the plant up to the full contract term.

- Full capture plant operational costs, including payment for use of the T&S network are covered by Government. Payments may be made against a combination of actual and forecast costs to provide an incentive for the EII to minimise on-going operational costs over time. This would be balanced against the need to ensure the scheme’s attractiveness by managing risk to EIIs and any disincentives to run the capture plant.

- Some carbon value is retained by EIIs, such that their carbon price exposure is lower after the introduction of CCS. This helps to create a compelling business case for the Board of the EII, which can be set against the risks of developing CCS. After the support period, the EIIs have a CCS system for their long-term use, albeit covering the operating costs themselves.

**Government:**

- Government, through the CCSDC, provides partial upfront capital to support the investment in CO₂ capture equipment, in the form of a grant.

- Government provides capex repayment, with an agreed return for the proportion of the capex funded by EIIs, plus opex support during the [15year] life of the contract. On-going support costs are reduced for Government as they receive a proportion of the value of CO₂ savings from the CCS.

- Payments made to the T&S provider by the EII are covered on a full pass-through basis by the CCSDC. These T&S payments are assumed to be sufficient to cover the fair proportion of the costs of developing and operating a large and well-utilised T&S network.

- The scheme aligns with Government perspectives on industrial CCS in two ways:
  - Value for money carbon reduction in line with Carbon Budgets with wider economic advantages arising from providing low carbon industrial infrastructure. This model is a powerful incentive for industry retention in the UK, job creation, and the attraction of new industries to industrial clusters with CCS, including companies that use CO₂ as feedstock.
  - When compared to alternative approaches, the support structure lessens tax payer contributions to the scheme by lowering the need to provide large returns to the EII to compensate for investments outside of their usual scope (such as T&S).
Although various parameters have to be agreed between the parties, feedback on this model indicates it could be sufficiently attractive to encourage EIIIs to participate, while aligning well with a range of Government investment and domestic policy objectives. We therefore present this proposed model as a solution for Government to use to deliver the infrastructure for UK based industrial Carbon Capture and Storage.

Allocating CCS support to CO₂ emitting industries

As noted above, overcoming cross-chain risk, where the performance of one investment is highly dependent on the performance of other parts of the CCS chain, has proved to be one of the biggest challenges for full chain CCS projects. This model, as in the Lord Oxburgh report, advises separation of the capture from the T&S. Accessing the well-recognised benefits of hubs – reducing emissions from large and multiple emitters to capture economies of scale and reduce risks for follow on projects – makes it worth overcoming the challenge of coordinating several projects.

The process for allocating contracts therefore needs to sufficiently de-link the capture investment process from the decision on T&S, while allowing for the development of multiple capture sites. Our proposal for the process of allocating CCS support to emitting industries and power, and the link to the T&S development is summarised in Figure 4.

Figure 4 – Overview of capture contract allocation process

The first step in the process is for Government: to define a clear strategy for CCS – this will include the decision to target support to particular storage sites and industrial and power CCS, as well as taking the necessary legal and regulatory steps to establish the CCS delivery bodies. A strong strategy is essential upfront to attract potential EII and regional participants to invest the significant resource required. The process steps are designed to allow for the decision on the T&S hub to be taken with key information in-hand from potential capture projects and vice-versa. We envisage that the final investment decisions (FID) on proceeding with construction of T&S and the signing of the initial capture contracts would be targeted to happen concurrently.

Our proposal should enable simultaneous development of industrial CCS with power based CCS. This alignment gives a strong message of Government commitment, although it is quite possible that EII projects would actually be the first to use the store.
1. BACKGROUND

1.1 Introduction

Initiatives to stimulate the large scale deployment of CCS in the UK go back over ten years, and for many reasons have focused on large power stations. Unfortunately, these efforts reached a major hiatus with the cancellation of Government funding of the two power sector based CCS commercialisation projects at Peterhead and on Humberside in late 2015.

To date Government activity to develop CCS for industry has focused on funding the efforts of the Teesside Collective – with £1.3 million funding from Government, energy intensive industries on Teesside have invested time and effort to scope opportunities, costs and financing mechanisms for CCS on several industries. Following the cancellation of the UK CCS Commercialisation Programme, and an evident need to gain industry confidence after a number of failed competitions for power-based CCS, there is a need to endorse and expand this effort in a more structured approach.

In October 2016, Pöyry were engaged to develop a business model for UK based industrial carbon capture and storage (ICCS) on behalf of and in collaboration with Teesside Collective. This report shows how a suitable business model may make near-term investment in CCS attractive to the Government and to the Energy Intensive Industries (EIs) that are both a major contributor to the UK economy and a large component of the country’s CO\textsubscript{2} emissions. For the majority of these sites, CCS is the only realistic way of achieving deep cuts in emissions beyond the levels that can be achieved by energy efficiency and recycling waste heat.

In addition to a major reduction in UK CO\textsubscript{2} emissions, there would be considerable economic benefits to the UK in decarbonising industry through the competitive advantages of insulating industry from future carbon policy, and creating a strong rationale to continue production in the UK. Taking the example of Tees Valley, Cambridge Econometrics reported in 2015 that developing a CCS hub in the region could support:

- over 1,000 direct and indirect short-term jobs in the UK during the four-year construction period (2021-2024 inclusive);
- a further 350 long-term jobs, directly and indirectly associated with the operation and maintenance of the CCS network; and,
- 2,400 direct jobs moved to the low carbon economy, supported by a further 3,500 in their supply chains.

Development of the CCS network would lead to an annual increase of around £85m in GVA over the first 4 years of operation, just from Teesside. This includes:

- £30m annual increase in direct value added to the region;
- a further £20m annual increase in direct value added to the rest of the UK; and
- an additional £35m increase in value added in the UK due to indirect effects.

More broadly, establishing a Capture hub which can incorporate emissions from industry, power, heating, and hydrogen production has several advantages. It can realise greater CO\textsubscript{2} volumes than a single project, thus maximising potential economies of scale and mitigating the risk from any single project not progressing. Such a hub, that offers a variety of low carbon options, would serve as a focus for inward investment in a low carbon future, both for the current investors and to attract new investors to the UK’s industrial heartlands.
1.2 Importance of decarbonising industry sectors

By far the largest CO₂ emitters are the four sectors of power, transport, buildings (inc. heat) and industry – and CCS can have a role in decarbonising all four.

**UK Industrial emissions**

At over 100mtpa, direct and indirect industrial emissions constitute almost a sixth of the total CO₂ emissions from the UK. As the diagram on the right from the Committee on Climate Change shows very clearly, many sectors are going to have to reduce emissions considerably to meet the 2050 target.

Source: Committee on Climate Change 2013

**Types of industry and their locations**

“Industry” is something of a misnomer – it represents a highly diverse group of organisations working in very different markets. While the individual markets have very individual dynamics, for the majority of them maintaining continuity of production is usually a high priority due to their capital intensity – an important consideration when decarbonisation processes are proposed.

In a geographical sense, for many reasons over time, the energy intensive emitters have tended to locate themselves in clusters at major river mouths around the country. As the map illustrates there are effectively five locations: Teesside, Humberside, Grangemouth, Merseyside, and South Wales.

Source: Carbon Architecture
**CCS is only option for many industries**

While some of the direct (non-electricity related) emissions from EIIs are from combustion processes, a large proportion (around half) are specific to the production process: for example where the CO$_2$ is produced in the chemical reactions in making ammonia or cement; or through processes like steelmaking where the very high temperatures can only be achieved by burning fossil fuels or hydrogen.

In practical terms the clear implication is that CCS is the only realistic deep decarbonisation approach for most of today’s UK heavy industries. Alternatives such as electrification of the process (using renewables to produce electricity), or substitution with biofuel sourcing, are either unfeasible or would require major redesign, testing and rebuilding of the complete production process. These are often more appropriate for new plants rather than as a retrofit to existing plants.

**The case for action now**

Action to address industrial emissions is urgent in part due to the climate related emissions targets set at a national and international level. In the UK these emission reduction targets are recommended by the Committee on Climate Change through carbon budgets and an annual progress report is produced for Government. In the 2016 progress report CCS is noted as a particular priority: ‘CCS is of critical importance to meet the UK’s climate targets at least cost, and requires a strategic approach to its development’ and it explicitly recognises the need for a new support mechanism for industrial CCS.

In addition, the establishment of a strong UK strategy and an attractive business model for industrial CCS provides a clear low-carbon route for heavy industry. Providing a credible option for CCS as a solution to avoid most of the CO$_2$ emissions from a range of industrial processes, allows industries to take the decision to maintain production in a low carbon future. It can also encourage the potential siting of new, low carbon production in the UK, rather than investment in countries with little carbon regulation or in other countries with an emerging carbon solution.

The case for action now also revolves around the low apparent benefits of a wait-and-see approach. CCS can be seen to work on a variety of industrial processes worldwide and significant experience has been gained in recent years through operating projects in the US, Canada and the Middle East. While technological improvements in CO$_2$ capture will be forthcoming in the future, a large percentage of the potential cost savings are likely to be delivered by the establishment of a large and well utilised hub. With the right business model and choice of hub, the costs of industrial CCS are modest when compared to many other options currently being pursued, even for the first few CCS projects.

1.3 Business challenges for EIIs

Decarbonised products are a fundamental part of the strategic goal for many EIIs. Industry themselves are very interested in CCS technology as a key part of the move to a decarbonised future – there is a strong and growing recognition that CCS is the only realistic option for deep cuts in many sectors. Against this backdrop the EIIs that we have contacted as part of this project have been very keen to engage in the process, while stressing the need to recognise the commercial realities of industry. A section of these key business challenges which apply across a range of industries are outlined below.
International competitiveness

British industry has fought for many years to maintain its competitive position in a marketplace that has seen far more international competition in recent decades. Lower labour costs, lower environmental and social regulations and often significant state support have all been cited as challenges for British industry. They have met these challenges partly by developing high gross value add processes, such as in the chemicals industry.

In this context, national carbon reduction commitments and the introduction of the EU ETS added to these pressures - outside Europe, few other countries charge their large industrial emitters for CO₂ emissions. Up to the 3rd Phase of the EU ETS, many industrial emitters have been given sufficient free EU Allowances to cover their emissions. The 4th Phase is expected to see a reduction in these free EU Allowances.

The flight of industry to alternative locations, e.g. the Far East, is a continuing theme that has a profound impact on the UK economy.

Consumer demand for green products

A growing theme worldwide in consumer products is for greener packaging and environmentally responsible actions. Companies like Coca Cola have engaged the Carbon Trust to measure the carbon footprint of its packaging and makes great play of its efforts to reduce this.

Government industrial policies have the opportunity to develop carbon infrastructure to make the UK an attractive place for these industries to locate their plants.

Time horizons

Industrial investments are taken in the context of the marketplaces for their products, as typified by contract durations, and the capital cycle involved in plant upgrades. Typically, these are far shorter than in the power sector, where the underlying need for the product is fairly well guaranteed and there is limited international competition. Furthermore, each sector has its own individual commercial and economic characteristics – so that while it is reasonable to say that most EII’s will have time horizons shorter than five years, many will be far lower than that, and a two to three year investment cycle is quite commonplace.

With typical investment payback periods being less than five years, the traditional structures used, for example in supporting renewable energy investment in the electricity generation sector are unlikely to succeed.

Carbon pricing through the EU ETS

As explained earlier, the carbon price created through the EU ETS places an additional business risk on the EII’s. In the early phases, some industrial sectors have been exempted, and in many others, EII’s are given free allowances. In practice, the relatively low prices seen in the market to date have meant that economic pressures from the EU ETS have been relatively second order. Nevertheless, it is widely expected that Phase 4 in 2021 will have considerably reduced proportions of free allocations for EII’s, with many forecasts showing increasing prices.

The spectre of higher but unquantifiable costs from the EU ETS (or a potential UK specific alternative) does therefore place some additional burden on them, but we observe that EII Boards are not sanctioning funds for carbon abatement. Instead they would rather spend their resources improving the production process.
We note that by the time the first UK industrial CCS projects are commissioned it is very likely the UK will have left the EU – it is therefore unclear what policy or set of policies will be governing carbon emissions at that point. For the purposes of this report we have assumed that the EU ETS or a similar international market mechanism for pricing CO₂ emissions continues to cover UK based industrial emissions. In the event that a different policy environment prevailed, we do not envisage that the underlying rationale would be too different. We would still be operating in a carbon constrained environment – most efforts to lower UK emissions are UK policy led rather than EU led – and industries would still face pressure to decrease carbon emissions.

**Taking on additional risks**

Amine capture technology, the predominant process to separate CO₂ from other gasses, is a relatively mature technology with widespread deployment in the oil and gas industry and in many other industrial processes. Nevertheless, the adoption of any capture technology will be a new step for many UK heavy industries.

For many, sound commercial reasons, the EIIs are as a group driven to reduce risks to the output and quality of their final product – contractual risks and enduring customer relationships are naturally a very high priority. In practice then, a high sense of caution to protect high value products and avoid perturbing sensitive production processes runs throughout the EIIs. With little industry experience in operating the carbon capture process equipment and a relatively small amount of existing in-house carbon capture experience, it is not surprising to find caution in the EII community.

Progress to date with Teesside Collective is good evidence that companies such as those in Teesside are willing to start the development of a network if the right commercial deal is available.

**Financial capacity**

As a group, EIIs do not have the financial capacity of oil & gas companies or traditional energy utilities, and initiatives to decarbonise these industrial sectors have to recognise their financial attributes. In particular, EIIs almost universally do not have the balance sheet strength to take on significant liabilities, such as the carbon cost liability in the unlikely event of a CO₂ leakage from the carbon store. Any viable business model for industrial CCS has to recognise this.

The investment opportunity for CCS also needs to be attractive when compared to the other investment options available to the EII. Investment decisions of this size are often made on a global level, as opposed to regional or even national level. Given the increasingly competitive international landscape, the pressures on investment decisions should also be considered. In this context the usual investment horizons of EIIs are significantly shorter, typically 3-5 years, than those in some sectors such as power.

1.4 **Building on other efforts**

**UK CCS efforts**

Stimulating the early development of CCS in the UK has long been a part of UK Government Strategy, where in addition to R&D funding, this has manifested primarily in two Government led competitions to develop frontrunner power-related CCS projects. While neither of these competitions has been progressed to deploy CCS, it must be recognised that a large amount of technical know-how and R&D support was mobilised in
support of these CCS developments. The utilisation of the knowledge generated through the competitions is a key opportunity for the development of a renewed UK CCS strategy.

At a national scale, organisations such as the Committee on Climate Change, The Crown Estate and the Energy Technology Institute have considered approaches to build a CCS industry beyond the power sector. All of these organisations have explicitly recognised the importance of Government facilitating the storage and transport infrastructures.

In this context, Teesside engineering, economic and commercial studies have combined together to develop practical and quantifiable propositions for Government.

*International Industrial CCS efforts*

There are a growing number of Industrial CCS projects in other countries – most notably in the Netherlands, Norway, US, Canada, China, and the UAE (Emirates Steel). In 2015 the Zero Emissions Platform published a report considering its importance, and made various conclusions, including:

- EII’s cannot reduce their emissions substantially without CCS;
- Meeting 2050 targets is only achievable if EII’s reduce emissions, and must start now;
- Incentives will be required, as well as upfront public investment in transport and storage infrastructure; and
- Large saline aquifers already identified have more than sufficient storage.

The Norwegian Government announced in 2016 its intention to take forward plans to capture CO₂ emissions from three industrial sites in south eastern Norway and use liquid CO₂ ship transfers to a North Sea store near the Sleipner aquifer – a sub-surface structure into which CO₂ from natural gas processing has been successfully and continuously injected and stored for more than 20 years.

In the Netherlands, the ROAD project has been developed based around CCS on a coal power plant, with the expectation that it can also support significant reductions in emissions from industry in the Port of Rotterdam.

The Canadian Government has supported the Quest project which employs CCS on three steam methane reformer units, capturing CO₂ generated in the production of hydrogen used to generate synthetic crude oil.

While there are likely to be differences in the commercial details, there is a common theme developing of a need to provide capital and operational support to reduce carbon emissions, rather than imposing penalties for production of carbon.

Also, in the absence of enhanced oil recovery projects, it is recognised that CO₂ transport and storage infrastructure has to be funded by the state.

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1 Developing a CCS network in the Tees Valley Region (Element Energy 2010); Blueprint for industrial CCS in the UK (Teesside Collective, 2015), including an investment mechanism report (Societe Generale), business case (Pale Blue Dot), engineering estimates (Amec Foster Wheeler / RHI), and economic impact report (Cambridge Econometrics).
Oxburgh Report

Many of these themes were echoed in the Oxburgh report, launched in September 2016. The challenge of embracing industry and heat sectors was a strong theme that was addressed in the report. Its main conclusions were that the Government should:

1. establish a CCS Delivery Company (“CCSDC”);
2. establish a system of economic regulation for CCS in the UK;
3. incentivise industrial CCS through Industrial Capture Contracts;
4. establish a Heat Transformation Group (“HTG”);
5. establish a CCS Certificate System; and
6. establish a CCS Obligation System.

This report is now being considered by Government in its formulation of a renewed strategy for CCS.

1.5 Key considerations in designing an ICCS business model

Investability

From the above, it is clear that a successful business model will have to provide a compelling business case to a diverse group of emitters to invest their corporate funds – and potentially to be able to refinance them in the financial markets.

Equally, a viable scheme must demonstrate Government value for money, including from a State Aid point of view, any potential for over-rewarding of the EIIs.

While the EIIs we have consulted are keen to engage, it must be recognised that they have limited capital resources and significant concerns about the additional operating costs and risks of adding carbon capture to their processes.

Compatibility with other sectors e.g. power

While the Oxburgh report argued for developing CCS clusters on an “anchor” power sector project, it may be possible to consider a process that allows EII based clusters to proceed without being contingent on an initial power project reaching a Final Investment Decision (FID). This report proposes that parallel power and industry developments be developed; this will enable the transport & storage economies of scale to most effectively be realised.

The Oxburgh report proposed that the Transport and Storage Co. would charge a fee for its services and take all long term liabilities away from the carbon emitter. A viable EII business model can embrace this approach – namely that the T&SCo is paid a fair value for the use of this shared infrastructure.

Strong proposition to Government and EIIs

A successful business model needs to offer a strong proposition to both Government and EIIs – particularly to give sufficient incentives to the EIIs, but also to ensure to Government that the allocation of funding minimises redundant spending. Government will consider not only their own policy appraisal guidelines and strategy, but also the need to abide by State Aid rules.
State Aid considerations are an important factor in any model design, although it is always difficult to reach a definitive positive opinion prior to testing with Brussels. Experience of the CCS Commercialisation projects and State Aid guidelines specific to CCS suggest that the European Commission may well recognise the market failures that have meant the well-recognised need for CCS for EIIs has not progressed to projects. Nevertheless, acceptable arrangements must avoid over-rewarding recipients of state support in their respective markets.

Even in the absence of formal European Union State Aid guidelines applying automatically (due to the UK leaving the EU) it is likely that similar considerations will apply in future bilateral trade deals – further consideration of State Aid issues is provided in Box 1 below.

Against this background, the following chapters outline a proposed model, one which addresses concerns heard from EIIs, and which tries to anticipate the concerns of Government.
Box 1: State aid considerations

Relevant state aid documents covering support for CCS include:

- General state aid guidance documents, and in particular those on energy: [http://ec.europa.eu/competition/state_aid/overview/index_en.html](http://ec.europa.eu/competition/state_aid/overview/index_en.html)

Section 3.6 of 2014/C 200 (Paragraphs 160-166) contains a specific set of guidelines applicable to the provision of aid to CCS. The paragraphs specifically recognise that CCS can contribute to climate change mitigation, that it entails significant costs which are a barrier to its adoption and that aid to cover these costs addresses residual market failures. The details of the allowable state aid are further spelt out as:

- 100% support intensity covering both incremental CCS capex investment and incremental opex – included in Annex 1 of the guidelines;
- there is a specific allowance for a need to support the development of Transport and Storage as well as capture; and
- the mechanism must also consider potential cost advantage from lower carbon emissions intensity as part of the ‘funding gap’.

**The mechanism we propose follows the same logic in seeking to address the funding gap between the case with and without CCS and therefore starts from a similar position to the Commission State Aid guidelines.**

The more general paragraphs of the state aid guidelines also make clear that aid can only be provided under certain conditions. The most of important of these conditions would appear to be:

- A starting point of competitive allocation of the funding but recognising that there will be circumstances in which competitive allocation is not appropriate – for renewable technologies this circumstances are specifically noted in Para 126 as:
  - limited number of projects (insufficient competition);
  - competitive process may lead to higher support levels; and/or
  - competitive process may lead to low project realisation.
- Where funding is not to be allocated as a competitive process and where funding exceeds a threshold of €50m for a CCS project the state aid process will be subject to a process of individual project notification and approval (Para 20f).
- Funding can be provided at appropriate levels of profitability for developer, and that this can be against returns commonly observed in industry as a whole (Para 61).
- For aid provided while operating the Commission states that the state may reward operational costs based on an ex-ante calculation to allow for the incentive to reside with the developer to reduce costs (Para 47).
- Funding should minimise distortion of competition in the internal market – i.e. cannot provide a competitive advantage over and above competition implying state aided CCS should not be insulated from EU ETS price if competition is not (Para 27e).

*Note: We are not presenting a full assessment of state aid nor are we providing a legal opinion as to the compatibility to such guidelines as have been examined.*
2. BUSINESS MODEL OVERVIEW

2.1 Model overview

Our proposed industrial CCS solution is a fixed-term contract between Government and the industrial company, to specifically support the development of CO$_2$ capture at the industrial site. Under this model CO$_2$ transport and storage infrastructure is developed separately by the Government – the industrial company will have a contractual relationship governing the sending of CO$_2$ and any associated payment of transport and storage fees.

Figure 5 presents an overview of the business model structure, the main money flows within the contract and the key parties: the EII company capturing CO$_2$ at the site; the Government body assumed as tasked with delivering CCS (the CCS Delivery Company or CCSDC); and T&ScO – the company developing CO$_2$ transport and storage. The key features of the business model for Government and EII are as follows:

**Government:**
- Government, through the CCS Delivery Company, provides partial upfront capital in the form of a grant. Government also provides capex repayment with an agreed return, plus capture plant opex support during the [15-year] life of the contract. The on-going support costs are reduced by a proportion of the value from the CCS related carbon savings netted off from on-going support payments – the net support costs from Government therefore reduce in line with rising carbon prices.
- The wider economic advantages for the Government come from upgrading industrial infrastructure encouraging industry retention in the UK, job creation from CCS and the attraction of new industries to an industrial cluster with a carbon solution. It also sees value for money domestic carbon reduction in line with Committee on Climate Change recommendations.

**Energy Intensive Industries:**
- EII invests part of the capex upfront, and then receives repayment from Government with an agreed return on their investment. This payment stream from Government is shaped such that the majority of the original capital outlay is recovered by the EII in the first few years of operation to fit with EII restrictions on investment return periods. Capital related payments from Government are much lower in later years of the contract, but ensure that the EII will only earn a higher return on capital if it continues to operate the plant up to the full contract term.
- The capture plant operational costs, including payment for use of the transport & storage network, are covered by Government. Some EU ETS cost mitigation is included, particularly for early adopters, although it is proposed that carbon cost savings are shared with Government. After the support period$^2$, the EII have a

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$^2$ At the end of [15 year] contract period it may be beneficial to both parties to sign a contract extension. Such an arrangement could occur when CO$_2$ prices are too low at the end of the contract for the EII to continue operating the capture plant (against the incremental opex costs which would be incurred) but where Government was seeking to reduce CO$_2$ emissions. Such a contract should not require capex related payments (unless significant refurbishment was required) but could retain the opex and carbon value components of the contract.
CCS system long-term for their use, albeit being required to cover the capture plant operating costs themselves.

**Figure 5 – Overview of proposed ICCS Business Model**

Note: In the diagram we assume that a CCS Delivery Company is the responsible body within Government for the delivery of UK Carbon Capture and Storage including the contracting of Industrial CCS. Figures in brackets are parameters to be negotiated between parties and are subject to change.

Although various model parameters have to be agreed between the parties – including those shown in [square brackets] in Figure 5 – sample feedback on this model indicates it could be sufficiently attractive to encourage EIIs to participate, while aligning well with a range of Government investment and domestic policy objectives. We therefore present this proposed model approach for Government to build on to deliver the infrastructure for UK based Industrial Carbon Capture and Storage.

The model clearly requires the separate establishment of CO₂ transport infrastructure.

**Evolution of proposed model over time**

Given the current stage of UK CCS development, we focus in this report on the business model features required to establish the first industrial CCS projects from a new capture hub in the UK. These first-mover projects face additional technological and operational risks from the early adoption of capture technology in certain industries, as well as significant policy related uncertainty before contracts are signed and a CCS hub is committed.

These risks are likely to be significantly mitigated for follow on projects that can learn from operational experience at early projects and feed into a pre-established hub. We propose that the level of support provided to the EIIs may decrease between the initial contracts developed before the hub is operational and those developed later, as the risks of developing CCS change.

However, such an evolution would not need to entail a new business model but could be supported through adjusting the level of support provided in the proposed business model. A reduction in support could be through less than full coverage of capex costs, a partial pass-through of opex or a larger proportion of carbon savings accruing to Government.
2.2 Approach

Our approach builds upon the excellent and recent base of work on the crucial nature of, and potential development pathways, to financially begin the UK CCS industry in general and industrial CCS in particular.

In addition to Pöyry’s own work for the ETI, CCC and others, this work includes the original Teesside Collective blueprint work (2015) and subsequent work to build a regulated return model for an expanded Collective membership and develop those ideas with broader industry (2016). It also builds on the Key Knowledge Deliverables and the Lessons Learnt around financing CCS from the Government’s CCS Commercialisation Programme (2016), plus the recommendations of the 2016 Lord Oxburgh Parliamentary Advisory Group report.

Essentially, an investment in CO₂ capture by emitting industries needs to account for five areas, which together must be reflected in any Industrial CCS contract. They are developed in turn in Section 3 below:

- supporting the initial capital investment for CO₂ capture (Section 3.1);
- supporting the capture plant CCS fixed and variable operating costs (Section 3.2);
- accounting for the benefits of dramatically reduced CO₂ emissions, for a given level of industry production (Section 3.3);
- technical performance risks, of the capture plant but also any increased risks to the rest of the production operations (Section 3.4) – this also includes how such risks and incentives will change over time and
- a clear solution for the CO₂ once it leaves the boundary of the capture site (Section 3.6).

In each section, in addition to our proposed approach we have identified the broad options, the parameters that can be varied within the model, and how the mechanism could be expected to evolve over time both within a contract and between contracts. To present this Industrial CCS contract in context of wider initiatives on industrial infrastructure and carbon reduction we also to consider two further areas:

- the mechanism for allocating CCS support to emitting industries, the link into power generation within the same region, plus wider developments in the CCS industry in the UK is covered in Section 4; and
- initial quantification of the mechanism – shown in Section 5 – enables us to see example cost structures, to estimate some ranges of total support costs and to show the timing of payments from the proposed support approach on Government.
3. MODEL FOR INVESTING IN UK INDUSTRIAL CARBON CAPTURE AND STORAGE

3.1 Supporting capital expenditure on CO₂ capture

The building of carbon capture at energy intensive industrial sites in the UK will necessarily entail upfront capital investment in CO₂ capture infrastructure. This infrastructure will primarily include CO₂ absorption and amine regeneration facilities (where a stream of relatively pure CO₂ is not already present), CO₂ treatment facilities (purification and drying), and CO₂ compression and pumping equipment for pressurising the CO₂ for transfer into the transport and storage network.

Within the context of normal industrial investment levels for UK industrial players, such capital expenditure is significant. For a business model to be successful a clear solution is required to sufficiently reward capture investors for capital expenditure and construction work at their site, whilst, to the extent it is supported by public funds, costs must be justifiable to Government.

Proposed solution for remunerating the additional capital burden

The capex model we propose is shown in Figure 6 where the total incurred project capex for the capture infrastructure investment is shared between:

a) a publically funded grant for infrastructure investment paid by the Government as capital expenditure is incurred; and

b) an EII upfront funded infrastructure investment, with an associated CCS Development Company contract to receive a payback on that investment over time once the capture plant is operational.

The publically funded grant element would be paid out to a schedule agreed at the FEED project stage (e.g. as in the Regional Growth Fund) as the Government and industry are used to these arrangements. If the project capital costs come in over budget then this risk could be partly on the company, creating the incentive for the EII to deliver the project on budget. If the project is delivered under budget then we would generally expect the EII to receive the benefit although, where costs come in more than, say, 10% lower than expectations, a contract variation clause could be included. For early adopter EII projects, given their relative novelty it might also be appropriate to mitigate or cap this risk in some way.
We propose that the EII funded investment is paid back with ‘shaped’ repayments. That is, a high level of payment is used in early years, and a lower repayment is used in later years. This structure helps provide a solution to the mismatch between EII’s typical investment horizon of ~3-5 years, and the Government’s interest in ensuring publicly funded assets are utilised for a substantial period of time, typically > 10 years. This structure is shown in Figure 7, displaying an example cumulative net cashflow from/to an EII that invests £60m in a capture plant during the construction period but across three different corporate borrowing rates (represented as WACC of 0%, 8% and 12%).

The repayment mechanism is front-loaded such that the EII recovers the base capital expenditure within a short space of time (say ~3 years after commissioning) – the enhanced capital repayment period. In the example shown, during this time the EII receives £25m per annum, recovering both the initial capital outlay of £60m + a return of 8%. Payments during the enhanced capex repayment period start on commissioning and are made so long as the capture plant does not decommission. There is therefore a strong incentive on the EII to keep the plant operational in the ‘Enhanced capex repayment’ period, and one that also remains a material consideration through to the end of the contract.

Residual capital related payments continue under the contract for a tail period, so that, assuming the plant continues to be operational, the EII can earn a greater return during the tail period on the capital invested. Residual payments are much smaller than in the enhanced capex repayment period, with payments based on operation of the plant such that they are pro-rated down in the event that the plant does not operate, providing an incentive to keep the plant operating. In the example shown, payments continue at around £1.6m per annum for a further 12 years after the end of the enhanced capital repayment period, and the EII therefore earns a 12% return on capital invested after operating for the full 15 years total contract length.
Options considered for remunerating additional capital costs

A range of options to cover additional capital investment in capture are possible. Conceptually we can present these as varying in two dimensions:

1. The % of up-front capital support that is provided by the developer (rather than upfront via a grant), which will vary between extremes of:
   - 100% developer-led financing (i.e. 0% grant); to
   - 0% developer-led financing (i.e. 100% grant), or Government ownership of capture assets, as per the Lord Oxburgh Report recommendation for power.

   We have selected a mid-point in the proposed model.

2. The risk associated with the proportion of capital invested by the developer. This dimension will vary between:
   - a position where the developer bears a very high degree of risk to the capital committed on the investment, as would be the case if repayment was based on operational output over long time-frames such as in a full CfD style mechanism; and
   - a position where the developer bears a low degree of risk on the capital committed to the investment, as would be the case if the capital repayments are guaranteed and returned over short time periods.

   We have selected closer to the latter in the proposed model.

These options and potential solutions considered in this work and elsewhere are shown in Figure 8. We assess that while certain business models would fail to address the
fundamental need to appeal to both EIs and Government, theoretically at least, a range of options could still be mutually acceptable.

Figure 8 – Conceptual options for support of capture capital costs

The mechanism we propose is not the only potential solution to remunerate additional capital costs but has the following advantages:

- Allowing for direct payback of capital invested by the EIs, with relatively low capital investment risk as the CCSDC is highly credit worthy, and payback is not solely linked to capture plant capture rates. From our interviews with EIs, and from earlier work on market failures within the CCS sector, such capital support is regarded as a necessary element for creating a business case for CCS within the EIs.

- The use of a public grant for a proportion of the investment reduces the capital raising burden on the EIs and is likely to significantly increase the number of EIs that can then consider an investment in CO$_2$ capture within their own investment constraints.

- The inclusion of a proportion of the investment directly funded by EIs, reduces upfront Government grant requirements and allows for the introduction of incentives on the EI to develop at reasonable cost and also keep the asset operational over time (as capex repayments and return in the residual period would be dependent on continued operation).

- The use of shaped repayments allows for the EIs to recover the incurred capex spend over relatively short-time scales, while also allowing for Government to create a longer-term incentive for the EI to keep the asset operational in the UK. This meets both EI investment horizon requirements, and also helps to align the incentives of the EI with Government.
Parameters to be set within the preferred model

Within the framework of the preferred business model, there remain a series of parameters that may vary between different contracts, depending on the preferences of Government and the EIIs. We tentatively propose the process for setting these parameters as follows:

- Government would lay out ranges that it would potentially consider acceptable for each parameter – this would help to remove the need for unnecessary rounds of negotiation if no solution can exist;
- EIIs will submit a proposal in pre-FEED covering the key parameters to be negotiated – see Section 4.3;
- This will be reviewed in an application round by CCSDC and can be finalised as part of the FEED process before contracts are signed.

The four main parameters required as part of the contract are:

1. **Split of capex between the percentage covered by a direct grant and the percentage covered upfront by the EII:**
   - We have started our discussions with both the EII and Government with a 50:50 capital split as an equal partnership.
   - However, we could imagine that a range of splits of up to 80:20 grant to EII investment or 20:80 grant to EII investment would also be possible depending on the preferences of the parties negotiating the contract.
   - We do not consider that having a very low (less than 20%) or no grant would be acceptable to the EIIs, due to internal capital restrictions.
   - A very high (over 80%) or full grant might not be acceptable to Government as it increases the upfront burden on Government, reduces the commercial incentives for the EII to procure the optimal capture plant, and reduces incentive options in other elements of the contract (e.g. the residual capital cost payments may be so low as to remove the incentive on the plant to remain open).

2. **Contract length:** we have used 15 years as an example total length contract to align with current Government contracts for capacity and renewable electricity – however, the overall length of the contract and the length of the two periods (enhanced capex repayment period and residual capex repayment period) could both be varied within the model. Varying the contract length parameters will impact the investability of the contract to EIIs, but a longer contract can substantially increase the volume of carbon captured during the term, as well as increasing the likelihood of the plant being maintained by industry after the contract period (due to expected rising carbon prices).

3. **Rate of return on EII invested capex** (both within the enhanced period and by the expiry of the contract): is assumed to be set via a pre-FEED negotiated process.

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3. It is worth noting that a grant funding looks cheaper to Government, in terms of a £/tCO₂ assessment, than private funding with payback over time as the Government borrowing costs will be lower than those of industry.

4. As indeed the trigger for moving from one period to the next could be negotiated, but would need to be consistent with other terms in the contract. For example, is the end of the ‘enhanced capex repayment’ period a set number of months after commissioning or after a set number of hours of operation or after a set number of tonnes of CO₂ tonnes captured?
The acceptable position will depend on the hurdle rate requirements of EIls, but also the value perceived by the parties in the remainder of the contract:

- For Government such value will need to make sure that the investment still makes sense from the perspective of public value and also from any state aid requirement (see Box 1).
- For the EIls the acceptable return will depend on the perception of risk to repayment of capex but also the EII perception of risk and reward in the rest of the contract.
- For contracts after the first round, when the hub is clearly committed and risks have reduced, there is the potential that some fraction of the capex may not be repaid by Government, with EIls willing to accept a carbon benefit as a return on part of their investment.

4. **Calculation of capital cost to be repaid** may be made based on actual costs properly incurred, or on forecast capital spend with under- or over-spend either borne by the EII or shared by the parties (pain/gain share).

**Evolution of mechanism for remunerating additional capital burden**

**Variation of payments within a contract**

Under the proposed contract design, the capital related payments will be split into three distinct periods:

1. In the construction period a grant will be paid based on an agreed % of forecast costs (i.e. a fixed amount in GBP) and EIls will fund the remaining capital costs upfront through their own financing channels.
2. In the early years of operation, during the ‘enhanced capex repayment period’ capex related payments from Government to the EII will be relatively high to allow the EII to recover their incurred proportion of capital costs.
3. In the later years of operation, during the residual capex repayment period, capex related payments over the tail period will be much lower, but build up to provide a higher rate of return to the EIls by the end of the contract.

**Variation of mechanism between contracts**

We would expect the structure of the mechanism to change over time principally via the four model parameters as explained in the previous list.

Once the scheme is up and running, industrial CCS is successfully operational and a hub is established, we expect the risk perception to change and new contracts to evolve with lower negotiated returns, a lower fraction of grant funding, and potentially with some capex investment by EIls that is not repaid by Government. Making this explicit within the scheme would help to indicate to industry that there is an advantage to joining early, helping to combat the natural inclination to “go later” to minimise costs and risks, as well as waiting to see how the carbon price develops (when it might be too late for production extension or expansion decisions by their International Boards). It is also important to ensure that in the early efforts of the CCSDc, there is opportunity to effectively utilise the new infrastructure, and to diversify its risks.

3.2 **Supporting operational costs**

The operational cost associated with the running of equipment to capture, treat and pressurise CO₂ is significant, not least because the processes as currently envisaged
requires additional energy\(^5\) in the form of heat and electricity. Operational costs will also include maintenance, personnel, insurance and potentially additional materials such as amines for the capture process. In the following section we categorise operational payments into two categories – fixed costs incurred at the same level regardless of the level of CO\(_2\) captured and variable costs, which rise or fall in line with CO\(_2\) captured.

In parallel to the capital cost support, any business model for industrial CO\(_2\) capture must propose a clear solution to cover the fixed and variable operational expenditure associated with the capture plant installed for CCS. Please note, any remuneration of operational costs is concerned with additional site costs associated with the capture plant; we are not proposing that operational costs that would have been borne without the installation of carbon capture (e.g. those for manufacturing processes) should be supported.

In line with the principles outlined in Section 1.5, in this model we assume that the transport and storage of CO\(_2\) is being undertaken by a separate company or companies and that the EII has a contract for the offtake of CO\(_2\) at the site boundary. We include any payments to the transport and storage company as part of these operational costs.

**Proposed solution for remunerating operational costs**

The operational cost remuneration model we propose is shown in Figure 9: total incurred project opex is passed through directly to Government, based on actual costs properly incurred, with eligible cost categories defined as part of the contract award process.

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\(^5\) Where such energy can come in the form of previously wasted heat, then a synergy exists which may lower the incremental cost burden. However, both high pressure/temperature heat and electricity are relatively useful and therefore expensive forms of energy; so it is likely that using those will come at a cost.
Options considered for remunerating capture plant operational costs

In considering options for supporting the additional operational cost burden we considered three aspects:

1. Payments for transport and storage should cover any fees charged to EIls, but the level of these fees is dependent on access arrangements, and there could conceivably be no fee:
   - We propose that payments to transport and storage cover the proportional use of shared infrastructure, assuming that such infrastructure is well utilised. This is further discussed in Section 3.6.

2. Payments for capture plant operational costs could be based on actual costs incurred, or on a theoretical target cost (or some combination of the two):
   - Payment against actual operational costs properly incurred removes risks from the EII as it is not financially impacted by higher or lower costs over a given period.
   - Payment against forecast costs imposes operating cost risk on EIls. However, it generally increases incentives on the owner to operate efficiently and potentially helps to drive down operational costs over time, as the EII can retain cost savings over a period if costs are lower than forecast.

We propose the former structure, at least for the first adopters, although the latter may be more appropriate as the sector matures: new lower costs could then be used a starting point for future forecasts, such that costs savings were partly passed through to Government.

3. A fraction of the capture plant operational costs could remain with the EII rather than being passed through direct to Government, as long as other elements of the contract were attractive enough to compensate for the additional cost burden. We believe that the inevitable increase in complexity of the contracts involved would be undesirable, although this approach may have merit as the sector matures.

Our proposed mechanism has several distinct merits:

- Explicit coverage of capture plant operational costs forms part of the contract, minimising the cashflow implications and risk perception for the EIls from installation of CCS and helping to enhance the attractiveness of the investment for EIls. However, under the proposal to reduce the costs of CCS, we propose the payment of actual incurred costs i.e. no return would be made by the EIls on capture plant operational expenditure.

- As noted in Section 1.5 a key consideration within this model is the fit with schemes to establish a new separate CO₂ transport and storage network to service CO₂ capture hubs. The inclusion of a fee for T&S, at a “fair” rate to cover the use of shared infrastructure enhances both the compatibility with T&S business models and CfD based CCS support mechanisms in the power sector (where all users of the network whatever the support scheme can pay a similar fee to access transport and storage). The proposed relationship between the capture site and the transport and storage site is considered further in Section 3.6.

- The removal of the operational cost burden from the EII removes a potentially significant perverse incentive on the EII to avoid using the CCS plant once installed in order to avoid opex costs.
From a Government perspective, the on-going operational cost commitment can be at least partially netted off against any carbon value if such value is later shared, as further detailed in Section 3.3. We propose separate payment streams:

- to make more transparent commercial evaluations for the first EIIs; and
- because operational costs are not only incurred on a £/tCO$_2$ basis, so there is risk to parties of under- or over-recovery in combining the two payment streams.

Under such a scheme there will be a pre-agreed definition of eligible operating costs, and how such costs should be incurred – there should be a principle of transparency to minimise costs and risks to all parties.

**Parameters to be set within the proposed operating cost remuneration model**

Within the proposed business model framework there remain a series of parameters that may vary between different contracts, depending on the preferences of Government and the EIIs. The main parameters are:

1. **Contract length for operational cost recovery**: 15 years has been used as an example length of contract, to align with the length of the contract that remunerates capital costs. Both of these contracts could vary in length.

2. **Fraction of the operational costs passed to Government**: initial projects will have a high risk profile, both on out-turn operational costs and project completion, and we expect that 100% passthrough of operational costs will provide the most cost-effective solution for both Government and EIIs. As CCS is rolled out and greater certainty develops as to actual operational cost levels, EIIs will be better able to bear some of the operational costs.

3. **Calculation of operational cost incurred** can be varied in two ways:
   - defining which costs are eligible for pass-through to the Government and which, if any, have to be excluded; and
   - part of the operational costs may be assessed based on a forecast of operational costs, with the EII able to keep some or all of the benefit if actual costs are less than the forecast levels. A balance should be maintained between Government bearing risks to make the scheme attractive to EIIs, and providing an incentive to EIIs to reduce Government risks and minimise on-going operational costs.

**Evolution of mechanism for remunerating operational costs**

**Variation of payments within a contract**

Under the proposed contract design, operational payments will vary over time to match underlying operational costs. It should be noted that current UK Government projections show rising future fossil fuel and electricity prices in real as well as nominal terms. Maintenance costs would be expected to vary year-to-year.

Sharing of carbon value, with some value passed from the EII to Government, will lower the net support required from Government and will vary over time. This payment stream is discussed in Section 3.3.

**Variation of mechanism between contracts**

Once the first projects have received funding, industrial CCS is operating successfully and a hub is established, we would expect risk perception of operational costs to reduce and new contracts to evolve. The structure of the operating cost support would change over time principally via the model parameters, particularly through a greater burden being...
passed to EII’s who seek to retain a larger carbon value, and the transfer of a greater risk share to EII’s, creating incentives to minimise operational costs.

3.3 Accounting for avoided cost of CO₂ emissions

Energy intensive industries within the EU, Iceland, Liechtenstein and Norway are subject to the EU Emissions Trading Scheme (ETS), requiring them to present tradeable permits to cover their CO₂ emissions. Following the UK’s decision to leave the EU, there is uncertainty as to UK involvement in EU schemes and future Government policy on exposing UK industry to carbon prices. In this section we have assumed that either the EU ETS, or a similar international market mechanism for pricing CO₂, continues to cover UK based industrial emissions. In the event that there is no pricing mechanism on CO₂ then there is no direct monetary carbon benefit to either company or Government, however, where emissions reductions are still required, there may still be a carbon based driver to install CCS.

Many of the EII’s sites fall within the EU Emissions Trading Scheme. Each tonne of carbon dioxide emitted needs the EII to submit an allowance (or “permit”) to cover it.

Permits can be bought and sold, generally through Government run auctions or bilateral trades. For many EII sites they are also supplied directly and free of charge in recognition that it is at risk of ‘carbon leakage’ i.e. competing with overseas sites which have no carbon pricing. In the current and third phase (2013-2020) of the EU ETS many of the EII’s that this report targets receive enough free allowances to cover a significant percentage (or all) of their emissions.

Auctioned allowances are mainly distributed to member states, who then sell them into the wider market. In contrast, free allowances are provided annually direct to the EII’s by the EU. A single ETS-wide algorithm allocates free allowances to the EII’s from all member states. While member states actually implement it, they do not have the option to revise it. It appears likely that Phase 4 will have lower levels of free allowances, and that this downward trend will continue in subsequent phases, although at this point in time there is little certainty in the actual figures.

As in any market, there is a great deal of uncertainty in future EU ETS prices: at the time of writing allowances are trading at £4-5/tCO₂, but in the past have been as high as £20/tCO₂, and DECC’s 2015 Reference scenario projects 2030 prices of £47/tCO₂.

Building CO₂ capture plant at an EII will typically reduce the CO₂ emissions of a particular process by up to 90%. When the CO₂ is then permanently sequestered it is counted as not-emitted under the EU ETS. Under current allocation rules in Phase 3 and our understanding of proposed allocation rules in Phase 4 (2021-2030), the free allowance allocation seems likely to be largely unaffected by the addition of CCS.

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6 EU ETS Phase 1 ran from 2005-2007 and was a market testing phase with price ranging between €0 and €30/tCO₂ and allowances primarily provided for free to all sectors. Phase 2 ran from 2008 to 2012 as the first full phase of the market.

7 A legal framework for the safe geological storage of carbon dioxide – CCS directive 2009/31/EC.

8 The process for assigning free allowances is based on an international benchmarks rather than installation emissions. When an installation takes an action to reduce its emissions...
These factors create some important challenges to developing an appropriate business model:

- the current combination of low EU ETS prices and high levels of free allowances do not give strong incentives to invest in carbon capture plant; but
- there is some possibility of a future of higher EU ETS prices and/or far less free allowances in the future, which would then mean that the capture plant could be delivering very significant value to the EII; and
- for the early EII adopters there are additional risks from making the investment in the absence of a mature carbon transport and storage system and the history of cancelled CCS initiatives.

To deal with the first point, high levels of Government support are needed, but if the situation described in the second point arises, the value received by the EII will have been paid for by Government support.

So, an enduring business model should be robust to the potential future variation in free allowances and prices, while also recognising that the early adopters require stronger support.

In principal this could be done by a mechanism which:

- returns some of the value gained by the EII from captured carbon emissions (i.e. EU ETS price that would have been paid by that EII × volume captured) to Government; or
- some or all of the unused free allowances, arising from operation of the capture plant, are returned to Government. Government can then sell or cancel these allowances.

Both options allow a sharing of carbon value, but offer different risk profiles on overall carbon costs for the EII. The first reduces exposure to carbon prices, while the second option also passes exposure to (and value of) the level of free allowances from the EII to Government. From the industry perspective, the latter is attractive – reducing carbon cost uncertainty, and this would be required for the early adopters.

**Initial starting point**

In our discussions with EII, they have acknowledged the significant value that could attribute to them if the situation of high EU ETS prices and (under one mechanism) low levels of free allowances were to arise. We have discussed many possible ways in which this may be addressed, ranging from benefit sharing, capping/collaring based on CO₂ prices, or contract re-openers.

In their different market sectors, operations and parent company situations, EII are willing to forego unused free allowances as part of installing CCS, but are unwilling to proceed if they do not see a significant reduction in their carbon cost exposure.

As mentioned before, the first movers will perceive investment in CCS to be very risky, from technical, commercial and policy perspectives, and that they will therefore require a suitable proposition that brings their carbon risks close to those outside Europe in order to proceed.

below the benchmark they may receive more allowances than they need – these can then be sold on the market or retained for future periods.
We therefore proposed that for early adopters:

- 100% of the value of unused free allowances is passed to Government; and
- all the subsequent carbon value remains with the EIIls, sheltering them from carbon cost risks.

To the extent that some of the carbon saving value is transferred to the Government, it actually represents a potential upside for Government which can be netted off on-going operational cost support spent by the Government.

**Evolution of mechanism**

Once transport, storage and the first capture projects are constructed and operating, we expect that EII Boards’ view of the risks will significantly moderate, and it would be reasonable to reduce the overall rewards that are granted to EIIls, such as via a shift to a fixed percentage share of the carbon value, and/or reductions in other reward streams.

**Variation of payments within a contract**

The carbon savings will evolve over time within a contract based on at least two factors – the volume of CO₂ captured and the market price of CO₂, and potentially based on a third, the allocation of free allowances. The expectation is for CO₂ capture rate to be reasonably constant within a contract, but for the CO₂ price to rise over the life of the contract, and free allowances to fall. Where the value of carbon savings is shared between Government and the EIIls, then the value of their investment in CCS will increase as both parties will be impacted by CO₂ price increases.

**Variation of mechanism between contracts**

In initial contracts, we expect that full de-risking of carbon exposure, via a link to free allowances and transfer of unused allowances to Government, may be needed to attract interest from EIIls. In subsequent contracts, we expect that rising carbon prices will mean that more value is ascribed to the carbon savings, while falling free allowances may make the issue more pressing for many EIIls. This will increase the perceived importance of the sharing percentage and mechanism and may create the opportunity for the negotiated parameters of sharing percentages and floor levels to gain greater prominence in later negotiations, alongside potential reductions in capital and operational support payments. In addition, we would expect that with rising carbon prices companies will inevitably start to feel the financial pain and their financial drivers to participate will change.

**3.4 Technical performance risk of the capture unit**

CO₂ capture approaches depend on the process from which a site captures CO₂ – at its simplest e.g. an ammonia production plant, a pure stream of CO₂ can be dried and then pressurised ready for transfer to the transport and storage company. Other processes require a chemical separation process, typically through recycling amine solvent to extract the CO₂ from the flue gas, before it is ready for any final purification, drying and pressurising.

The capture of CO₂ is a technologically tried and tested process. For many decades, and around the world, CO₂ has been separated (“captured”) from a large variety of industrial processes, such as separating naturally occurring CO₂ from valuable hydrocarbons as they are produced from the ground. The separated “captured” CO₂ has been utilised, again for many decades, to improve fossil fuel recovery rates at oil, gas, or gas-condensate fields, after which it is stored in the same geological formation. However, the
limited scale of such European CO\textsubscript{2} projects means that it is not standard EII practice to capture CO\textsubscript{2} (apart from some ammonia production plants, for use in the soft drink industry) and that very few sites will have practical experience of high volume CO\textsubscript{2} capture. The capture of CO\textsubscript{2} from such processes primarily for the purposes of permanently storing that CO\textsubscript{2} is relatively novel but, assuming that such storage is dealt with by a third party and that appropriate technical and contractual safeguards are applied, it should not create significant additional operational risks on the main production processes of the EII.

However, though proven and well established, like any industrial process, CO\textsubscript{2} capture is not without operational risk\textsuperscript{9} and each capture site will come with its own unique set of engineering challenges. There will be periods of time when the capture plant must be taken down for planned and unplanned maintenance, with unplanned shutdown being more common in the early months of operation.

The business model should be built with these risks in mind. To be successful, a balance must be struck between leaving appropriate risks with the capture operator to incentivise efficient operation, and ensuring that the potential financial downside of any issue is not so punitive as to make the scheme uninvestable.

If the capture plant commissions on time, operates at expected levels and with expected rate of capture then the proposed capex remuneration structure in Section 3 sees the capital costs borne by the EII repaid according to a pre-defined schedule over the term of the contract.

However, there still remains a technical performance risk at the plant which could lead to unavailability of the capture site. Should the capture site be either unavailable for a period due to technical issues, or not used in the unusual scenario that the EII temporarily ceases production, then there may be ‘under-production’ of captured CO\textsubscript{2} where the level of operation may be lower than expected. In practice the capture plant may operate at better than expected levels over certain periods of time as production levels vary, and so the issue of over-production must also be assessed.

The capture plant could have warranties attached to it, to reduce technical performance risk. It might also allow some proportion of the financial risks to be passed through by the use of liquidated damages payments in the contracts. However, such cover comes at a cost, the coverage is likely to be limited to the early years of operation, and a high degree of cover is unlikely to be economic. Any residual capture performance risk can be addressed within the ICCS contract.

\textit{Proposed treatment of technical performance risks}

Following on from above, we consider the impact and incentives in the event that the capture plant is operating at less than its expected operational levels. Our proposed mechanism partially exposes EII\textsubscript{s} to CO\textsubscript{2}. We suggest this is done by reducing carbon related payments (i.e. unused free allowances) to Government when there is technical underperformance, but the EII does not receive full offset of the CO\textsubscript{2} costs (from the increased emissions) for two reasons:

\textsuperscript{9} The first year of operation of Boundary Dam, the world’s first and largest commercial-scale CCS project of its kind, achieved an operational level of 40\% against a target of 85\%. However, the reliability of the plant since October 2015 is much improved, with more than 1.3\textsuperscript{mt} cumulative captured CO\textsubscript{2} to December 2016.
Some of the value of reduced carbon emissions may lie with the Government; this is true if less than 100% of the carbon value is retained by the EII (envisaged for later adopters), or unused permits are returned to Government.

Some of the returned value could be calculated based on reductions in expected capture, thereby the EII bears some [50%] of the carbon price risk during an outage. This creates an additional incentive for the EII to return the capture plant to service in the event of a breakdown.

EIIls would continue to pay the capacity element of their T&S contract, but this cost would be passed through by CCSDC via the opex support arrangements.

We propose that EIIls are insulated from capex related payment risk during the ‘enhanced capex repayment’ period but they are exposed to them during the ‘residual capex repayment’ period:

- During the ‘enhanced capex repayment’ period, EII receives capex payments to a defined schedule and at defined levels, as long as the plant is not permanently decommissioned within the three year period after being commissioned:
  - CCSDC carries the capital risk of the project, although the EII under-recovers against incurred capex costs if the capture plant is permanently decommissioned within the three year period after being commissioned.
  - CCSRC risk is fixed; in the event the asset captures a higher volume of carbon than expected, either due to higher production at the plant, or due to a higher capture efficiency, CCSRC does not need to make any additional capex payments.

- During the ‘residual capex repayment period’ EII only receives payments to cover their return when the assets are operational and capturing CO₂ (pro-rated when not operating, rather than linked to CO₂ captured and potentially subject to [10%] overspend cap).

- EII potentially receives partial recompense for lost revenue to extent later years covered by any capture plant warranties (see above).

Finally, we propose to insulate EIIls from any changes to eligible opex:

- EII would continue to receive opex related payments based on eligible actual costs properly incurred, i.e.:
  - to the extent that eligible opex costs are higher or lower in a period due to non-operation this would be directly passed through to Government; and
  - to the extent that additional costs are classed as ineligible in the contract, these costs are either borne by the EII or a process for resolution is pre-defined.

**Options considered for treatment of technical performance risk of the capture unit**

A range of technical performance risk options could take different combinations of capex, opex and carbon exposure to adjust the risk/reward balance in the case of under or over-performance. They vary between:

- On one extreme the EII taking the maximum amount of operational risk, with all opex and capex payments based on a £/tCO₂ basis and carbon payments to Government guaranteed such that:
  - Government is financially insulated from the performance (notwithstanding any grant provision);
it places the maximum burden on EIIs and makes the investment appear relatively risky to their investment committees; and

- it presents the greatest incentive on EIIs to maximise operational performance of the capture plant.

At the other end of the spectrum the Government could take on the full technical operational risk, leaving the EII insulated from all performance issues such that it:

- leaves the Government exposed to the performance risk, such that payments would be made even in the event that the plant has poor technical performance;

- minimises the burden on EIIs as returns on investments are guaranteed; and

- presents very little financial incentive on EIIs to maximise operational performance of the capture plant.

A successful approach must aim to reduce the burden of operational risk perception to EIIs to such an extent that a technically good proposal can be investable, while still retaining incentives to operate the plant efficiently. This chosen approach is preferred because it:

- removes operational costs as a disincentive to undertake maintenance and as a disincentive to solve operational issues as the capture plant owner is not better off by avoiding incurring variable opex costs.

- partially protects the EIIs from operational issues in the ‘enhanced capex repayment’ period to help make the repayment of capital highly likely, making the capture plant investable to EIIs, while giving the Government comfort that the industrial site is incentivised to remain open. In the longer-run, the EII takes on more operational risk but could potentially earn a greater capex return by operating the plant more in the tail years.

- provides a mechanism to insulate EIIs from carbon costs (via a free allowance carbon linkage), but retains performance related carbon exposure (via a direct EII share of carbon value for later projects, and/or basing some of the allowance transfer on expected performance). This incentivises the capture owner to operate the plant and maximise availability in all years of the contract to reduce carbon costs. To the extent this creates an additional risk to the EII this would, other things being equal, reduce the attractiveness of the investment for the EII, however, if combined with a potential for the EII to retain some carbon value, it should be perceived as an acceptable risk.

**Negotiated parameters within the model**

Within the framework of the preferred business model there remain a series of parameters that may vary between different contracts, depending on the preferences of Government and the EIIs:

- whether calculations of carbon value to be returned are based on actual or expected performance of the capture facility, or a blend of both, as mentioned in 3.3; and

- the percentage cap on over-payment of the capital costs (in the event of better-than-expected performance) during the ‘residual capex repayment period’.
3.5 Drivers and incentives over time

Variation of performance incentives within a contract

Within an individual contract, the mechanism evolves over time to expose the EII to additional risk and reward, whilst removing some operational exposure to Government at the transition from the ‘enhanced’ to ‘residual’ capex repayment periods. This increase in exposure for the EII is considered to be an acceptable reflection of risk, as experience grows from operating the plant and once the original capex has been repaid.

For any individual site a balance must be struck regarding the degree of plant integration undertaken with the capture plant. A more integrated plant that makes maximum use of waste heat may have lower capital and operational costs, but comes at a cost of greater operational complexity and hence technical performance risk. It is not envisaged that any EII would install a CCS system whereby an operational problem on the CCS system would interrupt their main production.

With the mechanism changing over time we summarise the resulting impacts on the incentives for the EII in Table 1 below:

<table>
<thead>
<tr>
<th>Table 1 – Drivers and EII incentives over time</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Construction period [yr 0]</strong></td>
</tr>
<tr>
<td>Carbon – Approach</td>
</tr>
<tr>
<td>Carbon – Incentive</td>
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<tr>
<td>Capex – Approach</td>
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<td>Capex – Incentive</td>
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<tr>
<td>OpeX – Approach</td>
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<td>OpeX – Incentive</td>
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</tbody>
</table>

Variation of performance incentives between contracts

For later contracts, as operational experience is gained, technical performance risk should decrease. It is expected therefore that capture choices will tend to become more integrated with later projects, as operational experience grows across industries. Where such integration becomes standard, this will lower the underlying capital and operational cost to Government over time.
Where the combination of the technical solution and the operational experience still leaves the plant owner with a lower perceived operational risk it may also be possible to ratchet up the operational risk borne by the plant in later contracts by:

- increasing the CO₂ pain sharing percentage so the plant owner faces more technical risk; and/or
- linking the capital repayments to availability or output.

### 3.6 Relationship of CO₂ capture to transport and storage provider

The essence of a CCS chain is a three step process – i) the capture of CO₂, ii) the gathering and onshore transport of the CO₂ from the capture sites (possibly including some shared amine conditioning and compression) and iii) the offshore transport and permanent storage of that CO₂ to a sub-surface geological formation. Each of these steps requires different skill sets and has a different risk profile, which has in the past made it challenging to find a single party that is willing to undertake a full-chain project comprising all three steps in the process.

We have assumed in this model that the third step, the development of offshore transport and storage (T&S) is undertaken in a process outside of the capture contract.

Such an approach is compatible with that of Lord Oxburgh’s Parliamentary Advisory Group’s report recommendation to establish an independent but Government owned company to deliver CO₂ transport and storage (known as T&SCo). However, it is not dependent on that precise model and could fit with other models, as long as the transport and storage can offer a contract to off-take CO₂ and accept liabilities for the CO₂ at the point of transfer.

**Proposed solution for relationship of capture to transport and storage**

Any capture entity will need to have a contractual relationship with a company (or JV) that can transport and store the CO₂. This contract is assumed to comprise a minimum of five elements:

- A definition of the technical specifications (permitted impurities, maximum water content, pressure etc.) for the transfer of CO₂ into the transport network with defined approach to venting offspec CO₂.
- A process for measuring the volume of CO₂ transferred\(^\text{10}\).
- The transfer of ownership/all liabilities for the CO₂ at the point of transfer into the transport network.
- A fee to be paid to the transport company (provided the EII site is in business) for accepting delivery of the CO₂ – we would propose a fee is charged based on long-run average cost of a well utilised T&S system (i.e. not a marginal cost basis, so the starting point is the same £/tonne fee for all connecting to it (including power). This fee would be split into:
  - an annual capacity fee (defined in £ per max tonnes of CO₂ transferred per annum); and
  - a variable capacity fee defined in £/t of CO₂ transferred to the transport & storage network.
- Terms by which the contract may end; we assume that capacity payments do not continue if the capture plant decommissions.

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\(^{10}\) A tonnage is required; however, the stringent requirements of CfD contracts (with 30 minute reporting and regular auditing) are not proposed.
Unavailability of T&S

Our proposed solution to deal with potential unavailability of T&S in periods when the EII would be available to capture CO₂ is as follows:

- The EII is insulated from any additional CO₂ related costs such that its net position is unchanged compared to if the T&S had been available:
  - EII not obliged to run capture plant during any unavailability (outside of co-ordinated maintenance involving full chain) and can emit CO₂;
  - the EII is then compensated for the cost of any additional EU ETS emissions by T&SCo (and ultimately by CCSDC):
    - N.B. that there may be an advantage to doing this via a contract which assumes that the CO₂ is legally passed across to the T&SCo before venting even when the physical transfer does not occur.
    - returns carbon value to Government (i.e. in the form of free allowances) as if it were capturing CO₂ at forecast rates so that its net carbon position remains unchanged compared to a case when CO₂ is captured and stored.

- EII capex related repayments remain unchanged:
  - continues to be paid CCS capex payments as if operating at forecast rates.

- Opex related payments to EII fall in line with costs, so net position unchanged:
  - continues to be paid fixed elements of CCS opex compensation by CCSDC; and
  - does not incur variable related opex but nor is it remunerated for it, so Government operating cost exposure is reduced (although so is carbon benefit).

Options considered for the relationship to transport and storage

All options for transport and storage assume that a large shared network is developed outside of the mechanism for supporting industrial CCS. The range of options considered in this report for accessing this network principally vary based on the fee that would be paid:

- Whether a fee is paid at all – if the T&S is developed outside of this model and is paid for out of other funds it is conceivable that access to that network could be free of charge.

- Whether fees are dependent on the volume of CO₂ flow – the extent to which the transport fee varies with the volume transported, ranging from being based simply on the tonnes of CO₂ transported, through to being entirely based on the expected capacity per year to be stored. In an analogous situation, natural gas transportation contracts in GB have a fixed and a variable component to reflect the cost structure of the infrastructure.

- Whether the fee is based on the average costs of accessing its proportion of T&S, or the marginal cost – the price could be fixed based on the average costs of a well-utilised, shared network, or could be charged on a marginal basis to different parties (i.e. at different rates depending on when you connect) or could potentially vary over time as volumes in the system change. In the case of a more marginal approach to pricing we would expect declining costs per tonne over time as more sources are added to the network.
Our proposed approach of charging a £/tonne fee (with a capacity and a commodity component) based on a long-run cost of a well utilised T&S network is preferred as:

- the payment of a fee to T&S even for the first adopters allows for the potential privatisation of the T&S network to be clear from the beginning;
- it creates an immediate market signal for carbon storage, helping to alleviate the current widespread market failure of missing markets for European CO₂ T&S;
- the split of a fixed (capacity) and variable (commodity) charge is well known in other markets in the UK (e.g. gas transport) and, when weighted towards capacity payments, is representative of the cost structure of CO₂ T&S;
- it creates a more efficient signal for the utilisation of the T&S system as it attributes a cost to the transport and storage of CO₂ rather than providing it for free regardless of how much CO₂ you store, and would stop so called ‘bed-blocking’ as seen in the electricity networks in the past where companies block more capacity than is needed; and
- it does not unduly burden the first projects with paying for the whole network as costs are charged; assuming that additional CO₂ volumes will be forthcoming (which is the key point of establishing CO₂ hubs).

*Evolution of the relationship between capture, transport and storage over time*

**Variation of payments within a contract**

Within the contract we propose that the variable fee for transport varies directly with the volume transported. If volumes change year to year then the fees paid by the EII and passed through from Government will therefore also change (reducing from the 100% figure).

**Variation of mechanism between contracts**

Although our proposal is that a fixed long-run price is charged, based on the average costs of a well-utilised, shared network, such a fee could potentially vary over time (as say, operational costs fall due to efficiency savings). Alternatively, for later contracts, fee charging arrangements may differ in that costs are charged at more marginal rates (for example if average cost charging is leading to over-recovery of costs as T&S gets close to full utilisation). In this case we would expect declining costs per tonne over time as more sources are added to the network.

**Aggregation opportunities in conditioning and compression**

It is possible that in some cases, both construction and operating costs may be reduced by forming an aggregator that collects CO₂ plus amine from two or more industrial sites, and uses a ‘neighbourhood’ plant to recondition the amine (and send it back to the individual capture plants), to perform any further purification required and to compress the CO₂ for delivery ‘at the beach’ to the offshore T&S operator. The engineering feasibility first needs to be studied for its cost reduction potential, but such an aggregator could be supported under the scheme defined above. In such a case, Government would contract with a single body (the “aggregator”) to support capital and operating costs under the model described in this chapter. The aggregator would then remain responsible for setting up any payments that may be required between the aggregator and the industries involved.
The main difference between a Government contract with an aggregator and with multiple regular industries could be less tailoring of contracts for individual industries (although ranges could be accommodated). Whilst this has not been considered in detail, an aggregation contract may need revision as extra capture sites are incorporated, increasing the quantities of captured CO$_2$. This could be accomplished by allowing contract reopeners, or fixing fees relating to taking new volumes in the original contract.
4. CAPTURE CONTRACT ALLOCATION AND LINKS TO OTHER PROCESSES

4.1 Introduction

Handling the risks involved in coordinating different parties in the CCS chain has proved to be one of the biggest challenges in the development of full chain CCS projects. Furthermore, in order to gain the well-recognised benefits of scale – through greater utilisation of assets and directly and indirectly reducing project risks – a CCS policy has to overcome the challenge of coordinating not just one but several projects.

Our proposal for the process builds on a considerable body of work appraising and characterising potential storage locations, particularly the extensive work done on Goldeneye/Captain aquifer and 5/42 aquifer. It is also well aligned with the role of the CCS Development Company envisaged in the Oxburgh report, albeit it with an expanded scope to include industrial CCS in parallel.

Inevitably, such a process will be more cost effective if it includes some iteration to develop a suitable matching of emitters and injection capacity of stores. Our proposal envisages some development work that will not be of immediate use, but the filtering and iterating process should minimise this. From an EII’s point of view, we need to recognise the relatively scarce funds these organisations have for such development work and a degree of scepticism in the market given the CCS history in the UK.

We believe that our proposal will enable relatively quick deployment, taking a pragmatic approach where necessary.

Components of investment decision – explanation

We have defined the stages involved in reaching Financial Investment Decision (FID) for an EII capture project as follows:

- Government sets up CCSDC and T&SCo with a commitment to proceed with CCS based on a defined budget range and value for money criteria.
- Pre-FEED – Scoping work to define suitability and scope for CO₂ capture in specific regions, locations for capture, identify pipeline corridors, check to see if any major barriers to environmental consents; high level view of project costings and timescales with technical options and preferred technical solution.
- Front End Engineering & Design (FEED) – Advanced definition of the project engineering with firm offers and timelines; environmental and all other permitting in principle, commercial structures (including negotiated bilateral outline funding arrangements).
- Government Decision to Proceed.
- Company Final Investment Decision (FID) - Technical and commercial analysis required by Boards to commit funds based on actual contract offer and including financing arrangements.
4.2 Requirements for the allocation process

4.2.1 Alignment with Power Sector

While the Oxburgh report suggested that CCS clusters should be anchored by a power project, we believe that a parallel development processes for EIIs and CCS power stations demonstrates better value for money, as early EII uptake can provide value for money sources of carbon abatement in conjunction with the initial large volume from power.

The business model has the CCSDC coordinating the development of EII and power station projects. For example, it will be able to encourage CCS power station developers to choose locations that best coordinate with existing industrial clusters, to ensure that new development is sited appropriately to support further capture of CO$_2$ from existing emitters.

4.2.2 EII needs

Energy intensive industries have a significant concern about the potential carbon related costs to which they may be exposed, creating an interest in CCS. However, as the investment case is currently weak, and lacking business drivers to develop any project outside their core businesses, any scheme will have to have a high degree of Government or CCSDC funding for development work.

However, it will also be important for EIIs to have in their control any work which underpins their own investment decisions, particularly when carried out at their sites—so the FEED studies would naturally be commissioned by the EIIs, although likely to be largely Government funded.

Our discussions with EIIs suggest that they will need to believe that there is sufficient drive from Government to deliver CCS projects. This means that the setting up of the CCSDC with funding commitments, and an agreement to deliver the T&S infrastructure and to reduce costs by taking storage liabilities, will be a major first step to attracting interest from EIIs.

4.2.3 Government needs

In delivering value for money in making a decision to proceed with a CCS cluster, Government will require information from each phase of the process of moving from concept to firm proposition.

As such, the process must assess the value for money case for CCS using:

- Costs and CO$_2$ volume to be abated over time (see Figure 11 for example initial projects at Teesside and potential extension);
- Energy Intensive Industry commitment to proceed within Government defined, value for money parameters (starting points have been briefly discussed with Teesside Collective member companies to provide examples of industry viewpoints in this report);

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While we have assumed CCSDC coordinates CO$_2$ capture projects, this task could be carried out by a government department. This would not significantly affect the process described.
4.3 Overall description of proposition

The figure below illustrates the process we propose. Such a scheme delivers a good balance between keeping options open against not spending money on engineering studies unnecessarily.

Figure 10 – Overview of capture contract allocation process

In the following paragraphs we describe each key step in more detail:

4.3.1 CCSDC Strategy

The CCS Development Company will be tasked with delivering CCS and related transport and storage infrastructure.

In order to reduce timescales by several years, to maximise use of CCS Commercialisation Competition funded FEED work, and to focus the number of potential capture projects, we suggest that the CCSDC outlines its plans to first develop capture clusters that can connect to currently well appraised storage locations of Goldeneye/Captain and Endurance.
In order to build an adequate case for this direction, the CCSDC can make use of high level information (available from previous Government work (DECC, PAG) or Government or EU funded work, including work specifically carried out in the Humber, Teesside and Grangemouth areas). This includes the potential for capture cluster sites, key geographical and permitting considerations and costs for initial large scale transport and storage.

At the end of the strategy phase, we envisage that the T&SCo will be set up, increasing the confidence of EIlIs and power developers in the overall process. CCSDC can then advance the necessary permitting and design processes. Advancing T&SCo permitting may be simultaneous with pre-FEED to accelerate capture development, or may be before pre-FEED to give confidence to all parties.

### 4.3.2 Pre-FEED

Without being prescriptive, we expect the CCSDC to commission a number of pre-FEED studies to give it adequate information to decide what to take forward to the next stage (i.e. to FEED).

At the Pre-FEED stage each potential capture hub will characterise their project and create a value proposition to the degree where the CCSDC can select one or more groups of potential capture projects to take forward to FEED study status. It is envisaged that these would be Government (or CCSDC funded), with the EIlIs contributing their own staff resources to delivering them. EIlIs must be fully engaged in the project at this stage as it will require significant time commitment to develop the necessary evidence for the FEED application.

Technical concepts that will be determined at this stage, include defining technical options, technology selection, pipeline routes and environmental issues. Solutions that involve sharing local infrastructure (e.g. amine conditioning equipment and compressors) should also be considered. These could have the potential to be a cheaper option than each plant building its own capture, conditioning and compression.

Commercial issues to be resolved at this stage will include: likely capital and operating expenditure for the primary technology option, industry specific commercial challenges, and any particular issues specific to each site.

Consents and environmental permitting requirements would be identified in pre-FEED and typically developed in FEED, as appropriate on a case by case basis. The key element would be to identify any consenting or permitting issue that would represent a high risk to project completion.

Finally, the high level potential to combine individual project elements to get local infrastructural benefits will be determined by interaction with the EIlIs.

At the end of the pre-FEED studies, the CCSDC will be able to make a strategic decision, based on the potential value for money proposition for delivering both power and industrial CCS, on which hubs to proceed to FEED.
4.3.3 FEED

The CCSDC will take forward a sufficient number of projects to create the basis for a good use, together with power projects, of its choice of initial transport and storage infrastructure. Due to the pre-work and in kind support provided, it could be envisaged that this is likely to be the majority of projects that have participated in the pre-FEED stage.

FEED studies will be commissioned by the EIIIs themselves and be largely CCSDC funded. The EIIIs should have ownership of the output of the FEED studies, to take forward to their FID decisions. Companies will need to gain Board approval to conduct FEED studies and make this step with a clear vision for the technical approach – i.e. aggregation and sharing of infrastructure, and the CO₂ specification – which should be largely determined in conjunction with T&S-Co in pre-FEED.

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**Box 2: Teesside and the pre-FEED process**

In 2015 Teesside Collective launched its blueprint, for a cost of £1 million plus significant industrial in-kind support. Over the course of a year, Teesside delivered a series of studies and reports:

- A business case covering, cost model, risk allocation, rates of return, scenario testing, sensitivity testing, costs/tonne and cash flow.
- Economic Impact assessment.
- Design for onshore infrastructure for a 5 million and 15 million tonne per annum capacity pipeline including network quality spec and pipe design, onshore transport options assessment, pipe route assessment including know constraints and wayleaves, pipe route selection and virtual walk through, network operating pressure selection.
- Design for the offshore infrastructure to two identified offshore stores including basis for design, CO₂ spec and delivery conditions, HSE assessment, route options assessment, preferred route selection including engineering performance parameters.
- Engineering design for four industrial plants covering 2.8 million tonnes per year of CO₂ at Lotte Chemicals PET plant, BOC Steam Methane Reformer, CF Fertiliser Ammonia Plant, and SSI Blast Furnace. These were achieved to +50/-30% cost and included concept development, site selection, layout and utilities, design of capture plant including engineering performance parameters, process flow diagrams, heat mass balance, and major equipment lists.
- Capex and opex estimates for all parts of the chain.
- Execution plan for the project.
- Investment Mechanism for Industrial CCS.

All these reports were made public and can be found at [www.teessidecollective.co.uk](http://www.teessidecollective.co.uk)

This process was managed by Tees Valley Unlimited, the Local Enterprise Partnership.

It is expected that pre-FEEDs suggested by this allocation model would follow a similar model to Teesside Collective.
Commercial structures will be developed for each project, including any tailoring of commercial terms for individual sites. The FEED participants will require the T&SCo to have developed commercial terms for taking the CO₂ and storing it before these are finalised, although commercial terms may be negotiated before this is finalised provided the concept of T&S cost pass-through is agreed.

4.3.4 Decision on Storage Hub and T&S infrastructure

At the end of the EII FEED studies, the CCSDC will be able to combine them with the parallel processes for power-capture projects to make an investment decision on which hubs will proceed to construction, together with the final decision on which stores and offshore transport solutions to develop.

4.3.5 EII Contracts

With a full understanding of the choice of T&S infrastructure, the T&SCo will be able to determine the final parts of its commercial terms, and CCSDC will award contracts to the EIIIs in the cluster. At this stage, awards should not be contingent on all capture parties proceeding, but we expect that the lead up should ensure that only committed parties remain involved. The EIIIs in the cluster can then progress to take FID.

4.3.6 Coordination with Power and CCSDC activities

This process should be entirely compatible with development of any parallel processes for developing power-based CCS projects. It will be important for the CCSDC to carry these out in parallel to ensure coordination on hubs and delivery.

We would expect the CCSDC to have a wide understanding of new-power station developments, and to find sufficient information to ensure development in the absence of specific power projects so that appropriately sited EII projects can proceed if sufficient scale of carbon capture is foreseen to generate value for money.

4.4 Roles of EII, CCSDC (T&S) and Government

4.4.1 EII Role

To engage in this process EIIIs will need to:

- commit internal resources to the pre-FEED and the FEED studies;
- give ‘in principle’ commitment to the CCSDC to proceed once a FEED study is completed that meets pre-set criteria for value for money;
- engage in negotiations over the key commercial terms (particularly the structure of the capital funding i.e. funding split, return on capital); and
- take FID in timescale commensurate with CCSDC decisions to develop infrastructure.

If there is potential for EIIIs to more efficiently share e.g. conditioning and compression infrastructure we would expect them to cooperate and to make unified decisions in a timely manner to assist T&SCo’s system design.

4.4.2 CCSDC Role

To run this process the CCSDC needs:
- EIIls to collectively participate in the pre-FEED processes to give sufficient information on CO₂ volumes, locations, etc. to make choices about which CO₂ hubs to develop first (recognising that this will have to involve the T&SCo);
- to agree commercial terms in a timely manner and then monitor and manage commercial issues, such as dispensing capital grants and capex repayments;
- Government funding to support costs of pre-FEED and FEED studies, recognising that any studies on projects that are not in the first clusters will not be used immediately; and
- Government decision and support to proceed on development of the initial transport and storage infrastructure. We assume in this report that the transport and storage infrastructure owner will take responsibility for the CO₂ – including leakage liability – once it is transferred from the capture plant.

4.4.3 Government Role

We expect that Government funding for this process will be channelled through the CCSDC. Government will have responsibility for establishing the CCSDC, sanctioning its budget and then establishing the T&SCo.

More detail on likely funding costs at the different stages is included in Chapter 5.

4.5 Concluding remarks on allocation process

In designing this process we have developed a pragmatic approach to engaging energy intensive industries in wider carbon capture projects, one which recognises the need to encourage the various sources to participate in the development of larger hub-based schemes.

There could be some redundancy in the expenditure involved in studying more projects than strictly necessary, but the cost of this is relatively small, given the cost levels of pre-FEED and FEED studies. The alignment with development of potential power projects gives a strong message to EIIls of Government commitments, although it is quite possible that the EII projects would actually be the first ones to capture and store carbon.
5. FINANCIAL CONSIDERATIONS FOR GOVERNMENT

In the absence of carbon price clarity, uncertainty over its future trajectory means that CCS currently requires significant state support. The model outlined in this report is intended to provide a framework that will allow contracts with clear value for money to be agreed between EIIs and Government. This section uses pre-FEED cost estimates for three Teesside Collective industrial CCS projects and three follow-on projects to estimate the likely costs involved.

5.1 Total costs and CO$_2$ volumes

This report examines the costs involved in supporting industrial capture, conditioning and compression, together with payment of an offshore transport and storage fee. Figure 11 presents a summary of the costs involved in supporting the three facilities (CF Fertilisers, BOC Linde and Lotte) from the Teesside Collective Blueprint for Industrial CCS in the UK, three additional facilities in Teesside evaluated in a 2010 Amec Foster Wheeler study, and an example of other capture facilities that could be constructed to add additional CO$_2$ capture volume to fill say, a 5mtpa pipe to offshore storage. These costs, totalling around £17M of pre-FID costs, £110M for construction and £16M per year of operational costs (excluding T&S), would reduce emissions by 11 million tons of CO$_2$ over a 15 year support lifetime, and depending on technical lifetimes a similar volume may be expected after the end of the support period.

Figure 11 – Total costs involved in supporting Teesside industrial facilities

<table>
<thead>
<tr>
<th>CO$_2$ reduction (kt CO$_2$/yr)</th>
<th>Pre-FEED</th>
<th>FEED</th>
<th>Construction</th>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 Teesside blueprint EIIs</td>
<td>730</td>
<td>£2.2M</td>
<td>£15M</td>
<td>£110M</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>£16mpa OPEX</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>£13mpa T&amp;S Fee**</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-£31mpa CO$_2$ saving*</td>
</tr>
<tr>
<td>3 follow on EIIs</td>
<td>1700</td>
<td>£8M</td>
<td>£40M</td>
<td>£340M</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>£26mpa OPEX</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>£31mpa T&amp;S Fee**</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-£71mpa CO$_2$ saving*</td>
</tr>
<tr>
<td>Industrial inward investment</td>
<td>1400</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>850MW Teesside CCGT</td>
<td>2000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H$_2$ for domestic heating</td>
<td>1440</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>7270</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Costs of ICCS development in 2015 GBP, based on analysis of: (3 blueprint EIIs) Ryder Hunt International, 2015, estimates at +50%/-30% accuracy; (3 follow on EIIs) Amec Foster Wheeler, 2010, engineering estimates on Olefins 6, Conoco Phillips and Lucite Int. sites at approx. +50%/-30%, 2010 costs inflated from original USD estimates and converted using 0.738£/$ exchange rate. We have assumed that Pre-FEED and FEED cost 2% and 13% of the costs reported; with construction costs 100% of RHI estimates and 85% of the Amec Wheeler estimates. *Carbon saving is average over 15 years in 2015 DECC reference scenario, with CO$_2$ prices rising to £47/tCO$_2$ from 2030. We assume commissioning in 2025. **T&S fee is based on £18/tCO$_2$. 

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In Figure 11 we have added a fee paid to T&SCo, for transferring CO\textsubscript{2} “at the gate”. The best estimates for full lifecycle costs of access to transport and storage come from work by the ETI and Pale Blue Dot, as shown in Table 2, which investigated costs for five facilities and compared them using a common methodology to three sites appraised by other parties. Offshore cost per tonne estimates for eight fully utilised storage facilities ranged from £9/tCO\textsubscript{2} for Endurance to £32/tCO\textsubscript{2} for Goldeneye, with an average cost of £14.5/tCO\textsubscript{2}. We note that a figure based on Endurance and Captain only would be lower, around £11/tCO\textsubscript{2}.

Based on this work, we have assumed a T&S fee of £18/tCO\textsubscript{2}; slightly higher than the ETI average, to reflect the likely ramp up of utilisation over time and cover the onshore transport, and in line with the figure assumed in our 2016 work for the Committee on Climate Change\textsuperscript{12}. As well as the uncertainty of relying on initial engineering estimates, this fee could be lower if the initial ramp up was quicker. A coastal hub (e.g. Teesside or Grangemouth) would mean that only a modest onshore network was required (approx. £1/tCO\textsubscript{2}); the cost of capital could be below the 10% assumed, or the T&S fee could cover only on-going costs and not recover the initial capital costs. It could also be higher if a higher cost of capital was required, or if utilisation of the transport and storage was low.

Table 2 – Total costs involved in supporting Teesside industrial facilities

<table>
<thead>
<tr>
<th>Levelised Unit Cost (£/T)</th>
<th>% offshore transport</th>
<th>% offshore storage</th>
<th>Comparable estimates from earlier FEED study sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data and cost estimates for sites in this study</td>
<td></td>
<td></td>
<td>Endurance</td>
</tr>
<tr>
<td>Viking A</td>
<td>Captain X</td>
<td>Forties S, Site 1</td>
<td>Bunter CL36</td>
</tr>
<tr>
<td>16.66</td>
<td>17.74</td>
<td>18.27</td>
<td>12.33</td>
</tr>
<tr>
<td>28%</td>
<td>7%</td>
<td>24%</td>
<td>26%</td>
</tr>
<tr>
<td>72%</td>
<td>93%</td>
<td>76%</td>
<td>74%</td>
</tr>
</tbody>
</table>

Levelised cost of transport and storage, from the Strategic UK CO\textsubscript{2} Storage Appraisal Project by the Energy Technologies Institute (ETI), Pale Blue Dot, Axis and Costain, published April 2016. Levelised costs are for the full lifecycle, including pre-FID and post-closure activities, and are based on a 10% discount rate and full utilisation.

Depending on the funding scheme for supporting transport and storage, these T&S costs may be passed to T&SCo as payment for having constructed the transport and storage network. Alternatively, if Government has grant funded the network, then a significant fraction of the T&S payments could be used to fund development of T&S networks in other regions.

Ultimately, the T&S costs are funded by Government, and net costs to Government do not change if T&S access is free; an appropriate T&S fee is instead useful for a range of reasons covered in Section 3.6, including that it provides appropriate incentives and helps to develop the CCS industry towards a future independent of Government support. Significantly for evaluating total costs, including a lifetime T&S fee serves to reveal the full chain CCS cost in the capture contract. This means that the costs shown here (when including T&S) effectively cover (a volume-weighted share of) the full CCS chain.

\textsuperscript{12} “A strategic approach to developing CCS in the UK”, published by the CCC and Pöyry in May 2016.
5.2 Incidence of cost to Government

To give an example of the costs that could be incurred, we have modelled support for the three Teesside Collective facilities, assuming that costs and performance match the Ryder Hunt International estimates from 2015, and that Government covers pre-FID costs, provides 50% of the CAPEX as upfront grant, and provides an 8% return on EII capital within 3 years and 12% return after a scheme life of 15 years. Operational cost estimates are fully passed through to Government, following commissioning in 2025 and including a £18/tCO$_2$ T&S pass through fee. The total outturn costs to Government will depend on all these assumptions, and the form of contract negotiated; this section provides only a broad indication of likely costs and cost structure.

Figure 12 shows the incidence of costs and their origin (CAPEX, OPEX and the T&S fee), and the corresponding value of the carbon captured and stored, evaluated at different carbon prices. Carbon prices shown are the 2015 short-term traded carbon values used for UK public policy appraisal (High/Central/Low, rising to 118, 78 and 39 £/tCO$_2$ respectively in 2030 and flat from 2030), plus the projected European ETS price in the reference scenario from DECC’s 2015 energy price projections (rising to £47/tCO$_2$ in 2030 and assumed flat thereafter).

Under the scheme as described in Section 3, a significant fraction of the economic (i.e. ETS or equivalent) value of the carbon captured may be returned to Government (dependent on the final contract terms and free allowance levels). This value returned would be netted off the operational costs, reducing Government expenditure below that shown in orange, and potentially reducing expenditure to zero in the residual capex payment period if high carbon prices and (under our default model for first movers) high free allowance levels occurred.

Figure 12 – Incidence of costs: CF Fertilisers, BOC Linde and Lotte, 730ktCO$_2$pa

Example costs to Government (bars), given model assumptions in the text, and value of carbon captured, assuming carbon prices as in the DECC short-term traded carbon price 2015 (High/Central/Low) and the DECC energy projections reference scenario (second from bottom). Error bars show the projected cost range (+50%/-30%) on the engineering cost estimates.
5.3 Cost of carbon abatement

A full analysis of the costs and benefits of supporting industrial CCS will include the value of jobs created, future value of infrastructure and learnings developed, and the value of supporting the retention of industry in the UK. Here, we address only one part of the cost-benefit analysis, investigating the abatement cost from the perspective of cost-to-Government per tonne of CO₂ stored.

In this analysis, we make the same modelling assumptions as in the previous section, and use the DECC 2015 Reference scenario for evaluating the abated carbon value. We use the standard Government discount rate of 3.5% real for valuing both expenditure and carbon abated to produce a cost per tonne of CO₂. We assume that the additional electricity consumption associated with running the capture equipment is supplied from a decarbonised grid\textsuperscript{13}. With the inclusion of the T&S fee, this allows a calculation of the full project cost of carbon abatement from these projects through the support lifetime. In as much as the facility is likely to continue operating past this point, there is scope for greater overall benefit than shown.

Figure 13 presents the cost per tonne of CO₂ abated for the three Teesside projects, and the split between capital payments pre-commissioning, operating payments before netting off carbon, and the carbon value available, some of which will be netted off operating costs. Initial grant payments (including pre-FID costs) are £70 million for the three facilities, which after discounting future carbon savings equates to £9/tCO₂. Total payments during operational phase, excluding T&S fees and any carbon value transfer, average £32/tCO₂ £(9+22)/t over 15 years, while the total abatement costs, including the £18/tCO₂ T&S fee, are £58/tCO₂.

\textbf{Figure 13 – Government costs per tonne CO₂, CF Fertilisers, BOC Linde and Lotte}

Source: Pöyry Analysis, based on cost estimates from Ryder Hunt International, Teesside Collective Blueprint work, 2015. Real 2015 £/tCO₂, using 3.5% real discount rate. Carbon value – DECC 2015 Reference scenario ETS prices (rising to £47/tCO₂ from 2030). Costs are based on +50%/-30% engineering estimates; original estimates were inflated to 2015 GBP but not adjusted for changes to electricity prices or exchange rates.

\textsuperscript{13} If this were supplied instead from CCGTs, it would reduce the volume of CO₂ abated by ~45ktpa, increasing the cost per tonne abated by around £4/tCO₂.
To demonstrate the likely costs of a larger scheme, we have also included an analysis of the indicative cost of expanding the scheme, based on preliminary Amec Foster Wheeler engineering estimates of installing CCS at Olefins 6, Conoco Phillips and Lucite International sites in Teesside. These cost estimates, shown in Figure 14, show a similar total cost of carbon abatement, but with slightly higher capital costs per tonne of CO$_2$ abated, and lower operating costs. Supporting all six schemes would involve £300 million (+50%/-30%) of grant funding, and the same total cost of abatement (including T&S fees but excluding value of carbon abated) of £58/tCO$_2$.

Figure 14 – Government costs per tonne CO$_2$, six assessed sites

Source: Pöyry Analysis, based on cost estimates from Ryder Hunt International, Teesside Collective Blueprint work, 2015, and Amec Foster Wheeler work for Teesside Collective, 2010. Cost of Government support, in £/tCO$_2$, evaluated using a discount rate of 3.5% real. Costs are split by capital payments, operating payments and T&S. Carbon value based on DECC 2015 reference scenario ETS prices (rising to £47/tCO$_2$ from 2030). Costs are based on +50%/-30% engineering estimates; original estimates are used unchanged (other than inflation and FX conversion for USD 2010 estimates).

5.4 Summary of financial considerations for Government

The costs of supporting industrial CCS in the UK remain uncertain, with the best estimates to date based on concept-level engineering estimates performed in Teesside. We have investigated two sets of estimates, from Amec Foster Wheeler in 2010 and Ryder Hunt International (in conjunction with Amec Foster Wheeler) in 2015, both of which provided cost estimates for three different emission sites that are present in Teesside today. While costs varied between sites, both sets of estimates suggest industrial carbon capture could be supported under our model with an average cost around £40/tCO$_2$ including pre-FID, Grant and costs during 15 years of operations. Once a proportionate fee is paid for access to a transport and storage network, total costs are around £60/tCO$_2$, which would seem to provide good value for money when compared to support for many existing decarbonisation schemes. When compared to the short term cost of carbon for policy appraisal, these cost estimates sit below the Central 2030 of £78/tCO$_2$, and towards the lower end of the cost range (£39-118/tCO$_2$), implying that (subject to the engineering uncertainty) it is likely that the first round of projects will come in below Central appraisal costs, before any learning related cost reductions.
It is probable that a substantially larger number of sites around the UK could capture carbon at similar cost. While some sources will undoubtedly require more expensive engineering solutions, total non-electricity related industrial CO₂ emissions in the UK exceed 70mtpa, so the potential for CCS driven emissions reduction, based only on existing industry, is significant. Once an industrial CCS hub is available, it is also likely to attract further investment that will make use of the carbon solution.

To provide value for money, any CCS strategy requires delivery of hubs that can deliver economies of scale on transport and storage. While some hubs may ultimately deliver economies of scale based purely around industry, in early phases of CCS development, industrial capture is likely to best provide value for money by developing industrial carbon volumes alongside power sources to make use of large transport and storage networks.

The work here suggests that the abatement costs are low enough to warrant developing industrial capture in conjunction with other developments, rather than waiting for an established network to attract industrial interest. For example, if a first transport and storage connection was established near Teesside, the three Teesside Collective companies could initially store 730 ktCO₂ per year based on an initial grant around £70m, and on-going annual support (including T&S fees) averaging around £29m per year. Excluding T&S fees these costs to Government would be £16m per year, against which the shared component of the carbon benefit can be netted. This would represent a low cost mechanism, both in actual cost terms and £/tCO₂, to get a hub started in Teesside, after which further power and industrial sources would join.
ANNEX A – STATE AID GUIDELINES FOR CCS


General extracts (paragraphs numbered)

(47) For operating aid, the Member State must demonstrate that the aid is appropriate to achieve the objective of the scheme to which the aid is targeted. To demonstrate that the aid is appropriate, the Member State may calculate the aid amount ex ante as a fixed sum covering the expected additional costs over a given period, to incentivise undertakings to minimise their costs and develop their business in a more efficient manner over time I wonder whether this specificity should be added into the report

(61) In that context, the level of profitability can be evaluated by reference to methodologies which are standard practice in the particular industry concerned, and which may include methods to evaluate the net present value (‘NPV’) of the project, the internal rate of return (‘IRR’) or the average return on capital employed (‘ROCE’). The profitability of the project is to be compared with normal rates of return applied by the company in other investment projects of a similar kind. Where those rates are not available, the profitability of the project is to be compared with the cost of capital of the company as a whole or with the rates of return commonly observed in the industry concerned This seems to make our proposals state aid compliant

(80) Where aid to the beneficiary is granted in a competitive bidding process on the basis of clear, transparent and non-discriminatory criteria, the aid amount may reach 100% of the eligible costs. Such a bidding process must be non-discriminatory and provide for the participation of a sufficient number of undertakings. In addition, the budget related to the bidding process must be a binding constraint in the sense that not all participants can receive aid. Finally, the aid must be granted on the basis of the initial bid submitted by the bidder, therefore excluding subsequent negotiations.

(99) In order to keep the distortions of competition and trade to a minimum, the Commission will place great emphasis on the selection process. Where possible, the selection process should be conducted in a non-discriminatory, transparent and open manner, without unnecessarily excluding companies that may compete with projects to address the same environmental or energy objective. The selection process should lead to the selection of beneficiaries that can address the environmental or energy objectives using the least amount of aid or in the most cost-effective way

3.2.6.3. Additional conditions for individually notifiable aid

(101) The Member State must ensure that the negative effects as described in Section 3.2.6.1 are limited. In addition to the elements specified in Section 3.1.6.2, the Commission will take into account and assess whether the individual aid leads to:

(a) supporting inefficient production, thereby impeding productivity growth in the sector;
(b) distorting dynamic incentives;
(c) creating or enhancing market power or exclusionary practices;
(d) artificially altering trade flows or the location of production.
(103) The Commission will also assess whether the aid results in some territories benefiting from more favourable production conditions, notably because of comparatively lower production costs as a result of the aid or because of higher production standards achieved through the aid. This may result in companies staying in or re-locating to the aided territories, or to displacement of trade flows towards the aided area. In its analysis of notifiable individual aid, the Commission will accordingly take into account any evidence that the aid beneficiary has considered alternative locations.

But:

(19) For the purposes of these Guidelines the following definitions apply:

(43) ‘competitive bidding process’ means a non-discriminatory bidding process that provides for the participation of a sufficient number of undertakings and where the aid is granted on the basis of either the initial bid submitted by the bidder or a clearing price. In addition, the budget or volume related to the bidding process is a binding constraint leading to a situation where not all bidders can receive aid;

(20) Individual aid granted on the basis of an aid scheme remains subject to the notification obligation pursuant to Article 108(3) of the Treaty, if the aid exceeds the following notification thresholds and is not granted on the basis of a competitive bidding process:

(f) aid for Carbon Capture and Storage: where the aid amount exceeds EUR 50 million per investment project;

And:

(27) The Communication on State aid modernisation of 8 May 2012 called for the identification and definition of common principles applicable to the assessment of compatibility of all aid measures carried out by the Commission. For that purpose, the Commission will consider a State aid measure compatible with the internal market only if it satisfies each of the following criteria:

e) proportionality of the aid (aid kept to the minimum): the aid amount is limited to the minimum needed to incentivise the additional investment or activity in the area concerned: (Section 3.2.5);

(f) avoidance of undue negative effects on competition and trade between Member States: the negative effects of aid are sufficiently limited, so that the overall balance of the measure is positive; (Section 3.2.6);

(g) transparency of aid: Member States, the Commission, economic operators, and the public, have easy access to all relevant acts and to pertinent information about the aid awarded thereunder; (Section 3.2.7).
3.6. Aid to Carbon Capture and Storage (CCS)

(160) As recognised by Directive 2009/31/EC (73) (‘the CCS Directive’) and the Commission Communication on the future of CCS in Europe (74), CCS is a technology that can contribute to mitigating climate change. In the transition to a fully low-carbon economy, CCS technology can reconcile the demand for fossil fuels, with the need to reduce greenhouse gas emissions. In some industrial sectors, CCS may currently represent the only technology option able to reduce process-related emissions at the scale needed in the long term. Given that the cost of capture, transport and storage is an important barrier to the uptake of CCS, State aid can contribute to fostering the development of this technology.

(161) In order to promote the long term decarbonisation objectives, the Commission considers that the aid for CCS contributes to the common objective of environmental protection.

(162) The Union has taken several initiatives to address negative externalities. In particular the Union ETS ensures the internalisation of the costs of GHG emissions, which however may not, yet, ensure the achievement of the Union’s long term decarbonisation objectives. The Commission therefore presumes that aid for CCS addresses a residual market failure, unless it has evidence that such remaining market failure no longer exists.

(163) Without prejudice in particular to Union’s regulations in that field, the Commission presumes the appropriateness of aid provided all other conditions are met. Both operating and investment aid is permitted.

(164) The aid may be provided to support fossil fuel and, or biomass power plants (including co-fired power plants with fossil fuels and biomass) or other industrial installations equipped with CO₂ capture, transport and storage facilities, or individual elements of the CCS chain. However, aid to support CCS projects does not include aid for the CO₂ emitting installation (industrial installations or power plants) as such, but aid for the costs resulting from the CCS project.

(165) The aid is limited to the additional costs for capture, transport and storage of the CO₂ emitted. It is generally accepted that the counterfactual scenario would consist in a situation where the project is not carried out as CCS is similar to additional infrastructure which is not needed to operate an installation. In view of this counterfactual scenario, the eligible costs are defined as the funding gap. All revenues, including for instance cost savings from a reduced need for ETS allowances, NER300 funding and EEPR funding are taken into account (75).

(166) The Commission assesses the distortive effects of the aid on the basis of the criteria laid down in Section 3.2.6, taking into account whether any knowledge sharing arrangements are in place, whether the infrastructure is open to third parties and whether the support to individual elements of the CCS chain has a positive impact on other fossil fuel installations owned by the beneficiary.
ANNEX B – MODEL MATHEMATICAL FORMULATION

This annex provides a technical, mathematical description of the funding model proposed in chapters 2 and 3. The description is of the general model, and contains a number of parameters, indicated by single capital letters (e.g. \( G \) and \( X \)), that may be either set prior to contract negotiations (e.g. \( H \) in Section B.2), or are expected to be primary points that would be negotiated in each individual contract (e.g. \( G \) in Section B.2).

B.1 Performance parameters

In order to link payments to performance, to create performance incentives or remove perverse incentives (e.g. to turn the system off), a number of performance measures need to be built into payment models. We propose the following measures, which are used in subsequent sections:

- \( p \): the amount of CO\(_2\) produced by the processes on which carbon capture is installed.
- \( c \): the amount of CO\(_2\) captured by the capture unit (expected to be up to 90% of \( p \)) and passed “at the gate” to the T&S operator (regardless of whether that is then stored by the T&S operator).
- \( e = p - c \): the amount of CO\(_2\) emitted by the process on which carbon capture is installed (expected to be at least 10% of \( p \)).
- \( e = c / p \): the efficiency of the capture unit (expected to be up to 90%).
- \( f \): the number of free ETS allowances allocated to the process on which carbon capture is installed. Where this is not directly calculable from EU ETS awards (e.g. permits are allocated to a site based on production, and no breakdown by process is available), then we expect \( f \) to be some fraction of total site allowances awarded, reflecting the fraction of total site emissions on which CCS has been installed.
- \( p_0, c_0, e_0, e_0 \): the expected values of \( p, c, e \) and \( e \) under normal operating conditions. These may be fixed in the contract, or some measure may be defined for calculating values through the life of the contract.

Additionally, while not a performance parameter, we use:

- \( CCP \): the ‘carbon certificate price’ paid by EEs to emit CO\(_2\) (currently the EU ETS price).

All measures of performance must be defined over a given period. We expect annual reporting to be sufficient for most purposes, but this period could be settled quarterly or monthly and would need to be defined.

B.2 Capital payments

We use the following terms:

- \( CAPEX_{grant} \): the capital amount supported by a direct Government grant.
- \( CAPEX_{repcy} \): the capital amount supported through payments following plant commissioning.
- \( CAPEX_{FID} \): the expected capital cost of the capture unit at FID.
- \( CAPEX_{actual} \): the actual capital cost incurred in building the capture unit.
We propose two parameters, G and H, that may be negotiated to calculate the values of CAPEX\textsubscript{grant} and CAPEX\textsubscript{repay}:

\[
\text{CAPEX}_{\text{grant}} = G \times \text{CAPEX}_{\text{supported}} \tag{1}
\]
\[
\text{CAPEX}_{\text{repay}} = (1 - G) \times \text{CAPEX}_{\text{supported}} \tag{2}
\]

where

\[
\text{CAPEX}_{\text{supported}} = H \times \text{CAPEX}_{\text{FID}} + (1 - H) \times \text{CAPEX}_{\text{actual}} \tag{3}
\]

Parameter G determines the extent to which CAPEX is supported by Government grant (0 \leq G < 1), and parameter H (0 < H < 1) determines the extent to which construction risk is shared by Government: H = 0 means that the EII absorbs all construction price risk, while H = 1 would pass all construction price risk to Government, and provide no incentive to the EII to reduce capital costs during construction. In theory different values of H could be used for calculating the grant and repayments, but we do not see any benefit in doing so.

Repayments during the enhanced CAPEX repayment period would be set by:

\[
\text{Annual enhanced repayments} = \text{CAPEX}_{\text{repay}} \times \frac{R_1}{L_1} \tag{4}
\]

Where \(L_1\) is the number of years in the enhanced repayment period, and \(R_1\) is a repayment multiplier that determines the return on capital earned within this period. We expect \(R_1 > 1\) to cover:

- interest payments on capital during the construction period; and
- some return on investment for the EII.

Repayments in the residual CAPEX repayment period, of length \(L_2\), would be linked to capture unit performance:

\[
\text{Annual residual repayments} = \text{CAPEX}_{\text{repay}} \times R_2 \times \frac{c}{c_0} \tag{5}
\]

where \(R_2\) is linked to the level of return on investment gained by the EII, via payments linked to operational performance. The operational link is shown via expected and outturn quantities of captured CO\textsubscript{2}, while an alternative formulation might link payments to \(\varepsilon \varepsilon_0\), which removes any incentive to produce more CO\textsubscript{2}.

### B.3 Operational payments

During the support lifetime of the CCS facility, an operational payment would be made by Government to the EII consisting of:

\[
\text{Operating payment} = \text{OPEXpayment} + \text{T&Spayment} - \text{CarbonValueReturn} \tag{6}
\]

Subject to

\[
\text{Operating payment} \geq \text{Operating payment cap} \tag{7}
\]

The calculation of the quantities \text{OPEXpayment}, \text{T&Spayment} and \text{CarbonValueReturn} in equation 6 are discussed in the following subsections (equations 8 to 10). The operating payment cap is in place to avoid large payments from industry to Government, placing an undue risk on EII’s joining the support scheme rather than waiting to see how carbon prices develop. We expect the level of the cap to be negotiated, but can see three plausible levels:
### Operating payment cap

- **Operating payment cap = 0**: this ensures that in a high carbon price future an EII is no worse off, in operating payments, than if they had installed CCS without Government support.

- **Operating payment cap = - residual CAPEX payment**: this ensures that, after including CAPEX, there is no net payment from the EII to Government.

- **Operating payment cap = - cost of capital \times CCS replacement cost**: this ensures that in a high carbon price future an EII is no worse off, after accounting for capital costs, than if they had installed CCS without Government support. Note that we expect CCS replacement costs would be significantly lower than construction costs as the technology develops; actual construction costs should not be used here as they convey a first-mover disadvantage.

#### B.3.1 OPEX payment

We propose that:

\[ OPEX_{\text{payment}} = T_1 \times \text{Eligible costs} \]

Under a full passthrough model, \( T_1 = 1 \), but different values may be held as a way of either recompensing non-eligible costs (\( T_1 > 1 \)) or passing additional carbon value to the EII without over-reward (\( T_1 < 1 \)).

Alternatively, performance risk (and incentive) may be passed to EII’s:

\[ OPEX_{\text{payment}} = T_1 \times \text{Eligible costs} + T_2 \times \text{Expected costs} \]

We note that operating costs are strongly linked to facility production levels and external costs, particularly the price of consumables such as electricity and amines, and hence some fraction of the expected operating costs should be indexed to capture of CO\(_2\), and may also be indexed to consumable prices where there is a clear market price (e.g. electricity). Failure to do so may create a perverse incentive to operate a capture unit below expected levels (or not at all), to reduce costs, if any emission penalty is smaller than the saved operational costs.

#### B.3.2 T&S payment

We propose that the T&S payment fully covers the fees the EII must pay to the T&S company, and thus represent a pass-through arrangement.

#### B.3.3 Carbon value return

As discussed in the main report, we propose that the monetary value of captured carbon (equal to the volume captured multiplied by the permit price) be shared between EII’s and the Government, with an option of linking this sharing to the level of free allowances granted to industry. We propose:

\[
\text{CarbonValueReturn} = \text{ccp} \times Z \times (X \times c + Y \times \max(f - e, 0)) + \text{ccp} \times (1 - Z) \times (X \times c_0 + Y \times \max(f - e_0, 0))
\]

where \( X \) is a parameter that specifies what fraction of carbon value is passed to Government, \( Y \) specifies what fraction of unused free allowances are passed to Government, and \( Z \) specifies what fraction of value is assessed based on actual performance, with the rest \((1-Z)\) being assessed based on expected performance of the CCS unit. We expect that \(X+Y\) and \(Z\) will take values in the range 0 to 1. For example, at the limits of possible values:
- X=1, Y=0, Z=1 specifies that all carbon value that is generated is retained by Government.
- X=0, Y=1, Z=1 specifies that all “unused” free allowances granted to an EII are passed to Government, but “used” free allowances are retained to cover residual emissions. The max terms in equation 10 indicate that industry remains liable for the “gap” if free allowance levels fall below residual emission levels.
- Z=0 specifies that assessments are based on expected capture rates, and all performance risk (and potential benefit of good performance) is passed to the EII.
- X=0, Y=0 specifies that all carbon value is retained by the EII.

In general, there is an incentive on an EII to operate the capture plant efficiently provided that either X+Y<1, or Z<1. Under these conditions, the EII will be financially worse off if, for example, the capture plant is taken offline or operates at reduced performance.

Where calculations use a link to the expected capture of CO$_2$ we note that c0 and e0 can be calculated either based on forecast production (c0 = p0*e0) or on the basis of forecast capture efficiency (c0 = p*e0). Both of these provide equal incentives to run the capture plant efficiently, but provide different incentives on production levels, equivalent to a marginal production cost depending on with-CCS emission costs or without-CCS emission costs respectively.

### B.4 Variables within the formulation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Impact</th>
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<tbody>
<tr>
<td>G</td>
<td>The fraction of CAPEX supported by Government</td>
</tr>
<tr>
<td>H</td>
<td>The fraction of CAPEX support based on expected (rather than actual) capital costs.</td>
</tr>
<tr>
<td>R$_1$</td>
<td>Return provided in the enhanced CAPEX repayment period</td>
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<tr>
<td>R$_2$</td>
<td>Return provided in the residual CAPEX repayment period</td>
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<td>L$_1$</td>
<td>Length of the enhanced CAPEX repayment period</td>
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<tr>
<td>T$_1$</td>
<td>Fraction of eligible OPEX incurred funded by Government</td>
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<tr>
<td>T$_2$</td>
<td>Fraction of expected OPEX funded by Government</td>
</tr>
<tr>
<td>X</td>
<td>Fraction of captured carbon value returned to Government</td>
</tr>
<tr>
<td>Y</td>
<td>Fraction of unused free allowances returned to Government</td>
</tr>
<tr>
<td>Z</td>
<td>Fraction of carbon return based on actual, rather than expected, emissions</td>
</tr>
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## ANNEX C – QUALITY AND DOCUMENT CONTROL

### Quality control

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